UNITED STATES OF AMERICA
DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

In re:	) Administrative Law Judge
	) Hon. George J. Jordan
Proposed Waiver and Regulations Governing the Taking of Eastern North Pacific Gray Whales by the Makah Indian Tribe	) Docket No. 19-NMFS-0001
	)
	) RINs: 0648-BI58; 0648-XG584
	)

DECLARATION OF JOHN W. BICKHAM

I, John W. Bickham, Ph.D., declare as follows:

1. I am a geneticist specializing in the genetics of natural populations of fish and wildlife and a professor emeritus in the Department of Wildlife & Fisheries Sciences at Texas A&M University. I am under contract with the Tribe's legal counsel to provide expert testimony and testimony based on my personal knowledge of the International Whaling Commission's review of the Tribe's proposed hunt in this matter. My address is 31526 Lower Oxbow Trace, Fulshear, TX 77441.

2. For purposes of this hearing, I prepared and hereby incorporate the attached report and supporting exhibits as my written direct testimony.

3. The attached report includes: (1) expert opinions developed through my education, experience, research, and knowledge of genetics of natural fish and wildlife populations and of gray whales (and other marine mammals) in particular; and (2) testimony based on my personal knowledge of the proceedings of the International Whaling Commission regarding the Tribe's proposed hunt. My qualifications to testify as an expert are described in further detail at the beginning of the attached report.

4. The attached report provides factual and scientific information (and my expert opinion regarding such information) which, as qualified below, supports NMFS's proposed

waiver and regulations that would, in addition to tribal management measures, govern a ceremonial and subsistence hunt of gray whales from the Eastern North Pacific stock under the Tribe's treaty-reserved right.

5. I have reviewed NMFS's published issues for the hearing, *i.e.*, the "Issues that May be Involved in the Hearing," 84 Fed. Reg. 13639, 13641-43 (Apr. 5, 2019). As I describe in the attached report, I have concerns about some of the direct testimony NMFS has submitted in this matter and believe there is additional scientific information available that supports the proposed waiver and regulations. However, in general, as NMFS's proposed issues of fact relate to my testimony, I agree with the issues presented and support the waiver and regulations NMFS has proposed. The Makah Tribe has prepared and is submitting today a document entitled Makah Tribe's Position Regarding NMFS' Proposed Issues of Fact. The document identifies specific objections I have to certain issues presented by NMFS (or in some cases, that I have no comment), and I hereby adopt and incorporate those objections as a part of my written direct testimony.

6. The attached report provides support for additional issues of fact for the hearing. The Makah Tribe has prepared and is submitting today a document entitled Makah Tribe's Proposed Issues of Fact. The document identifies additional issues of fact for the hearing based on my attached report and I hereby adopt and incorporate those issues as part of my written direct testimony.

I declare, under penalty of perjury under the laws of the United States, that the foregoing (and the attached report) is true and correct to the best of my knowledge, information and belief.

John W. Bickham, Ph.D.

Dated: May 17, 2019

Testimony of John W. Bickham

Background, Qualifications and Experience of John W. Bickham, Ph.D: I am Professor Emeritus at Texas A&M University, in the Department of Wildlife and Fisheries Sciences, where I served on the faculty for 30 years (1976 to 2006). I also served on the Faculty at Purdue University in the Department of Forestry and Natural Resources and as Director of the Center for the Environment (2006 to 2012) and was a senior scientist at Battelle Memorial Institute from 2012 to 2016. I presently conduct research as a private contractor to Exxon and the North Slope Borough (NSB). Since 2003, I have served as a member of the U.S. delegation to the International Whaling Commission (IWC) Scientific Committee (SC), as well as a member of the NSB's bowhead whale research team. Since 2011, I have studied gray whales as part of the Joint Program for the Okhotsk-Korean Gray Whale Population Monitoring off the North-East Coast of Sakhalin Island funded by Exxon and Shell and as a consultant to the Makah Tribe on issues related to stock structure. My areas of expertise include genetics (cytogenetics, population and evolutionary genetics, genomics, genetic ecotoxicology, and evolutionary toxicology) of natural populations of fish and wildlife. I have studied a variety of marine mammals including Steller sea lions, bowhead whales and gray whales and I have published more than 240 papers in the peer reviewed literature. I recently (2010) co-edited a book *Molecular Approaches in Natural Resource Conservation and Management*. Recent publications on whales include descriptions of the bowhead whale genome and transcriptome, and the genome sequence of the gray whale. My CV is attached (Ex. M-0401).

Executive Summary: In this testimony I focus on issues of population structure of North Pacific gray whales (*Eschrichtius robustus*) as they relate to the proposed Makah Tribe hunt and its request for a waiver under the Marine Mammal Protection Act (MMPA). The eastern gray whale (EGW) population targeted by the hunt is robust, being comprised of nearly 27,000 whales, and the number of whales requested to be taken is small. Nonetheless, there are two small populations called the western gray whale (WGW) and the Pacific Coast Feeding Group (PCFG), some members of which have been observed within the area of the hunt. Inadvertent takes of WGW or PCFG whales could have significant conservation implications depending on the number of takes and the status (feeding group, breeding stock) of these populations.

My testimony does not focus on the potential number of takes of either WGW or PCFG whales in the Makah hunt. The National Marine Fisheries Service (NMFS) is proposing to regulate the Makah hunt to protect these whales. Under NMFS's proposed regulations, the likelihood that a Makah hunter would strike a WGW is extremely small; moreover, the hunt would be suspended in the event such a strike is confirmed. There is a greater likelihood that a Makah hunter would strike a PCFG whale than a WGW whale. NMFS's proposed regulations, however, carefully limit the number of PCFG whales that may be struck and require a minimum abundance of PCFG whales before the hunt can take place in any year. While these proposed regulations appear quite conservative to me, it is not the purpose of my testimony to evaluate these measures.

Instead, I provide background information on the stock definition of the WGW and PCFG, including primarily a review of the genetics data, and I attempt to explain the degree of uncertainty that exists regarding the stock structure hypotheses related to these groups. I first provide background on gray whales, including separate discussions of the WGW and the EGW, including the PCFG. In this discussion, it is important to distinguish current and historical populations because there is an important question

whether the current WGW population is a remnant of the historical WGW population. I then discuss the Rangewide Review of the Population Structure and Status of the North Pacific Gray Whale, which was recently completed by the IWC. The Rangewide Review provides the best general assessment of the stock status of gray whales based on currently available scientific information and includes 6 stock structure hypotheses that are considered plausible and are being used to model the population dynamics of gray whales. In my testimony, I explain these hypotheses and provide my opinion as to which hypothesis(es) are most plausible given the scientific data.

According to the International Union for Conservation of Nature (IUCN), the current WGW population is a small population that summers in the Sea of Okhotsk, mainly around Sakhalin Island with occasional observations on the east coast of the Kamchatka Peninsula and the northern Sea of Okhotsk, and winters somewhere in Asia. Until recently, the IUCN considered the current WGW population to be critically endangered and assumed that it is the remnant population of the historical WGW stock that was hunted to apparent extinction primarily by Japanese and Korean whalers in the early 20th Century. This assumption was supported by studies showing the current WGW population is genetically distinct by mitochondrial DNA (mtDNA) and microsatellites from samples of EGWs and occupies the feeding grounds of the historical WGW in the Sea of Okhotsk located between Sakhalin Island and the Kamchatka Peninsula (Ex. M-0444 (Lang et al., 2010b)); (Ex. M-0447 (LeDuc et al., 2002)).

In 2018 the summary and description of the WGW at the IUCN web site were updated (https://www.iucnredlist.org/species/8099/50345475#population) to include recent studies using satellite telemetry, genetics and photographic identification which have revealed that many or all the current WGWs migrate to Mexico and overwinter with the EGWs. Although the historical WGW wintering grounds and migratory routes are poorly known, the latter includes the east and west coasts of Japan and the coast of China. Whaling took place near Ulsan, Korea where there were two peak whaling seasons suggestive of a north bound and south bound migration. The wintering grounds were possibly near Hainan Island (Ex. M-0418 (Cooke et al., 2018)).

And, while some analyses using preliminary data based on genomics and nuclear single-nucleotide polymorphism (SNP) data support the differentiation of the current WGWs and EGWs, other analyses using these data fail to support this differentiation. Therefore, uncertainty exists regarding the true identity of these whales**.**

In the Rangewide Review, several different stock structure hypotheses are considered plausible. Two of these, 3a and 5a, are considered most plausible and are serving as the base models for evaluations of the status of gray whales in the Pacific Ocean, with other plausible hypotheses to be used as sensitivity tests. Considering the available information, uncertainty exists with regard to the status of the current WGW population. A spectrum of possibilities exists ranging from the current WGW population being a distinct stock comprising descendants of the historical WGW population thought previously to be extinct, to a small group of EGWs that might be defined as a feeding group, with several intermediate possibilities. Furthermore, under 5 of the 6 hypotheses considered plausible in the Rangewide Review, the portion of the current WGW population that migrates through the area of the Makah hunt is part of a western feeding group of the eastern gray whale breeding population. Under the sixth hypothesis (6b), which I do not consider the most likely to be correct, the portion of the current WGW population that migrates through the area of the Makah hunt is part of a western breeding stock which does not

resemble the conventional hypothesis of a separate western breeding population. That is, it does not show affinity to the Asian wintering ground but rather winters in both Asia and Mexico.

My opinion is that gray whales that feed in the Sea of Okhotsk and migrate to North America are not a stock descended from the historical WGW, as defined by the IUCN, but may be a population stock as that term is used under the MMPA, composed of somewhat isolated EGWs.

The population status of the PCFG is, in my opinion, much more straight-forward. The genetics data, as well as our understanding of the movements and behavior of gray whales, supports the PCFG as being a feeding group of the eastern gray whale breeding population and not a biological population or population stock as defined in the MMPA. There is no convincing evidence to suggest that the PCFG is an interbreeding population.

Introduction: The gray whale (*Eschrichtius robustus*) was once distributed in both the North Pacific and North Atlantic Oceans but was extirpated from the Atlantic by the early 1700s (Ex. M-0449 (Mead and Mitchell, 1984)). Gray whales in the North Pacific Ocean are found on both the eastern and western margins (Ex. M-0404 (Andrews, 1914); Ex. M-0460 (Rice and Wolman, 1971)). Conventional wisdom held that there were two populations or stocks. One population of gray whales wintered in the subtropical waters of Baja California, Mexico and migrated along the continental shelf of western North America to and from their summer feeding habitats in coastal waters of the Bering, Chukchi and Beaufort Seas, including waters off North America and Russia, and as far south as the eastern coast of the Kamchatka Peninsula. That population was frequently referred to as eastern gray whales (EGW) in the literature, but also as Eastern North Pacific gray whales (ENP) by NMFS (Ex. M-0473 (Weller et al., 2013)). A second population utilized summer feeding habitats in the Sea of Okhotsk, including areas off the northeastern coast of Sakhalin Island as well as the southeastern coast of the Kamchatka Peninsula (Ex. M-0404 (Andrews, 1914); Ex. M-0460 (Rice and Wolman, 1971); Ex. M-0468 (Weller et al., 2002)). This population was frequently referred to as western gray whales (WGW) in the literature (Ex. M-0418 (Cooke et al., 2018)), but also as Western North Pacific gray whales (WNP) by NMFS (Ex. M-0473 (Weller et al., 2013)). I use the terms WGW and EGW in my testimony (but, as noted above, will distinguish between current and historical populations). The migratory and wintering habits of the historical WGWs were not as well-known as those of the EGWs (Ex. M-0472 (Weller and Brownell, 2012)). Information, including historical whaling records as well as more recent observations since the 1930s showed the WGWs migrated in coastal waters off Japan and South Korea to wintering habitat somewhere in the South China Sea (Ex. M-0472 (Weller and Brownell, 2012)). Recent genetic studies suggested that current EGWs and current WGWs are discrete populations (Ex. M-0445 (Lang et al., 2011); Ex. M-0451 (Meschersky et al., 2015)). However, in this testimony, I will make it clear that there is a degree of uncertainty about this and that it is a hypothesis being tested in ongoing research projects by myself and others.

Hunting for gray whales occurred in the Atlantic Ocean and is thought to have caused or contributed to the extinction of the Atlantic gray whales (Ex. M-0449 (Mead and Mitchell, 1984); Ex. M-0472 (Weller and Brownell, 2012)). Hunting also occurred in the Pacific Ocean, where populations of both EGWs and WGWs were reduced to very low numbers. According to Alter et al. (2012) (Ex. M-0403) there were approximately 1,300 mature females at the nadir of the bottleneck for the entire North Pacific gray whale population. That contrasts with the estimated size of the pre-commercial whaling EGW

population of 15,000 to 20,000 whales based on whaling records (Ex. M-0428 (Henderson, 1984)). With regards to the WGW, Berzin and Vladimirov (1981) (Ex. M-0406) estimated the population numbered 1,000 to 1,500 individuals prior to 1910, and this number has been generally accepted. However, Alter et al. (2007, 2012) (Exs. M-0402, M-0403) estimated the historical population size of the entire North Pacific gray whale population based on genetics as approximately 100,000 individuals prior to whaling, but did not estimate the relative sizes of the historical WGW and EGW populations. Estimates of historical abundances based on genetics have been very high for some species, but for others they have been consistent with traditional methods. The very high estimate for gray whales by Alter et al. has not been generally accepted as accurate, nor has it decisively been shown to be incorrect. A key caveat to the use of genetics to estimate historical abundances is that it is difficult to accurately estimate genetic mutation rates on which the estimates of historical abundance are based. Notwithstanding the uncertainty of the pre-exploitation size of the WGW population, it is well-established that it had a considerably greater distributional range than now (Reeves et al., 2008) (Ex. M-0459) and it was reduced to a much smaller size than the EGW.

Western Gray Whales: WGWs are currently classified as endangered according to the IUCN (Ex. M-0418 (Cooke et al., 2018)). This is based on recent estimates of fewer than 50 breeding females. For example, in one recent estimate, the number of non-calves numbered about 140 in 2012 (Cooke et al., 2013) (Ex. M-0419), including only about 29 reproductive females (Burdin et al., 2012) (Ex. M-0414); Cooke et al. (2013) (Ex. M-0419) estimated 36 (±2) mature females in 2012.[1] These estimates are similar and clearly show the small size of the population.

More recently, however, Cooke et al. (2017) (Ex. M-0420) has revised this estimate upwards by also considering animals from the southeastern Kamchatka Peninsula as part of the WGW population. Including whales that summer in Kamchatka as well as Sakhalin, Cooke et al. (2017) estimated the non-calf WGW population in 2016 to be between 320 and 410. Note that this estimate is significantly larger than the annual estimates given above. Those earlier estimates were limited to whales summering only near Sakhalin whereas the latter includes all whales that summer near southeastern Kamchatka and/or Sakhalin. The later estimate by Cooke et al. (2017) would also include animals recruited during the intervening 4 years between 2012 and 2016.

Determining what whales comprise the WGW population is becoming more complex with the new focus of Cooke et al. (2017) (Ex. M-0420) on the Kamchatka whales. Those authors differentiate between an estimated 130−170 whales that feed **predominantly off Sakhalin,** an estimated 182−222 whales that feed at least **occasionally off Sakhalin,** and the previously mentioned 320-410 whales that feed off **both southeastern Kamchatka and Sakhalin**. To clarify, the smaller estimates are comprised of whales that are included in the larger estimates. Relaxing the definition of what is a WGW results in an increased abundance estimate. It should be recognized that no matter how the populations are defined, both the Sakhalin and Kamchatka populations have increased at an estimated rate of 2-5% per year.

Despite a steadily increasing population, the estimates are still small, but they have implications for the IUCN listing of the WGW population. Specifically, with these new estimates the population was recently re-classified by IUCN as Endangered, not Critically Endangered[2], as the population includes more than 50

[1] This contrasts markedly with the EGW: although it was reduced to approximately 2,000 whales, the 2015/16 estimate was about 27,000 whales (Ex. M-0426 (Durban *et al.*, 2017)).

[2] https://www.iucnredlist.org/species/8099/50345475

mature animals but less than 250. However, the modelling of Cooke et al. (2017) (Ex. M-0420) assumes that the Sakhalin feeding population includes both eastern and western breeding animals. Because the western breeding animals comprise 0 to 50 mature individuals (males and females), if such a western breeding population exists, it would be classified as Critically Endangered under IUCN's criteria. However, the eastern breeding animals (those that might migrate through the area of the Makah hunt) would be part of the large EGW population, and would not be endangered. As Cooke et al. (2017) rightly conclude (P.6): "Obtaining further information on the existence, nature and status of the relict western North Pacific breeding population is clearly a high priority."

It has been said that the loss of a single reproductive female annually could be sufficient to lead to the extinction of the current WGW population (Ex. M-0431 (IWC, 2006, pp.10, 67)). This was primarily because of the small number of reproductive females. Between 2006 and 2015 the number of WGWs has almost doubled (120 to >200; see discussion above and Cooke, 2018 (Ex. M-0421); Cooke et al., 2017(Ex. M-0420)), and the statement no longer appears to be true. Threats to WGWs include fisheries bycatch, poaching, ship strikes, and oil and gas development (Ex. M-0457 (Perrin et al., 1994); Ex. M-0468 (Weller et al., 2002)). As to the Makah hunt, as mentioned at the beginning of my testimony, it is my understanding that the likelihood that a Makah hunter would strike a WGW is extremely small (Ex. M-0452 (Moore and Weller, 2018)) and that NMFS's proposed regulations would suspend the hunt in the event such a strike is confirmed.

WGWs historically migrated along the coasts of Korea, China and Japan (Exs. M-0468, M-0473 (Weller *et al*., 2002, 2013)). The wintering grounds have never been known with certainty; suggestions have included the Seto Inland Sea of Japan (Ex. M-0456 (Omura, 1984)) and southern Korea (Ex. M-0404 (Andrews, 1914)). There is little evidence to support these areas as wintering grounds (Ex. M-0468 (Weller *et al*., 2002)), and it is more likely that WGWs wintered farther south along the mainland coast, perhaps as far south as near Hainan Island in the South China Sea (Exs. M-0468, M-0471 (Weller *et al*., 2002, 2012, and references therein)). In the western North Pacific, WGWs were hunted primarily in Korea and Japan in the first half of the 20th Century (Ex. M-0409 (Brownell and Chun, 1977); Ex. M-0460 (Rice and Wolman, 1971)). Gray whales were also hunted in the eastern North Pacific and the independence of these two populations was established based on the appearance that they were geographically isolated across the North Pacific Ocean basin, and because hunting pressure on one population did not seem to impact the other. According to the first report of the IWC Rangewide Review (IWC, 2014b; SC/65b/Rep08, p. 11) (Ex. M-0435), "Brownell reported that the large catches (>1,750 gray whales) by Japanese modern whalers in the East Sea of Korea from 1890-1966, but mainly in the first third of the 20th Century (Kato and Kasuya 2002) (Ex. M-0439), came at a time when the population of gray whales in the eastern Pacific was seriously depleted as a result of 19th Century whaling. This mismatch in the timing of peak catches in the eastern and western North Pacific is consistent with the hypothesis of separate populations." These observations are substantiated by the historical catch data summarized in Appendix A of Bradford (2003) (Ex. M-0408). See also Brownell et al. (2009) (Ex. M-0410).

By 1966 the WGW was considered extinct (Ex. M-0407 (Bowen 1974); (Ex. M-0468 (Weller *et al.*, 2002)). However, in the late 1960s and the 1970s some whales were sighted in the Sea of Okhotsk, South China Sea and the Sea of Japan (Ex. M-0455 (Omura, 1974)). It was assumed that these were surviving WGWs, and the population was estimated to be 100-200 individuals by Berzin and Yablokov (1978, cited in Ilyashenko, 2011) (Ex. M-0406).

By the turn of the 21st Century, the last surviving remnant of the WGW population was thought to be the gray whales that currently summer off the northeastern coast of Sakhalin Island and some of the whales that summer off southeastern Kamchatka (Exs. M-0467, M-0468, M-0471 (Weller *et al.*, 1999, 2002, 2012)). The fact that gray whales are occasionally seen or stranded in waters off Japan, Korea and China, ostensibly during the months of the WGW migration, is an indication that some gray whales summer in the Sea of Okhotsk and migrate south to wintering sites in Asia. This is thought to be a historical migration pattern of WGWs. A gray whale photographed as a calf in the Sea of Okhotsk was subsequently killed off Japan (Ex. M-0469 (Weller *et al.*, 2008); Ex. M-0472 (Weller and Brownell, 2012)); according to the authors, this was the first confirmation of the Asian migratory corridor in recent times. There are, however, alternative explanations for the presence of gray whales observed in Asian waters during the winter. They could be whales that did not have sufficient strength to migrate to Mexico and chose to stay closer to the summer feeding grounds. If so, they likely would have been forced south by ice conditions in the Sea of Okhotsk and ended up in Japanese waters. These whales could also be vagrant individuals exhibiting extralimital movement patterns. In recent years, at least two gray whales were seen in the Atlantic and one in the Laptev Sea off the northern coast of Siberia (Ex. M-0461 (Scheinin et al., 2011); Ex. M-0463 (Shpak et al., 2013)). Given that there are no existing populations in those areas, these observations demonstrate that gray whales do at times travel far outside their normal migratory corridor and feeding areas.

Data are being collected and analyzed to help determine the status of the WGW population, including photo identification (Ex. M-0414 (Burdin et al., 2012); Ex. M-0464 (Tyurneva et al., 2012)) and biopsy data (Ex. M-0444 (Lang et al., 2010b)) collected since 2002 from gray whales summering in the Sea of Okhotsk. Gray whales biopsied off Sakhalin Island are statistically significantly different from whales sampled from the EGW population based on biparentally inherited microsatellite loci and maternally inherited mtDNA (Lang et al., 2010b; Ex. M-0447 (LeDuc et al., 2002); Ex. M-0451 (Meschersky et al., 2015)). This evidence supports the hypothesis that the gray whales summering off Sakhalin Island are the remnant of the once presumed extinct WGW. However, satellite telemetry data has called into question previously widely held hypotheses about the movements of WGWs and their relationship with EGWs. In 2010, a satellite tag was placed on a 13-year old male WGW named "Flex" by researchers off Sakhalin Island (Ex. M-0448 (Mate *et al.*, 2015)). On December 12, 2010, Flex travelled eastward to the west coast of the Kamchatka Peninsula, swam around the southern tip of Kamchatka, and proceeded north toward the Commander Islands. He swam east on January 3, 2011, crossing the Bering Sea and heading toward North America. After crossing the Gulf of Alaska and turning south, he arrived at the Washington, USA coast near Queets by February 2, 2011. Three days later the transmitter failed with Flex near the Oregon coast and heading south. The study of Mate et al. (2015) was a landmark in gray whale science because it immediately upended the conventional wisdom of decades of North Pacific gray whale research. The result has been an exhaustive and healthy reassessment of stock structure hypotheses related to both the WGW and the PCFG, discussed below, through the IWC Rangewide Review.

Additional efforts to follow WGWs via satellite confirmed that Flex was not an isolated observation. On August 28, 2011, a transmitter was placed on a female WGW named "Agent" which, like Flex, travelled east towards North America beginning on November 24, 2011. Agent's transmitter ceased operating on December 31, 2011, when she was in the Gulf of Alaska. Another transmitter was placed on "Varvara", a female gray whale at Sakhalin Island in 2011. Varvara was tracked for more than a year during which

time she moved from Sakhalin to the EGW wintering lagoons of western Baja California, Mexico, and then returned to Sakhalin Island (Ex. M-0448 (Mate et al., 2015)).

The surprising journeys of the satellite tagged whales prompted examination of other data sources to determine if additional evidence of migration between Sakhalin and North America might be found. Photographic matches of whales photographed off Sakhalin and: (a) British Columbia (n = 6, Ex. M-0470 (Weller *et al.*, 2011)) and (b) Mexico (n = 17, Ex. M-0465 (Urban et al., 2012), Ex. M-0466 (Urban *et al.*, 2013)), and genetic matches (n = 2, Ex. M-0445 (Lang et al., 2011)) of whales biopsied at Sakhalin and Southern California, have now been reported as well as whales with satellite tags. Including the three satellite-tagged whales, 28 whales are known to have migrated from the Sea of Okhotsk to North American coastal waters. This is about 14% of the Sakhalin population if we accept the midpoint N = 202 of the range 182 to 222 given by Cooke et al. (2017) (Ex. M-0420) as the size of the Sakhalin population in 2016. It is uncertain what percentage of the WGW population migrates to North America, but Cooke estimated it to be between 30% and 100% of the mature (aged 7+) Sakhalin Island gray whales (Ex. M-0436 (IWC, 2017)). It thus seems likely to be a significant portion of the population, and perhaps all of them, that migrates east to North America and the EGW wintering grounds off Mexico instead of south to wintering grounds off the Asian coast.

Questions remain about the status and population biology of WGWs. A central issue focuses on the findings of statistically significant mtDNA and nuclear gene differences between WGWs and EGWs in the face of what appears to be a high level of mixing or potential mixing (Ex. M-0443 (Lang et al., 2010a)). Below, I will clarify two biological issues that are pertinent to the question of population structure of North Pacific gray whales. These issues concern the WGWs' status as a stock and their historical identity. The first issue can be addressed through population genetics, and the second through evolutionary genetics. I will review potential stock structure scenarios that are consistent with existing data on genetics, distribution and movements of these whales, including the scenarios currently being considered as a result of IWC's 5-year Rangewide Review of the Population Structure and Status of North Pacific Gray Whales.

A Brief Explanation of the Genetics Methods and Terms Relevant to Gray Whale Population Structure: The field of genetics is a rapidly progressing area of science in terms of both technology and theory. The basis for studying the genetics of gray whales, or any other wildlife species, is that variation exists in the DNA of individuals as a result of mutations that change the DNA sequence of a gene (or the more general term locus) by substituting a nucleotide (also referred to as a base or base pair since DNA has two strands) with an alternative one (there are 4 nucleotides, abbreviated A, T, G, and C). This is like changing a sentence by replacing one word with another. Given that the genome (i.e., all of the DNA of a cell or individual) contains the developmental blueprint as well as the operating manual of the individual, these variations can have significant implications.

We study the DNA variation using a variety of methods that are discussed in sections below. These include genetic analyses that target specific genes or regions of the DNA, and genomic analyses that include analysis of the entire genome. Genetic studies result in the assessment of hundreds or a few thousand nucleotides of DNA sequence, whereas genomics might cover the entire 35 billion bases of DNA in the gray whale genome. They use substantially different analytical approaches.

Three genetic methods are now commonly used and will be discussed below. Mitochondrial DNA (mtDNA) analysis analyzes the sequence of one or more genes on the mtDNA chromosome. This

chromosome is outside the nucleus of the cell, is part of what was once a symbiotic living bacterium that became incorporated into our ancestor's cells at the origin of higher organisms several billions of years ago. Although there are many copies of the mtDNA chromosome in any cell, the copies are typically identical, and the term "haplotype" is used to refer to mtDNA variants (in contrast to the term "allele," which is used to refer to variants of bi-parentally inherited genetic markers). Because of certain special properties mtDNA is easy to study and highly variable. It also is strictly maternally inherited; males and females both inherit it, but only females pass it to their progeny. So, it is used as a marker of female lineage diversity. Most studies focus on a few hundred base-pairs of the highly variable Control Region of the mtDNA. Due to its characteristics, this genetic marker gives us a unique window into the female contribution to population genetics.

A second frequently used kind of genetic markers is called microsatellites. These are found in the nucleus of the cell and typically they are bi-parentally inherited markers, being located on the autosomal chromosomes (which contrast with the sex chromosomes, the X and Y, which will not be discussed here). Microsatellites are short, two- or three-base repeats, such as CACACACACA, that are found throughout the genome. These repeats are highly variable in terms of the number of repeats because of a process of slippage which occurs during DNA replication. Such mutations that change the number of repeats are far more common than base substitutions, which change one nucleotide for another. Moreover, microsatellites are analyzed using a method called fragment size analysis, which estimates the number of repeats at a locus, instead of a sequence analysis like the mtDNA. Ultimately, this is a method that reveals a high degree of genetic variability because each locus will have a large number of variants, or "alleles" in the lexicon of genetics (in contrast to the term "haplotypes" used to refer to mtDNA variants). Typically, and as is the case in the gray whale studies below, the locations of the microsatellite loci are unknown, and the loci have been derived from different species which leads to potential scoring and analytical problems.

A third method that is becoming more frequently used because it does not have the analytical problems of microsatellites is called Single Nucleotide Polymorphisms (SNPs or snips). A SNP locus is any location on the DNA where alternative nucleotides are found on different chromosomes. These are almost always two-allele (bi-allelic) markers and since they are frequently derived from a whole genome sequence, their location (i.e., if they are associated with a known gene or not) is known. There are millions of these in any mammal species; in fact, DeWoody et al. (2017b) (Ex. M-0424) identified 2,057,254 SNPs in the gray whale genome from which they developed a panel of 96 SNPs located in genes of known function. As mentioned, SNPs have certain advantages of analysis compared to microsatellites including clarity or ease of scoring since they are a sequence-based analysis, not a fragment size analysis. And, because they are sequence-based the data can be archived and used from study to study as is the case for mtDNA.

Genomic analysis is the future of all genetic studies. The cost of sequencing a genome was about $100 million in 2001, and today is only about $1,000. Along with the rapid advance of the technology to sequence the genome, there has also been rapid advances in bioinformatics (the methods by which large scale genomics data are analyzed using supercomputers) to analyze the sequence, availability and capability of supercomputers to do this work, and analytical programs for both evolutionary and population genomic studies. DeWoody et al. (2017b) (Ex. M-0424) reported the genome sequences for two WGWs and one EGW, and Arnason et al. (2018) (Ex. M-0405) reported genome sequences for two additional gray whales. Soon we will have the ability to sequence entire genomes from large numbers

of individuals and analyze millions of genetic markers. However, at this time, the gray whale genomic data has served as a resource to identify SNPs to be used for population genetic analysis, as well as comparing a small number of EGWs and WGWs to reconstruct the population evolutionary history as described in Brüniche-Olsen et al. (2018b) (Ex. M-0412).

Genetics and genomics provide the modern methods to study population genetics and evolutionary genetics. Such studies are critical in conservation and management because they directly address two key issues in conservation biology: 1) population structure which guides the identification of management units, and 2) measuring genetic diversity in populations which is a key driver for extinction probability. These methods and issues are discussed below more fully as they pertain to gray whales.

Genetic Studies of Western Gray Whales: Comparisons of the genetics of the current WGW population to the current EGW population have been made in a series of studies primarily using biopsies from whales observed off Sakhalin Island (and a few from southeastern Kamchatka), and biopsies or tissues of stranded, harvested, or biopsied EGWs from a variety of localities including their summering and wintering habitats and migratory corridor. These studies have employed mtDNA (Ex. M-0447 (LeDuc et al., 2002); Ex. M-0438 (Kanda et al., 2010); Ex. M-0451 (Meschersky et al., 2015)), nuclear microsatellites (Ex. M-0441 (Lang, 2010); Exs. M-0443, M-0444 (Lang et al., 2010a, 2010b)), and both (Ex. M-0445 (Lang et al., 2011)). Consistent evidence of genetic divergence between the WGW and the EGW populations, expressed as statistically significant differences in mtDNA haplotype frequencies (F_{ST}) and microsatellite allele frequencies (F_{ST}), have been found. The two populations have similar levels of genetic diversity (e.g., heterozygosity) in nuclear microsatellites, and similar nucleotide diversity of mtDNA. But the EGWs have greater mtDNA haplotype diversity than the WGWs (Lang et al., 2011). These studies show significant genetic variation is present in the WGW population, despite the history of commercial whaling and current small estimate of abundance of the group. The pattern of frequency distribution of mtDNA haplotypes differs in WGWs and EGWs; there are two haplotypes in very high frequency in WGWs (Figure 1; haplotype 1, 0.51 and haplotype 2, 0.44) whereas in the EGW population the frequency of the most common haplotype (1) was 0.15. The results of these studies, which utilized appropriate methods when they were conducted, are consistent with two demographically distinct populations of drastically different sizes and numbers of breeding females as the studies cited above concluded.

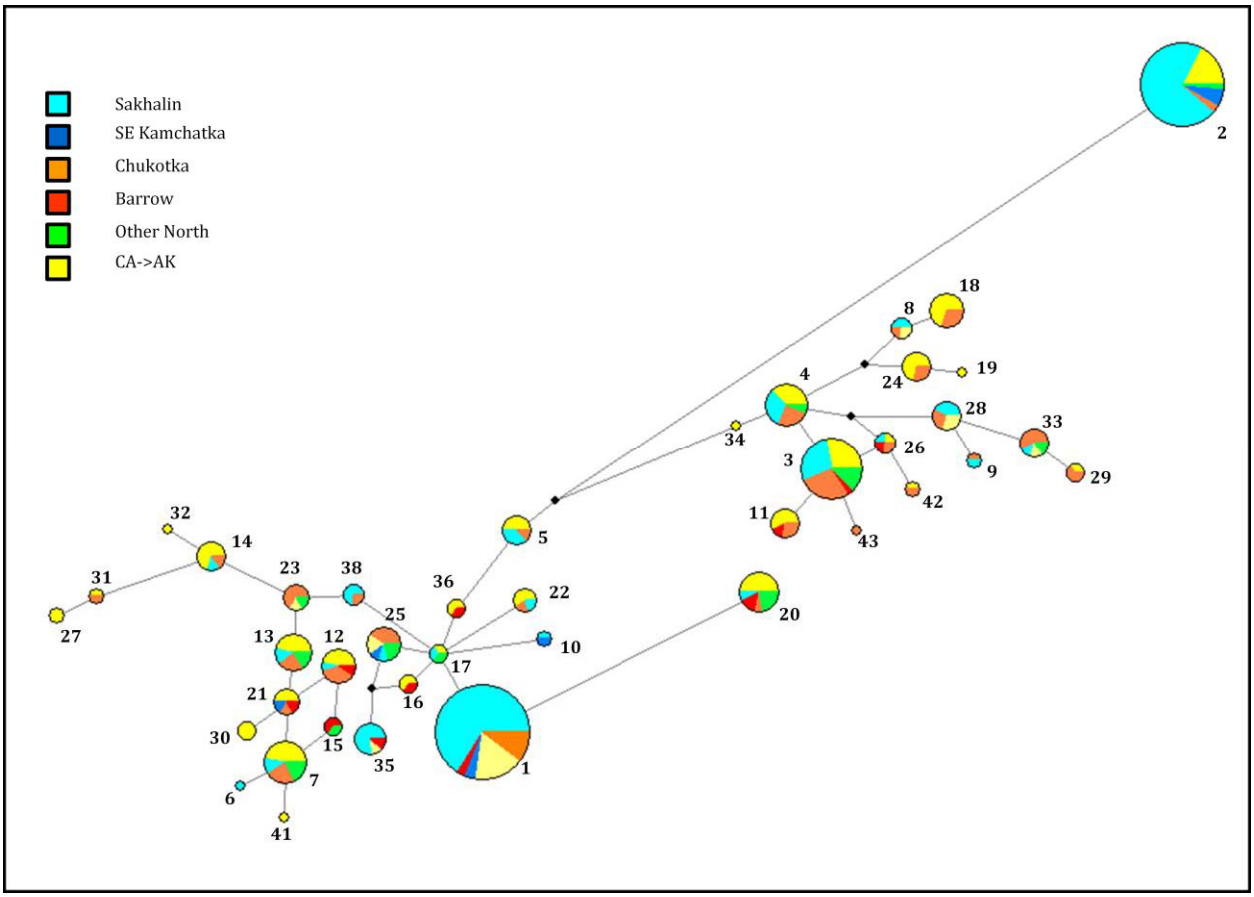

Figure 1.—This is Figure 3 in Lang et al. (2011) (Ex. M-0445) and shows the mtDNA haplotype network for control regions sequences. Note that there is no evidence of population structure in the form of nested groups of related haplotypes that are found only in EGW or WGW populations. Compare this to Figure 2 which shows evidence of stock structure in Steller sea lions.

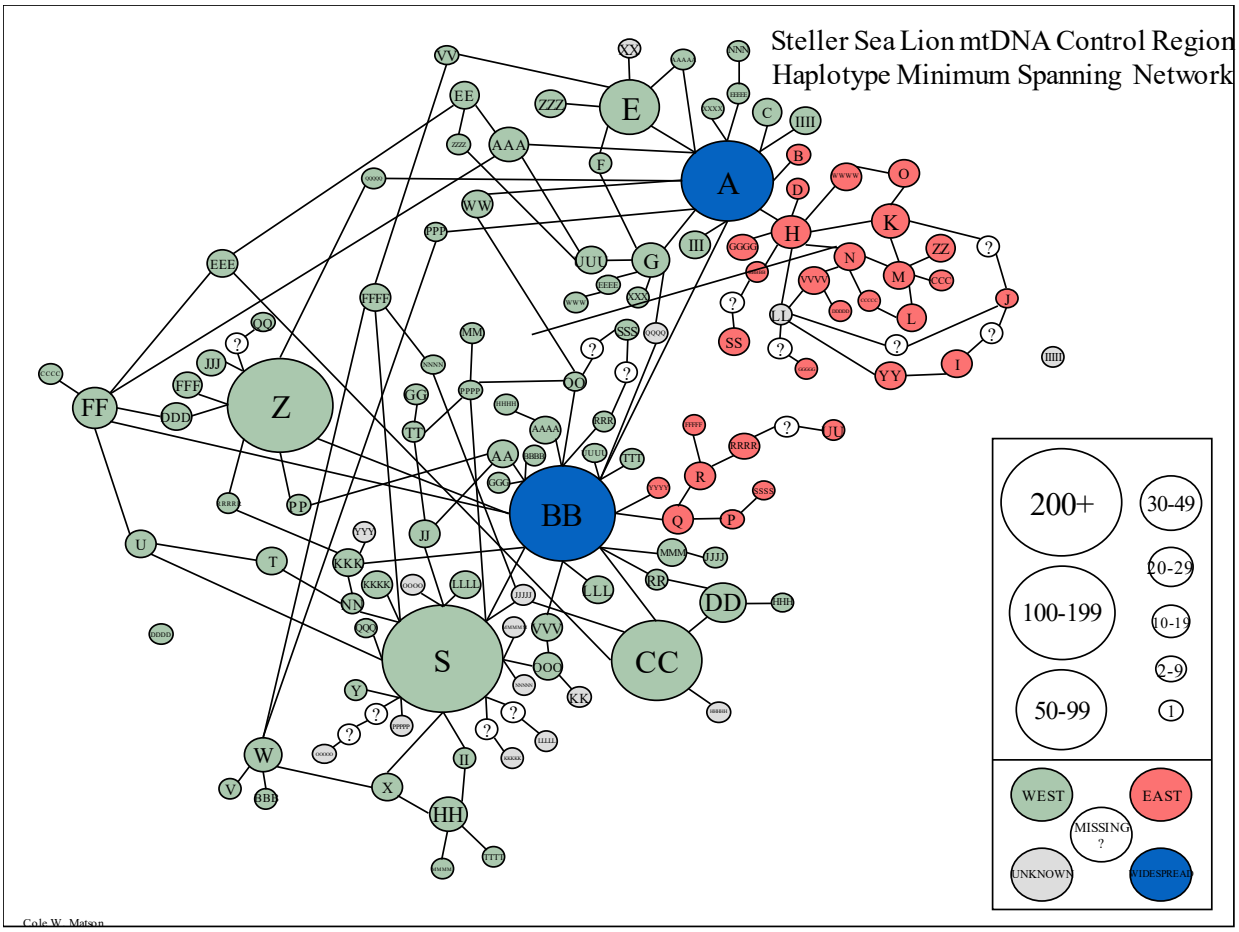

Figure 2.—Steller sea lion mtDNA haplotype network from control region sequences. Notice the groups of related (nested) haplotypes that are unique to the eastern (red) and western (green) stocks. This figure is unpublished, but the pattern of nested haplotypes in Steller sea lions has been examined by Harlin-Cognato et al. (2006) (Ex. M-0427a) and Phillips et al. (2011) (Ex. M-0458).

The observed, statistically significant, genetic distinctness between the two populations, however, is surprising given the observation of a substantial proportion of WGWs that migrate to North America rather than to wintering habitats in Asia. In fact, males and females in approximately equal numbers are known to migrate to North America (Ex. M-0466 (Urban et al., 2013)) so mating during migration among members of this population is possible. Nonetheless, Lang et al. (2010a) (Ex. M-0443) reported evidence of male mediated dispersal or gene flow from the EGW population into the WGW population. Male biased dispersal was supported by the fact that most mtDNA haplotypes found in only one or two Sea of Okhotsk gray whales are represented only by males (Ex. M-0447 (LeDuc et al., 2002); Ex. M-0445 (Lang et al., 2011)). These could be EGW males that have followed Sea of Okhotsk gray whale females back to the latter's summer feeding grounds. That is, they are not the sons of WGW females and so don't have the mtDNA haplotypes found in those females. Because they are males, they do not pass their mtDNA to offspring and so their distinctive haplotypes will not persist or increase in the WGW population. Moreover, the level of differentiation of nuclear microsatellites is quite low between EGW and WGW, with F_{ST} = 0.010. This low, but significant (p=0.001) measure of Fst, was based on only 8 loci (Lang et al. 2011). Together, these observations provide an unclear picture of the population structure of North

Pacific gray whales. That is, some evidence is consistent with the WGWs comprising a distinct population, but other evidence suggests gene flow with the EGW population and low level of nuclear differentiation based on a small number of loci. Understanding the limits of gene flow among populations is key to understanding population structure and, in this case, it would be preferable to have a larger dataset, particularly in terms of the number of nuclear loci.

The pattern of differentiation between WGW and EGW in mtDNA is also meaningful in any discussion of stock structure. The significant F_{ST} for mtDNA means that haplotypes differ between the populations in their frequencies of occurrence. This frequency difference could be the result of long-term isolation such as would be expected of distinct stocks. But it could also be the result of a recent founder effect such as a small group of EGW colonizing a new habitat, or the result of genetic drift in a small, isolated population of EGWs. An examination of Figure 1 shows that the haplotypes found in WGW are also found in EGW. That is, there are no haplotypes unique to the WGW. Moreover, there are no groups of related haplotypes that would indicate that the Sakhalin population was isolated for a long period of time from the EGW population. An examination of Figure 2 shows such a pattern wherein eastern and western stocks of Steller sea lions have unique haplotypes, as well as groups of related haplotypes found only in that stock. This pattern is what we might expect of the Sakhalin whales if they are indeed the historical WGW population, that is, the descendants of the whales hunted to the verge of extinction by whalers in Japan and Korea and isolated by the North Pacific Ocean basin from the EGW. Instead, the existing pattern of significant F_{ST} but no unique haplotypes seems more likely to be due to recent divergence and a founder effect from a small group of EGWs.

The question of the relationship between the Sakhalin and Kamchatka feeding populations was addressed recently by Cooke et al. (2017). Their population model assumes two feeding populations, Sakhalin and Kamchatka, and two breeding populations, an eastern breeding population that migrates to Mexico and a western breeding population that migrates to an unknown wintering area in Asia. According to Cooke et al. (2017, P. 3) (Ex. M-0420) "The "Sakhalin" feeding population is defined to consist of the whales that feed predominantly off Sakhalin but may also be seen off Kamchatka, and possibly in other areas. The "Kamchatka" feeding population is defined as whales that feed predominantly off SE Kamchatka but may also be seen off Sakhalin or in other areas." The model also assumes that the Sakhalin feeding area contains both eastern and western breeding whales and the Kamchatka feeding area contains only eastern breeding whales. They address the issue of stock structure by making use of genetic paternity data (Ex. M-0441 (Lang, 2010); Ex. M-0443 (Lang et al., 2010a)) to test two hypotheses of genetic closure (meaning that the population breeds within itself and is thus closed to mating with members of the other population): *(i) paternities are within each feeding population; (ii) paternities are not necessarily within each feeding population, but are within the two feeding populations combined* (Cooke et al., 2017 p. 5). The authors conclude that preferential mating occurs within the Sakhalin population, but it is not "exclusive" meaning the population is not closed. Thus, hypothesis *i* is rejected ($p < 0.05$) meaning that the Sakhalin feeding population is not genetically closed. In sum, the authors conclude (P. 6) *"*that the Sakhalin feeding aggregation is probably not genetically closed but that the Sakhalin and Kamchatka feeding aggregations, taken together, may be genetically closed. However, genetic data from Kamchatka would be required to confirm this.*"* This analysis is suggestive that the Sakhalin whales, combined with the Kamchatka whales, could be a discrete population but the results are not definitive.

Recent advances in sequencing methods (next-generation sequencing), genomic analyses, and bioinformatics have made possible new approaches to study the genetics of natural populations. These methods were not available, or were exorbitantly expensive, at the times the earlier studies of gray whale genetics were done. Studies were recently conducted using genomics methods that are relevant to measuring population differentiation of EGWs and WGWs. DeWoody et al. (2016, 2017a, 2017b) (Exs. M-0422, M-0423, M-0424) sequenced the genome of two Sakhalin whales and one EGW from Barrow, Alaska. Using the genome assembly, 92 Single Nucleotide Polymorphism (SNP) loci were identified. These included 2 SNPs useful for sex identification, 2 useful for mtDNA haplotype identification, and 88 gene-associated, bi-parentally inherited nuclear markers. The SNP panel was tested using 35 biopsies from Sakhalin WGWs and the single EGW from Barrow used in the genome sequence analysis. The data were used in preliminary assessments of relatedness and population structure, among other things. Among the 36 tissue samples there were 29 unique genotypes, indicating 7 instances where WGWs were biopsied twice. The relatedness analyses revealed apparent examples of parent-offspring, full sibling, half sibling, and other close relatives. These included two cow/calf pairs and one ostensible full-sibling pair (sisters).

A following paper (Ex. M-0411 (Brüniche-Olsen et al., 2018a)) using the SNP panel included the data in the first study as well as additional Sakhalin whales and whales from the wintering grounds in Mexico. The resulting sample sizes were 55 Sakhalin and 111 Mexican whales. These authors found a low (F_{ST} = 0.039; D = 0.017) but significant (p = 0.001) level of population subdivision. They analyzed the data for population structure using multiple methods including Discriminant Analysis of Principal Components (DAPC), STRUCTURE, and Lea (which is similar to STRUCTURE). The program BayesAss v3.0 was used to estimate recent migration. A genetic similarity measure was also calculated (M_{xy}).



Figure 3.—Lea analysis showing the presence of two genomes (brown and yellow) which are found at markedly different frequencies in the Mexican wintering grounds and the Sakhalin (Russian) summering grounds. Individual whales (columns) can have 100% yellow or brown genomes, or they can be admixed meaning that they are of mixed ancestry. This figure is from Brüniche-Olsen et al. (2018a) (Ex. M-0411).

There was an approximately 65-fold greater migration rate for whales migrating into the Sakhalin population, as compared to whales migrating into the eastern population. This is consistent with the large difference in estimated numbers of EGWs versus WGWs. The DAPC showed that the two

populations could be separated, but with a considerable degree of overlap. The Lea (Figure 3) and STRUCTURE analyses both showed evidence of two distinct lineages that differed considerably in their frequencies in the two populations, as well as the presence of admixed individuals. One lineage predominated in the Mexican population and the other at Sakhalin, but the Sakhalin population showed more even proportions of the two lineages, and more admixed individuals. Between-individual genetic similarity (M_{xy}) was higher in the Mexican population than at Sakhalin.

All in all, this study (Ex. M-0411 (Brüniche-Olsen et al., 2018a)) is consistent with previous work (Ex. M-0445 (Lang et al., 2011)) showing that the Sakhalin population is genetically distinct but goes further in revealing that it appears to be a mixed stock assemblage (Figure 3). Whether the two identified lineages correspond to WGWs and EGWs is not known, since individuals of both lineages migrate from Sakhalin to Mexico. But it seems clear that considerable immigration and admixture is taking place at Sakhalin. One possible interpretation is that a sub- stock of the EGW population (western feeding group) has long been present in the Sea of Okhotsk and that it is mixing with recent immigrants from the northern feeding group of the EGW population. This would be consistent with stock structure hypothesis 3a from the Rangewide Review in which the western breeding stock is extinct. It could also be consistent with hypothesis 6b in which the western breeding stock migrates to Mexico and Asia, but this seems less likely to me for three reasons. First, there is a low level of genetic divergence between putative eastern and western gray whales as measured by mtDNA, microsatellites, and SNPs. This is consistent with a small population recently derived from the larger population, but not what one would expect of a distinct stock isolated by an ocean basin. Second, there are no mtDNA lineages or even haplotypes (according to the data shown in Lang et al., 2011, see Figure 1) that are unique to the Sakhalin whales. Again, this is consistent with a small population recently derived from the larger population, but not what one would expect of a distinct stock isolated by an ocean basin. And, third, depletion of the EGW population by commercial whaling did not seem to impact the WGW population. This strongly suggests that at the time of whaling the EGW and WGW populations were distinct and isolated from one another. I discuss the stock structure hypotheses from the Rangewide Review in more detail below.

A study recently accepted for publication, Brykov et al. (2019) (Ex. M-0413), sequenced 4 mtDNA genes (control region, and the following protein-coding genes: cytochrome b, cytochrome oxidase I, and NADH dehydrogenase 2) from Sakhalin whales. Gray whales with the "eastern" SNP genotype had statistically significantly different mtDNA haplotype frequencies compared to gray whales with the "western" SNP genotype using Fisher's exact test for both the control region ($p = 0.034$), and for the combined protein coding sequences ($p = 0.013$), analyzed separately. This gives some confidence that despite small sample sizes, the Lea analysis is identifying biologically meaningful groups. Potentially these groups are comprised of individuals representing different populations. The study goes on to analyze the evolutionary relationships of the haplotype sequences using haplotype networks for both the control region and the combined protein coding sequences. No unique clades of related haplotypes were found among the western SNP genotype animals, for either of the two networks. From these data the authors concluded the following: "This is not consistent with long-term isolation during the Pleistocene as seen in many other marine mammals with similar distributions. Rather, the "western" and "eastern" genotypes likely have diverged recently, possibly since the end of commercial whaling in the early 20th Century, but more likely post-Pleistocene."

Although the study of Brykov et al. (2019) (Ex. M-0413) is based on small sample sizes and for this reason the authors recognize the results are preliminary, it is yet another indication that the Sakhalin population is a mixed-stock aggregation and that the "western" genotype animals are most likely not the descendants of the historical WGW population that migrated along the coast of Asia. Rather, it is more likely to be a subset of the EGW population.

Another relevant study was an analysis of the previously reported genome sequences of the two Sakhalin whales and the single EGW using population genomics methods (Ex. M-0412 (Brüniche-Olsen et al., 2018b)). Several observations are of interest here. 1) Using the genome sequence data to estimate long-term effective population size, estimates from the three individuals did not differ very much. Estimates based on the two Sakhalin whales were *N*e = 555,557 and 582,749; the EGW estimate was *N*e=706,102. These differ between the two populations but not to the expected degree since the EGW abundance was only 1.2-fold greater than the WGWs. 2) A relatedness analysis showed results that conflicted with the traditional stock structure hypothesis; although the two Sakhalin whales were more closely related to each other than expected by chance, one of the Sakhalin whales was also more closely related to the EGW than by chance. Again, this is an unexpected result. 3) The pairwise population concordance (PPC) test, which evaluates probabilities of population differentiation, indicated that the null hypothesis of all three individuals belonging to the same gene pool was not rejected. Some genomic evidence was also found that is consistent with the two Sakhalin whales belonging to a different population from the EGW individual. 4) Genome-wide genetic (nucleotide) diversity was measured for the three whales and it was found that the two Sakhalin whales had lower diversity estimates than the EGW. Various estimates of inbreeding, based on measures of Runs of Homozygosity (ROHs), consistently showed that the Sakhalin whales had higher levels of inbreeding than did the EGW.

Another very recent study of gray whale genomics was published (Ex. M-0440 (Lammers et al., 2019)) which examined the phylogenetic patterns of transposable elements (TEs) based on published genome sequences of baleen whales. In the study, they examined TEs of two WGWs (i.e., the genomes reported by DeWoody et al. (2017b) (Ex. M-0424) and the genomes of two EGWs (reported by Arnason et al., 2018 (Ex. M-0405)). There was a high degree of differentiation of TEs between the WGWs and EGWs, much greater than between any other within-species comparison and on the order of the difference between right whales and bowheads (which are in different families). This observation is at odds with all of the other studies of gray whale genomics and genetics. This, combined with the fact that TEs are not as well understood as the other genetic markers used in gray whale studies, makes me doubt the relevance of this study to gray whale stock structure. It does, however, indicate a future research direction.

While some of the genomic data can be taken as support for the concept of two distinct populations of gray whales in the North Pacific Ocean basin, the analyses of Brüniche-Olsen et al. (2018b) (Ex. M-0412) also provide evidence that population structure and status of the WGW might not be so straight-forward. Notwithstanding that their analyses were based on only 3 individuals, they showed that the hypothesis of a single population of North Pacific gray whales could not be rejected. And, perhaps more interesting, is the fact that the two Sakhalin whales sampled were significantly different from each other in some analyses, such as inbreeding level, and that one individual, identified as WGW1 in the paper, was consistently intermediate between WGW2 and the EGW. Moreover, in the relatedness analysis

WGW1 and the EGW were more closely related than by chance. WGW1 is also one of the WGWs known to migrate to North America.

Taken together, the results presented in DeWoody et al. (2016, 2017a, 2017b) (Exs. M-0422, M-0423, M-0424), Brykov et al. (2019) (Ex. M-0413) and Brüniche-Olsen et al. (2018a, 2018b) (Exs. M-0411, M-0412) do not provide a definitive answer as to the nature of the WGWs because sample sizes are too small. They do indicate that further work is needed to resolve the issue of stock structure. Importantly, they employed methods of analysis that were not available to the authors of the earlier papers, *e.g.,* Lang et al. (2011) (Ex. M-0445), and provide new perspectives on the issue of population structure. That is not to say that the earlier studies did not employ the appropriate methods for their time, it is just that the rapidly progressing field of genetics has moved beyond those methods. Genomic studies of gray whales are continuing at Purdue University and NMFS.

But while these studies are not in and of themselves conclusive, the weight-of-evidence they provide indicates that the Sakhalin whales are comprised of two groups and both of the groups are likely to have been recently derived from the EGW population. These results provide greater insight into the issue of gray whale stock structure. Genetics and genomics, combined with several examples of tagged whales and other indicators of individual whale migratory behavior, demonstrate that the current populations considered as WGW and EGW are not isolated, are genetically much more closely related than expected, and experience what appears to be a considerable degree of mixture. Below, I discuss how these studies dovetail with the findings of the Rangewide Review and go into the various stock structure hypotheses in more detail.

Eastern Gray Whales (Including the Pacific Coast Feeding Group): Early in the 20th Century it was recognized that the EGW population was heavily depleted and possibly on the verge of extinction (Ex. M-0429 (Huey, 1928)). Unlike the WGW, the EGW population has made a remarkable recovery and the current abundance estimate is 26,960 (Ex. M-0426 (Durban et al., 2017)). As presently conceived, the EGW population consists of a large general population, sometimes called the Northern Feeding Group (NFG) because the bulk of the population feeds in the Beaufort, Chukchi, and Bering Seas, and a small group of whales called the Pacific Coast Feeding Group (PCFG), with a current estimated abundance of 243 (Ex. M-0416 (Calambokidis et al., 2017)). The use of the term "feeding group" in the IWC Rangewide Review as well as by NMFS in Weller et al. (2013) (Ex. M-0473) for both the NFG and PCFG is somewhat confusing because in the case of the PCFG it is referring to a group that is not thought to breed primarily with members of its own group, whereas whales of the NFG primarily do so. Thus, the term is being used for groups of animals that differ in their placement on the heirarchy of social structure. The NFG would seem to be a stock or breeding population whereas the PCFG is a group of whales with a shared learned behavior (*i.e.*, a true feeding group) that is part of the larger NFG stock. Whales that feed in the Sea of Okhotsk, including whales that migrate to North America, are sometimes referred to as the Western Feeding Group (WFG) in the IWC Rangewide Review. These terms are used by the IWC Rangewide Review in order to differentiate among different groups or aggregations of whales in the various stock structure hypotheses being modelled. I will explain this more fully below. The estimated 26,960 whales that migrate along the western coast of North America, and are counted in California, include the small numbers of PCFG whales and the WFG whales that migrate to North America, and the very large NFG.

It is well known that gray whales found off the coast of the Pacific Northwest in summer and fall appear to have different affinities to the area. Some whales return frequently and account for most of the sightings between 1 June and 30 November. On the other hand, some whales are encountered only in a single year, typically remain for a shorter period, and are not found in as many areas as the frequently observed whales. The IWC defined PCFG gray whales as: whales observed between 1 June to 30 November within the region between northern California and northern Vancouver Island (from 41°N to 52°N) and photo-identified within this area for two or more years (Ex. M-0433 (IWC 2012)). This same definition has been adopted in most studies including Calambokidis *et al*. (2017) (Ex. M-0416) and Weller et al. (2013) (Ex. M-0473).

Lang et al. (2014) (Ex. M-0446) investigated genetic differentiation between PCFG and NFG whales. They found a low, but statistically significant difference in haplotype frequencies between the two feeding groups. They conclude that "it is plausible that the PCFG represents a demographically independent group". The acceptance of the PCFG as a management unit hinges largely on the difference in mtDNA haplotype frequencies, as no statistically significant difference in microsatellite allele frequencies (in nuclear DNA) between the PCFG and NFG has been observed (Ex. M-0425 (D'Intino et al., 2013);Lang et al., 2014)). A significant difference in mtDNA haplotype frequencies was also observed by Frasier et al. (2011) (Ex. M-0427), based on a smaller sample size of whales collected off Vancouver Island compared to samples of the greater EGW population collected from stranded gray whales along the migratory route and samples from animals hunted for subsistence in Russia. Frasier et al. (2011) explain the reason for the genetic difference as being due to behavioral segration of the PCFG. They point out (P. 40) : "Subdivision with respect to summer feeding ground use is common in baleen whales, and results from maternally directed site fidelity to different feeding grounds." They go on to discuss the well-known example of genetic divergence of feeding aggregations of humpback whales. Because mtDNA is maternally inherited, it is a useful marker to track female behavior and any resulting site fidelity in subsequent generations. Behavioral segregation begins during the first year of its life, when a calf will learn from its mother the location of good feeding habitats and is more likely to return to these localities in later years. Over the course of generations this process will increase the numbers and frequencies of the few haplotypes associated with the females that were the original founders of the feeding group. Thus, a feeding group may become statistically different in mtDNA hapylotype frequency from the larger population even if the founders of the feeding group did not differ from the larger population. This is because any haplotypes present only in male founders will disappear when those animals die. Simultaneously, the haplotypes of the female breeders will increase in the population as their offspring, male and female, learn from their mothers to utilize the PCFG area. Ultimately, the genetic makeup of the feeding group will be determined by genetic drift in a small population, the number (if any) of female immigrants which will tend to homogenize the mtDNA haplotype frequencies with the larger population, and the degree of breeding within the feeding group which will lead to population differentiation. Thus the fate of a nascent feeding group can include several alternatives: remain a feeding group with different mtDNA frequencies but not biparentally inherited markers; become a discrete breeding stock if internal breeding is high enough; or become indistinguishable from the greater population if immigration into the feeding group is great enough to homogenize the mtDNA haplotpe frequencies.

However, defining exactly which whales comprise a feeding group is not easy, particularly when we are dealing with groups of whales whose migratory and feeding areas overlap, offering extensive

opportunithy for genetic exchange. In the case of the PCFG, some gray whales show a high degree of faithfulness to the PCFG feeding area, returning year after year. Other whales are observed with less frequency, but still more than the 2-year requirement to be counted as PCFG whales, and some whales seem to be visitors that are seen in one year and never seen again. It seems likely that whales that satisfy the IWC definition of PCFG, having learned the location of the feeding area from their mothers or immigrated to the feeding group and having been sighted in at least two or more years, return frequently to the PCFG foraging area. However, this definition is subjective. According to Report of the National Marine Fisheries Service Gray Whale Stock Identification Workshop (Ex. M0473 (Weller et al. 2013, P. 19)), "The TF [NOAA Task Force] concurred that on an annual basis, whales observed in the area used by the PCFG could be characterized as a collection of individuals whose residence patterns vary along a continuum such that some whales use the area for a single year (e.g., transients), some for a few years, and others on a consistent long-term basis." Weller et al. (2013) go on to say (P. 19) "Laake characterized the PCFG as a "leaky bucket", in that some whales are immigrating in while others are emigrating out." Nonetheless, despite the leaky bucket analogy and the IWC definition of the PCFG, there appears to be a group of whales that uses the PCFG area to a greater degree than others, and it is this group that appears to be captured mainly by the photographic and biopsy programs. These individuals are likely driving the difference observed in mtDNA haplotype frequencies.

PCFG whales associate with one another, or are in proximity, during the summer months but the available evidence demonstrates they do not necessarily mate with other PCFG whales. In gray whales, mating is thought to occur primarily during migration, and PCFG and NFG whales are known to associate then (see discussion below). Mating between PCFG and NFG whales would explain the absence of divergence of the PCFG from the NFG at the nuclear DNA loci. The difference in mtDNA is likely maintained by having sufficient recruitment into the PCFG of calves born to PCFG mothers to maintain the distinct haplotpe frequency. The mtDNA of the "foreign" males mating with PCFG females is not incorporated into the PCFG because of strict maternal inheritance of mtDNA. And external recruitment of females must be small enough to not homogenize the mtDNA frequencies with the NFG whales. If this conventional wisdom is true and considering the available information, the PCFG is not a population or a stock in the usual meaning of these terms as a breeding population. Rather, it is an aggregation of whales that are associated by a shared learned behavior (feeding off the Pacific Northwest during the summer and fall) and, for at least some members of the aggregation, is descended from a small number of founding females.

There is also evidence through photographic idenification studies of external recruitment into the PCFG. Immigrants into the PCFG likely would have the effect of reducing the level of mtDNA differentiation between the PCFG and the NFG. It would not affect the nuclear loci because those do not differ between the the PCFG and the NFG. Modeling by Lang and Martien (2012) (Ex. M-0442) found the immigration of 1 to 8 whales a year into the PCFG is consistent with genetic differentation observed in mtDNA with a most plausible estimate of 4 whales per year. In addition to a small number of annual immigrants, a "pulse" of whales was recruited into the PCFG following the 1999-2000 gray whale Unusual Mortality Event (UME) (Ex. M-0415 (Calambokidis *et al.* 2012)). In the Rangewide Review, annual immigration levels of 0, 2, 4, and 8 whales were being modelled, as was a one-time pulse of immigrants of 10, 20 and 30 whales (Ex. M-0436 (IWC, 2017, Table 7, P. 654)). Thus, the Rangewide Review considered annual immigration as well as pulse immigration into the PCFG as being plausible. However, recruitment of new

whales into the PCFG that were born to PCFG mothers must also be occurring at a sufficient rate to maintain observed differences in mtDNA haplotype frequencies.

A recent study by Calambokidis et al. (2017) (Ex. M-0416) investigated the composition of migratory gray whale groups to determine if PCFG whales migrate together. They found through photo identifications in Southern California that PCFG whales have been observed to migrate in groups that include other PCFG whales, and thus have an opportunity to breed with other members of the PCFG. They also found that migrating groups of whales that included multiple PCFG whales occurred in both southbound and northbound migrations. Moreover, groups with multiple PCFG whales were more frequently observed in the southbound migration when mating is thought primarily to occur. In the second paragraph of the Discussion (the manuscript is unpaginated) the authors state: "An important implication of this work is that it extends the time PCFG whales would be associated through the year and would increase the potential for breeding with other whales from the same feeding group." While this is true for at least some PCFG whales, it does not come close to providing convincing evidence that the PCFG is a breeding population. To the contrary, this paper provides evidence that is consistent with the PCFG being a feeding group because, while it does show that PCFG whales migrate together with some frequency, it also shows that they frequently migrate with ostensible NFG whales and thus there is adequate opportunity for outbreeding. Four of the seven groups observed on the southbound migration (when mating could occur) containing at least one PCFG whale (calculated from Table 1 in Calambokidis et al., 2017) included one or more individuals not identified as PCFG whales. We can assume that these are likely NFG whales given the location and that NFG comprise more than 95 percent of non-PCFG gray whales. Thus, about half the time there could be non-PCFG whales available for breeding. This does not speak to issues of mating preference, which could be in either direction, or not present at all. In light of the facts that Lang et al. (2014) (Ex. M-0446) found no evidence for nuclear gene differentiation of the PCFG and the NFG, and Calambokidis et al. (2017), based on a limited sample size, show frequent opportunity for the two feeding groups to interbreed on the southbound migratory route, the status of the PCFG as a feeding group, rather than a breeding population, seems well supported.

One could also argue this from a theoretical perspective. Typically, populations diverge as a result of geographic isolation. Clearly the PCFG and the NFG are not geographically isolated. That means that genetic differentiation of the PCFG would have to be the result of strong pre-mating isolating mechanisms; primarily this would be due to PCFG females preferrentialy mating with PCFG males. This is unlikely to be the case because it violates basic principles of evolutionary biology. Specifically, reproductive strategies evolve to maximize the fitness of one's offspring, which includes the avoidance of inbreeding. For any pre- mating reproductive isolating mechanism (i.e., female mate preference with other PCFG whales) strong enough to reduce gene flow to such a low level as to allow for genetic divergence of the two feeding groups, there would have to be a very high selective advantage to breeding within the group. It is hard to imagine what that would be. The other side of the coin here is, why would a female PCFG whale restrict herself to mating with a small number of PCFG males when there are literally thousands of NFG whales swimming by? In my opinion, in the absence of any genetics data to the contrary, it is implausible to consider the PCFG as a breeding population.

IWC's Rangewide Review of North Pacific gray whales: In response to the new information described above about the movements of WGWs, in 2014 (8-11 April 2014) the IWC convened the first *Workshop*

on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales in La Jolla, California (hereafter these workshops collectively will be referred to as the Rangewide Review). Rangewide Review workshops were held annually thereafter in 2015, 2016, 2017 and 2018 and included international experts in gray whale biology and population dynamics. Among the objectives of the Rangewide Review was: *(1) review available information (especially new telemetry, genetics and photo-ID data) and reappraise the population structure and movements of North Pacific gray whales with a focus on examining status* (Ex. M-0434 (IWC 2014a. P.21)). Understanding stock structure was one of the critical components to allow the completion of the other objectives which included: *(2) develop a modelling framework to better assess the status of gray whales and the potential impact of human activities and possible changes in regime or climate; and (3) provide information for updating the IUCN/IWC Conservation Management Plan for western gray whales.*

A series of plausible stock structure hypotheses were developed for potential use in the population models, from which three were **initially** selected as being of highest priority. Those hypotheses included 3a, 3e, and 5a; an additional (fourth) hypothesis, 3c, was retained as a sensitivity test in the population models. Additional stock structure hypotheses were added to this list in subsequent meetings including hypothesis 6b in 2016 and 3b in 2017. Ultimately, in 2018, the Rangewide Review (IWC, 2018b; SC/67B/REP07) (M-0437a) and the IWC SC (Ex. M-0437 (IWC, 2018a.)) decided instead to retain 3b, 6b and 3e as sensitivity tests based on information presented in Scordino and Bickham (2018) (Ex. M-0462). So, for the Rangewide Review's final modeling, hypotheses **3a** and **5a were** used as base cases in the population modelling exercises, and the remaining plausible hypotheses were modelled as sensitivity tests, including hypotheses 3b, 3c, 3e and 6b. This is discussed in Section 4.2 of the 2018 Rangewide Review final report (IWC, 2018b; SC/67B/REP07) as follows: "*The Workshop **agreed** that stock hypotheses 3a and 5a would form the references for the analyses as they appear to be most plausible, while trials would also be conducted for stock hypotheses 3b, 3c, 3e and 6b.*"

The full series of stock structure hypotheses developed in the Rangewide Review is provided in Table 1, and the terminology used in the hypotheses is explained in Table 2. Notice that in Table 1 hypothesis 3b is listed as low priority. This is because the report that included this table was produced prior to that hypothesis being reconsidered and raised to high priority (Ex. M-0437 (IWC 2018)). It can be seen by perusing Table 1 that a broad spectrum of scenarios was considered, and only the ones with highest plausibility, i.e. those that are consistent with the current data, were used in the modelling. For purposes of this testimony, it is not necessary to review all of the specifics of the hypotheses being modelled or to debate their relative merits. Instead I will discuss the variable features of the hypotheses modelled in light of their relevance to the issues impinging on the proposed Makah hunt.

The two high-priority hypotheses (**3a and 5a**) considered the PCFG to be a feeding group and part of the Eastern Breeding Stock (i.e., EGWs). Judging from the fact that none of the hypotheses modelled, either as base cases or sensitivity tests, considered the PCFG to be a breeding stock, we can assume that this was thought to be implausible by the Rangewide Review participants. We can conclude from this that the best scientific evidence is that PCFG whales do not breed primarily among themselves, at least not to a sufficient degree that it has resulted in a detectable differentiation of the PCFG from the NFG according to the existing genetics (microsatellite loci) data.

Table 1.—Stock structure hypotheses taken from Table 6, P. 11 in SC/67a/Rep04.

A summary of the stock structure hypotheses initially under consideration (2015, 2016) and their status

Description	Status	Comment
(1) Panmixia with no matrilineal fidelity to feeding grounds - persistent		
A single breeding stock; no matrilineal fidelity to feeding grounds	No	not consistent with available data (IWC 2015)
(2) Panmixia with no matrilineal fidelity to feeding grounds - post-exploitation		
A single breeding stock exists, although multiple stocks may have existed in the past. No matrilineal fidelity to feeding grounds.	No	not consistent with available data (IWC 2015)
(3) Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating		
(a) A single breeding stock (EBS) exists. The EBS includes three feeding groups: NFG, PCFG, WFG. SKNK is used by some whales that belong to the WFG and some whales that belong to the NFG.	*High*	
(b) The EBS is as described in 3a, except that NFG whales do not feed off SKNK. In addition, a WBS exists that overwinters in VSC and feeds in the OS (but not SI) and SKNK. Thus SKNK is used by both the WFG whales and the whales of the WBS.	Low	few or no data to assess plausibility (IWC 2015), but may be reconsidered during SC67a
(c) Same as 3a except that WFG whales migrating from SI to M occasionally travel through BSCS.	Medium	Sensitivity test
(d) Same as 3a except the EBS contains the original three feeding groups and a fourth feeding group that uses SEA.	Low	few or no data to assess plausibility (IWC 2015)
(e) Same as 3a except that a WBS exists that feeds in the OS (but not SI), EJPJ, and KWJ and overwinters in VSC.	*High*	
(4) Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, non-random mating		
(a) Two breeding stocks exist and overwinter in M. One breeding stock includes NFG and PCFG, and the second breeding stock includes WFG whales. Separation between breeding stocks is maintained by WFG whales mating largely with each other while migrating to M.	Low	represented in the same way as other hypotheses in modelling (IWC 2015)
(b) Same as 3b except that a WBS exists and is made up of WFG whales that largely breed with each other while on migration to M.	Low	represented in the same way as other hypotheses in modelling (IWC 2015)
(5) Maternal feeding ground fidelity, two migratory routes/wintering grounds used by Sakhalin whales, random mating.		
(a) Two breeding stocks exist: EBS and WBS. The EBS includes three feeding groups: PCFG, North, and the WFG that feeds off SI. The WBS whales feed in SI, OS, and SKNK and then migrate to VSC to overwinter. SKNK is used by the WFG, the NFG, and the feeding whales that are part of the WBS.	*High*	
(b) Three breeding stocks exist. The EBS is as described in 5a. Two breeding stocks exist in the WNP. Both W breeding stocks feed in SI, OS, and SKNK but whales show fidelity to two different migratory routes (Pacific coast of Japan and eastern Sea of Japan) and use two separate wintering grounds.	Low	few or no data to assess plausibility (IWC 2015)
(6) Maternal feeding ground fidelity, Sakhalin whales use two migratory routes/wintering grounds without fidelity, random mating		
(a) A single breeding stock exists that uses wintering grounds off M as well as of VSC. Whales do not exhibit fidelity to a wintering ground. Three feeding groups exist: WFG, NFG, and PCFG. SKNK is used by both WFG and NFG.	Low	few or no data to assess plausibility (IWC 2015)
(b) Same as 6a, except the WFG whales largely breed with each other during migration, creating a second breeding stock. Whales from both breeding stocks overwinter in M and in VSC, and show no fidelity to a wintering ground.	*High*[1]	
(c) Same as 6a except that females' part of the WFG show fidelity to one of the two wintering areas (M and VSC), while males of the WFG do not show fidelity to a wintering ground.	Low	few or no data to assess plausibility (IWC 2015); modelling framework represented in the same way as other hypotheses (IWC 2015)
(7) Maternal feeding ground fidelity, Sakhalin whales use two migratory routes/wintering grounds with fidelity, non-random mating		
Three breeding stocks exist - a breeding stock comprised of WFG whales that migrate to M, a breeding stock (EBS) comprised of PCFG and NFG whales, and a WBS that includes whales that feed off SI and in the OS.	Low	modelling framework represented in the same way as other hypotheses (IWC 2015)

[1] Initially considered to be of low priority because modelling framework represented in the same way as other hypotheses (IWC 2015); when revisited, the Workshop determined that this hypothesis does differ from 5a, in that: (1) all catches off Japan are assumed to be Western stock animals; and (2) the abundance estimates off Sakhalin are assumed to relate only to the Western stock. Thus the Workshop agreed to change the status of this hypothesis to high priority (IWC 2017).

Table 2.—Terminology for stock structure hypotheses taken from Annex D, P. 19 in SC/67a/Rep04

Terminology used with respect to stock structure hypotheses

Breeding stocks. There are up to two extant breeding stocks: Western (WBS) and Eastern (EBS).

*Feeding groups or aggregations**. There are up to three feeding groups or aggregations. There is dispersal between the PCFG and North Feeding Group (NFG), but the Western Feeding Group (WFG) is demographically independent of the other two feeding groups (i.e. there is no permanent movement of animals from the NFG or PCFG to the WFG).

	Feeding groups or aggregations	Abbreviation	Definition (may vary with hypothesis)
1	Western Feeding Group	WFG	Animals that feed regularly (define?) off Sakhalin Island* according to photo-identification data
2	Pacific Coast Feeding Group	PCFG	Animals that feed regularly (define?) in the PCFG area according to photo-identification data
3	North Feeding Group	NFG	Animals found in other feeding areas (and for which there is relatively little information including photo-ID)

* May need revising with regard to Southern Kamchatka animals given Justin's paper.

Sub-areas. The model includes 11 geographical sub-areas that are used to explain the movements of gray whales (breeding stocks and feeding groups) in the North Pacific and two 'latent sub-areas' used to link model predictions to observed indices of abundance.

	Sub-area	Abbreviation
1	Vietnam-South China Sea	VSC
2	Korea and western side of the Sea of Japan	KWJ
3	Eastern side of the Sea of Japan and the Pacific coast of Japan	EJPJ
4	Northeastern Sakhalin Island	SI
5	Southern Kamchatka and Northern Kuril Islands*	SKNK
6	Areas of the Okhotsk Sea not otherwise specified	OS
7	Northern Bering and Chukchi Sea	BSCS
8	Southeast Alaska	SEA
9	British Columbia to Northern California	BCNC
10	California	CA
11	Mexico	M
12	Latent sub-area	Calif-3
13	Latent sub-area	BC-BCA-3

* New at this workshop – replaces the old East Kamchatka and Kuril Islands to recognise the information from telemetry and photo-ID.

The situation with WGWs is quite different from that of the PCFG; two stock structure hypotheses were being modelled as base cases and are thus considered the most plausible ones by the IWC Scientific Committee. Under **hypothesis 3a**, there is a single breeding stock (Eastern Breeding Stock) that winters in Mexico and all the gray whales found in the Sea of Okhotsk (except for occasional strays) migrate between Mexico and the Sea of Okhotsk. These whales are considered as the WFG and part of the Eastern Breeding Stock. Under this hypothesis the historical WGW population is extinct. **Hypothesis 5a** has both Eastern and Western Breeding Stocks, and the Sakhalin whales include both Eastern Breeding Stock whales migrating to Mexico and Western Breeding Stock whales migrating to the Asian wintering ground.

It is also worth mentioning the hypotheses that were demoted to sensitivity tests. **Hypothesis 3b** is like 3a except that there is both a WFG of the Eastern Breeding Stock that migrates from the Sea of Okhotsk to Mexico, as well as a Western Breeding Stock, *i.e.*, the descendants of the historical WGW population, that migrates between the Sea of Okhotsk and the Vietnam/South China Sea wintering ground. However, the Sakhalin whales are all WFG whales and migrate to Mexico, whereas the Western Breeding Stock whales summer elsewhere in the Sea of Okhotsk. **Hypothesis 3e** differs from 3b only in that the Western Breeding Stock whales feed not only in the Sea of Okhotsk (other than Sakhalin Island),

but also in Korea, the eastern and western sides of the Sea of Japan, and eastern Japan. **Hypothesis 6b** is succinctly described in footnote 4 on page 654 of the Report of the Third Rangewide Review (Ex. M-0436 (IWC, 2017)) as follows: "Two breeding stocks – one includes whales from the PCFG and Northern feeding sub-stocks that migrate to Mexico and largely breed with each other, and the other includes all whales that feed off Sakhalin and breed largely with each other whether on the ENP or WNP migratory routes/wintering grounds." (Note that the term sub-stock is not one officially used by the Rangewide Review, but here the reference is to a feeding group which is one kind of sub-stock). Hypothesis 6b does not resemble the conventional or historical hypothesis of two populations, WGW and EGW, that migrate along opposite coasts of the North Pacific Ocean basin. Rather, under hypothesis 6b the Sakhalin whales represent a stock, which may or may not be the extant Western Breeding Stock, *i.e.*, the historical WGW population, that migrates along both the North American and Asian coasts with breeding occurring within the group during migration.

Notice that under four of these hypotheses (3a, 3b, 3e and 5a), including the two considered most plausible (3a and 5a), the "western gray whales" that might be encountered by Makah hunters would be WFG whales that are part of the Eastern Breeding Stock. It is only under one of these hypotheses (6b) that the "western gray whales" that might be encountered by Makah hunters would be members of a Western Breeding Stock. In my opinion, hypothesis 6b is the least plausible of these hypotheses. This is because, as explained above, hypothesis 6b assumes that the Western Breeding Stock migrates along both the North American and Asian coasts, but commercial whaling along the North American coast, which depleted the EGW, did not seem to impact the historical WGW population (Ex. M-0435 (IWC, 2014b)).

Also, Scordino and Bickham (2018) (Ex. M-0462) presented a paper at the 2018 Rangewide Review that addressed the plausibility of hypothesis 6b. They noted that in part the change to high plausibility in 2016 was due to consideration of a paper about humpback whales, which form large breeding aggregations considered to be modified leks. The paper considered the possibility that humpback whales from a "source" population moved to the breeding ground of a larger "base" population for the purpose of enhancing their breeding possibilities (Ex. M-0417 (Clapham and Zerbini, 2015)). The possibility that gray whales might also have such flexibility in selecting breeding or wintering grounds led the Rangewide Review to elevate hypothesis 6b to high priority. Scordino and Bickham pointed out that this scenario really does not fit with our knowledge of gray whale biology because gray whales do not form large breeding aggregations such as those formed by humpback whales. Nor do gray whales communicate with sound to the extent that humpback whales do, and it is therefore difficult to see how they might be attracted to such breeding aggregations from a long distance, even if such breeding aggregations existed. The Rangewide Review subsequently changed the status of hypothesis 6b to a sensitivity test.

Gray Whale Stock Structure and the Makah Hunt: With regards to the proposed Makah hunt, there are two primary stock structure issues. The first can be condensed to the question "Is the PCFG a stock or a feeding group?" In the absence of any genetics data to support the PCFG as a breeding population, *i.e.*, a stock, I concur with the Rangewide Review and consider it to be a feeding group. The existing microsatellite data are convincing that no significant difference exists between the PCFG and non-PCFG whales of the EGW population such as the NFG. It is possible that future studies with better technology might shed a different light on this, but at present I see no existing data to cause me to doubt this conclusion.

The second issue related to stock structure is "What is the stock status of the whales that summer in the Sea of Okhotsk but migrate to North America?" In part, this stems from the fact that genetic studies have shown this population differs from EGWs in both mtDNA and microsatellites. Any genetically distinct and small population will be given high conservation status by the IWC. Additionally, this group has been considered to be the remnant WGW population, the sole surviving descendants of the historical WGW stock that was hunted mainly in Korean and Japanese waters and declared extinct by the 1960s as explained above. Therefore, the ancestry of this population is a key issue in determining its evolutionary significance. This is because populations isolated by large ocean basins are likely to have had significant time and opportunity to evolve distinct adaptations that are important to conserve. Thus, how distinctive a population is, which stems from its evolutionary history, is an important consideration in conservation biology. The fact that several stock structure hypotheses are considered as plausible by the Rangewide Review points to the fact that the status of the current WGW whales is uncertain.

The identity of current WGWs is relevant to management of the Makah hunt. A key issue that has emerged is the risk to the population of accidentally killing WGWs in the hunt. Depending on the number of whales that were killed, this could be problematic because they might represent a significant proportion of the population. From an evolutionary perspective, removal of WGW whales could mean the loss of genetic diversity that could reduce the fitness of the population. As mentioned at the beginning of my testimony, it is my understanding that NMFS's proposed regulations address this concern by minimizing the likelihood that a Makah hunter will strike a WGW to extremely low levels and by suspending the hunt in the very unlikely event of such a strike.

However, for purposes of my testimony, it is also important to note that continued use of the descriptor "critically endangered western gray whales" is misleading. It means, or at least implies, that these are the last remaining descendants of the population thought to have been made extinct by commercial whaling in Japan and Korea early in the 20th Century. Moreover, because that population was isolated by an ocean basin, it likely was very different from the EGW population genetically. We don't know this for sure because the genetics of the pre-whaling western population has never been studied. But other marine species isolated in this way show deeper levels of genetic divergence than has been observed between the current WGW and EGW populations.

In fact, as I discuss in detail earlier in my testimony, genetics studies of the current WGW population, as described above, shows they are not very different from the EGW population. For mtDNA, there is a statistically significant haplotype frequency difference between them, but the WGW haplotypes are also found in the EGW population and there are no haplotype lineages, or groups of related haplotypes, that are unique to the WGW. For microsatellites, the level of differentiation is also statistically significant, but the magnitude of the difference is not great. And with regards to the comparisons made with genomics, some indicators suggest the WGW to be a distinct population and other analyses do not. The SNP analyses suggest that the Sakhalin population is a mixed-stock aggregation. In my opinion, the existing genetic data point towards the current WGW population as being subtly different from the EGW population, but the historical relationship of that population to those whales hunted off Japan and Korea is uncertain. It is possible that the WGWs that could be exposed to a Makah hunt are in fact part of the EGW population (i.e., the Eastern Breeding Stock); this would be the case under two hypotheses that are presently considered to have the highest plausibility and were being modelled as base cases in the Rangewide Review (3a and 5a). In that event, harm to a WGW whale would not only be unlikely but also would be of low biological concern because there would be limited to no loss of genetic diversity.

Of the other hypotheses that were retained for sensitivity trials, only hypothesis 6b suggests that WGWs that could be exposed to a Makah hunt are part of a distinct western breeding population, and that hypothesis is no longer considered to be highly plausible. Notably, even the WGWs that could be exposed to the Makah hunt under hypothesis 6b do not resemble the conventional or historical hypothesis of a geographically distinct WGW population, since WGWs under this hypothesis migrate to wintering grounds in Mexico (as well as Asia). So, the worst-case scenario, that some survivors of the historic WGW population could be exposed to the Makah hunt (where the likelihood that one might be struck would be extremely small) is only one of a spectrum of possibilities. In my opinion it is more likely that if any whales from the historical WGW population have survived, they are still migrating along the coast of Asia. Recall that Cooke et al. (2017) (Ex. M-0420) considered the Sakhalin and Kamchatka whales that migrated to Mexico as being members of the eastern breeding stock and calculated that there were from 0 to 50 Sakhalin whales that were members of a Western Breeding Stock. The latter group of whales would not migrate to Mexico and would not be susceptible to the Makah hunt. In my opinion, all whales struck during the Makah hunt will most likely be EGWs, because gray whales that migrate through the Makah's hunting area, even those that seasonally feed in the Sea of Okhotsk, are most likely EGWs.

Key Terms and Definitions Pertaining to the Marine Mammal Protection Act (MMPA): In this section, I summarize the terminology used under the MMPA to make it clear how my explanations of population structure of gray whales relate to the terminology and the goals of the MMPA. The reason this is necessary is that the terms used by IWC and the Rangewide Review, which provide the best basis for addressing the stock structure issues related to the proposed Makah hunt, differ from those used by NMFS related to the MMPA.

The MMPA uses the term "population stock" (or just "stock" or "population") to describe the fundamental unit of conservation. A population stock is: "*a group of marine mammals of the same species or smaller taxa in a common spatial arrangement, that interbreed when mature.*" This is given in the MMPA (Sec. 3) and discussed in Weller et al. (2013, P. 3) (Ex. M-0473). The two key elements of this definition are that the animals occur in the same geographic location and interbreed. Thus, members of the same population have the opportunity to and in fact do breed with one another, and not, at least to the same degree, with members of another population even if they are at times found together. The latter may be because they are not found together at the critical time of breeding, or potentially because of mating preference (pre-mating reproductive isolation), but this is not likely if they are members of the same species for reasons discussed earlier in my testimony.

The objectives of the MMPA are given in Sec. 2(2) and Sec. 2(6) and include:

(1)*"[marine mammal] species and population stocks should not be permitted to diminish beyond the point at which they cease to be a significant functioning element in the ecosystem of which they are a part, and, consistent with this major objective, they should not be permitted to diminish below their optimum sustainable population."*

(2)*"… the primary objective of their management should be to maintain the health and stability of the marine ecosystem."*

It can be seen from these two objectives that the MMPA's goal is the conservation of marine mammals for the purpose of ecosystem protection. Populations are to be maintained at levels to ensure their

function in the ecosystem, at a level of optimum sustainability. Note that the goal is not to maintain an optimal level of genetic diversity, biological diversity, or evolutionary potential in the populations. Nor is the goal to recover populations to some historical level of abundance. One can surmise that such goals are consistent with the goals of the MMPA and might be achieved. Nonetheless, because populations are defined based on their reproductive relationships to other populations, genetics can be used as an effective means to test population structure hypotheses. Population genetics methods can be used to identify populations that have diverged sufficiently to have statistically significant differences at markers like mtDNA or nuclear loci, and evolutionary genetics can be used to reveal past historical relationships and features such as historical abundance and migration (gene flow) rates.

In 2016 NMFS published new Guidelines for Assessing Marine Mammal Stocks (GAMMS). This follows from a series of workshops that addressed issues of stock assessment called GAMMS I, GAMMS II and GAMMS III. The 2016 document (NMFS, 2016) (M-0454) (81 Fed. Reg. 10830) presents the findings and conclusions of the GAMMS III workshop. The guidelines recognize feeding aggregations may be comprised of members of one breeding population, or multiple breeding populations. Moreover, they can represent a single demographically-independent unit, or be comprised of a mix of two or more demographically independent units.

NMFS explained how an understanding of stock structure and the relationships of populations or feeding groups impacts conservation as part of the response to comment 13 on P. 10835 as follows:

> The definition of ''population stock'' as ''a group of marine mammals of the same species or smaller taxa in a common spatial arrangement, that interbreed when mature'' is vague from a biological perspective. To some degree, all ''groups'' within a species interbreed when mature or else they would be considered different species according to the biological species concept. Clearly, population stock was intended to mean interbreeding at some greater level but that level is not specified. Interpretation becomes more difficult when considering known cases of migratory species with strong fidelity to both feeding and breeding grounds. Consider, for example, humpback whales that feed in Southeast Alaska and breed in Hawaii. These individuals can interbreed when mature but can (and do) interbreed with individuals that feed in other areas. If a threat occurred within Southeast Alaska that resulted in unsustainable deaths in that area, then if the ''Southeast Alaska whales'' were a stock, that stock's PBR could be used as an indicator that management efforts to mitigate that threat were warranted. In contrast, if ''interbreed when mature'' considered all the whales in Hawaii, then the human-caused mortality in Southeast Alaska may never exceed the PBR based on Hawaii, and eventually the ecosystem in Southeast Alaska would cease to have humpback whales as a functioning part. Such cases result in an apparent conflict between the words ''interbreed when mature'' and the goal to maintain population stocks as functioning elements of their ecosystem. Often, changes to stock delineations in the SARs have relied on interpretation of genetic data. The Pacific SRG asks where one draws the line on what level of genetic exchange suffices to qualify as a stock. Interpretation has been based on the guidelines: ''Demographic independence means that the population dynamics of the affected group is more a consequence of births and deaths within the group (internal dynamics) rather than immigration or emigration (external dynamics). Thus, the exchange of individuals

between population stocks is not great enough to prevent the depletion of one of the populations as a result of increased mortality or lower birth rates.

In my opinion, this quote is a useful description of NMFS's perspective on the difference between a population and a feeding group. Populations are composed of the members of a species that interbreed (when mature). Despite NMFS's statement, there is nothing vague about the definition of population or stock in the MMPA. It is consistent with how geneticists define a population. And yes, there can be low levels of gene flow (interbreeding) among populations. On the other hand, feeding groups are composed of individuals from one or more populations that occur together for the purpose of feeding, not mating. The quoted paragraph illustrates the dilemma of managing a feeding group that is imperiled. If it is considered a population, then based on the calculation of the Potential Biological Removal (PBR) for the group, the usual management efforts under the MMPA would be initiated upon the discovery of mortality caused by humans that exceeds the PBR calculated for the group. But perhaps the comparison of PBR and human-caused mortality would not trigger a management response under the MMPA if the PBR were derived from the true, interbreeding population and not just the smaller feeding group within that population. The dilemma stems from the fact that the MMPA seeks to protect the ecosystem role or function of marine mammals by conserving population stocks, but some population stocks separate into smaller feeding aggregations that play a role in multiple ecosystems. Unfortunately, this has resulted in efforts on behalf of some to redefine what is a population under the MMPA or to shoe-horn a feeding group to fit the population definition, as I will discuss below.

Are the Current WGW and the PCFG Population Stocks Under the MMPA? Because the nomenclature used by the MMPA to define populations differs somewhat from that used by IWC and elsewhere, I will consider whether or not the current WGW and the PCFG should qualify as population stocks under the MMPA.

In my opinion, the current WGW does qualify for status as a population stock under the MMPA because the genetics data currently indicate some degree of genetic differentiation at nuclear microsatellites and SNPs, as well as at mtDNA, from the EGW. Whereas mtDNA differences alone could be explained as this being a feeding group, the nuclear markers are indicative of some degree of reproductive isolation, or of demographic isolation or independence. Or, to say it another way, they "interbreed when mature" to a degree sufficient to be distinct at these loci. My testimony above, however, explains the uncertainty about this conclusion in that the nuclear microsatellite data show a low level of differentiation (F_{st} = 0.01) based on a small number of loci, and the SNP data seem to indicate the presence of two genomes being present at different frequencies at Sakhalin and Mexico. This latter point indicates that the Sakhalin whales represent a mixed-stock assemblage. One might question whether this indicates there is sufficient gene flow and immigration that Sakhalin whales don't currently "interbreed when mature" despite the differentiation of nuclear markers.

Though the existing data indicate differentiation between the current WGW and the EGW, the affinities of the current WGW population are by no means certain. They could be descendants of historical WGWs (western breeding stock) or they could be an isolated population of EGWs (western feeding group). The conservation implications of these two possibilities are quite different in my opinion, although the implementation of conservation measures under both scenarios might be the same. This is because there are only a few things that we can do to protect great whales. These measures include controlling fishing, whaling, shipping and industrial activities. Therefore, an understanding of exactly

what it is that is being protected, part of a large population, a distinct population or stock, a subspecies, etc., is important because it helps managers asses the risk to the species as a whole of the loss of the entity. At the 2018 IWC Scientific Committee meeting, hypotheses 3a and 5a from the Rangewide Review were given priority for modelling because they are considered the most plausible hypotheses. Other hypotheses, including 3b, 3c, 3e, and 6b, were used as sensitivity tests. According to the SC (IWC 2018, p. 39) (Ex. M-0437): "In summary, Hypothesis 3a assumes that whilst two breeding stocks (Western and Eastern) may once have existed, the Western Breeding Stock is extirpated. Whales show matrilineal fidelity to feeding grounds, and the Eastern Breeding Stock includes three feeding aggregations: Pacific Coast Feeding Group (PCFG), Northern Feeding Group (NFG), and the Western Feeding Group (WFG). Hypothesis 5a assumes that both breeding stocks are extant and that the Western Breeding Stock feeds off both coasts of Japan and Korea and in the northern Okhotsk Sea west of the Kamchatka Peninsula. Whales feeding off Sakhalin include both whales that are part of the extant Western Breeding Stock and remain in the western North Pacific year-round, and whales that are part of the Eastern Breeding Stock and migrate between Sakhalin and the eastern North Pacific." The implication of this for the proposed Makah hunt is that under the two hypotheses considered most plausible by IWC, the Western Breeding Stock does not migrate through the area of the Makah hunt. The Western Breeding Stock is either extinct (3a) or stays in the western North Pacific (5a). The whales from Sakhalin that migrate to North America are considered to be WFG whales, and part of the Eastern Breeding Stock.

The PCFG does not qualify as a population stock under the MMPA, in my opinion, no matter how one parses the definition. This is because members of the PCFG do not "interbreed when mature", at least to the degree necessary to allow the population to become differentiated at nuclear loci. Let's imagine a human analogy to the PCFG. There are distinct and small populations of humans, such as the San or bushmen of southern Africa. Such populations are demonstrably genetically distinct and would qualify as populations using the MMPA definition of population stock. But there are other uses of the word population to mean, for example, a group of people with some learned skill. Perhaps the population of people who quilt tend to learn this skill from their mothers and thus are recruited into the quilting population in this way. One can imagine that this small population might be distinct from the overall population in terms of mtDNA haplotype frequencies, that no unique haplotypes exist in this population for obvious reasons, and that nuclear genes do not differentiate this population also for obvious reasons. And notwithstanding the fact that we can refer to such people as a population, it is not a population in the biological sense of the word even though internal recruitment may predominate. So, the quilting population would not qualify as a population under the MMPA because they do not "interbreed when mature." This analogy closely parallels the feeding groups of whales as we understand them. Despite having qualities that we wish to conserve, and even though internal population dynamics may predominate, neither conforms to a population as defined in biology and the MMPA.

Addressing the Concerns of the Animal Welfare Institute

In a letter dated July 31, 2015 and addressed to Steve Stone of NMFS, DJ Schubert of the Animal Welfare Institute outlined concerns with regard to the Makah Tribe's application for a waiver under the MMPA. Of the numerous points made in the 130-page letter, one is particularly germane to my testimony. On page 4 of the letter, Mr. Schubert writes:

"Furthermore, before proceeding with this decision-making process, it is imperative that NMFS render a determination as to whether PCFG whales constitute a population stock under the MMPA."

I agree that the status of the PCFG is an important issue. However, it is important to remember that, as mentioned above, NMFS has proposed regulations to protect the PCFG regardless of its status. Moreover, I disagree with Mr. Schubert on p. 23 where he states:

"The best available scientific information provides ample support for the designation of PCFG whales as a stock."

In fact, as I discuss in detail above, the evidence does not support this. Under the MMPA members of a "population stock" occur together in "a common spatial arrangement" and they "interbreed when mature." Again, the intended definition of a population stock under the MMPA is essentially the same as the typical definition of a biological population in which individuals breed with other members of that population and not, or at least with less frequency, with members of another population. There is no evidence that the PCFG satisfies this definition. Rather the PCFG is a feeding group, which in this case means an aggregation of whales that share a common behavior, feeding in the PCFG area during the summer and fall, but do not predominantly breed among themselves. The significant F_{ST} in mtDNA is the result of the strict maternal inheritance of the molecule, combined with the maternally directed learned feeding behavior.

This is not to say that the PCFG does not deserve to be conserved (and, as noted, NMFS has proposed regulations for that purpose), but it goes to the point that we need to be clear and transparent in our use of scientific terminology. We cannot ascribe a definition to a group that imparts characteristics not possessed by the group. If the MMPA is to be applied to feeding aggregations like the PCFG, then the law should clearly state it. Because it does not do so, I agree with NMFS's position (Ex. M-0473) Weller et al. (2013), (Ex. M-0453) NMFS, 2015)) that the PCFG is not a population stock under the MMPA.

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AFFIDAVIT OF JOHN BICKHAM
EXHIBIT LIST

Exhibit No.	Citation	Document
M-0401	Bickham, John 2019	Curriculum Vitae 2019
M-0402	Alter et al., 2007	Alter S. E., Rynes E. and Palumbi, S.R. 2007. DNA evidence for historic population size and past ecosystem impacts of gray whales. *Proc. Natl. Acad. Sci. USA* 104:15162–15167.
M-0403	Alter et al., 2012	Alter S.E., Newsome S.D. and Palumbi, S.R. 2012. Pre-Whaling Genetic Diversity and Population Ecology in Eastern Pacific Gray Whales: Insights from Ancient DNA and Stable Isotopes. *PLoS ONE* 7(5): e35039. doi:10.1371/journal.pone.0035039.
M-0404	Andrews, 1914	Andrews R.C. 1914. Monograph of the Pacific Cetacea. I. The California gray whale (*Rhachianectectes glaucus* Cope). *Mem. Amer. Mus. Nat. Hist*. 1: 227-287.
M-0405	Arnason et al., 2018	Árnason, Ú., F. Lammers, V. Kumar, M. A. Nilsson, A. Janke. 2018. Whole-genome sequencing of the blue whale and other rorquals finds signatures for introgressive gene flow. Sci. Adv. 4, eaap9873.
M-0406	Berzin and Vladimirov, 1981	Berzin A.A. and Vladimirov V.L. 1981. Changes in the abundance of whalebone whales in the Pacific and the Antarctic since the cessation of their exploitation. *Rep. int. Whal. Commn* 31:495–499.
M-0407	Bowen, 1974	Bowen S.L. 1974. Probable extinction of the Korean stock of the gray whale (*Eschrichtius robustus*). *J. Mammal*. 55:208–209.
M-0408	Bradford, 2003	Bradford, A.L. 2003. Population assessment of western North Pacific gray whales (*Eschrichtius robustus*). M.S. Thesis, Univ. Washington, 115 pp.
M-0409	Brownell and Chun, 1977	Brownell, R.L., Jr. and Chun C.I. 1977. Probable existence of the Korean stock of the gray whale (*Eschrichtius robustus*). *J. Mammal.* 58:237-239.
M-0410	Brownell et al., 2009	Brownell R.L., Jr., Lang A.R., Burdin A.M., Bradford A.B. and Weller D.W. 2009. The western gray whale population is distinct: a response to SC/61/BRG22. Paper SC/61/BRG30 presented to the IWC Scientific Committee (unpublished). 10 pp. [Available at http://www.iwcoffice.org]
M-0411	Brüniche-Olsen et al., 2018a	Brüniche-Olsen, A., J. Urban R., V. V. Vertyankin, C. Godard-Codding, J. W. Bickham, and J. A. DeWoody. 2018a. Genetic data reveal mixed-stock aggregations of gray whales in the North Pacific Ocean. Biology Letters 14: 20180399. http://dx.doi.org/10.1098/rsbl.2018.0399
M-0412	Brüniche-Olsen et al., 2018b	Brüniche-Olsen, A., R. Westerman, Z. Kazmierczyk, V. V. Vertyankin, C. Godard-Codding, J. W. Bickham, and J. A. DeWoody. 2018b. The inference of gray whale (Eschrichtius robustus) historical population attributes from whole-genome sequences. BMC Evolutionary Biology 18:87. https://doi.org/10.1186/s12862-018-1204-3.

M-0413	Brykov et al., 2019	Brykov, V. A., K. V. Efimova, A. Brüniche-Olsen, J. A. DeWoody, and J. W. Bickham. 2019. Population Structure of Sakhalin Gray Whales (*Eschrichtius robustus*) Revealed by DNA Sequences of Four mtDNA Genes. Pp. 227-240 in From field to laboratory: A memorial volume in honor of Robert J. Baker (R. D. Bradley, H. H. Genoways, D. J. Schmidly, and L. C. Bradley, eds.). Number 70, Special Publications, Museum of Texas Tech University, Lubbock. (In Press).
M-0414	Burdin et al., 2012	Burdin A.M., Sychenko O.A. and Sidorenko M.M. 2012. Status of western gray whales off northeastern Sakhalin Island, Russia in 2011. Paper SC/64/BRG5 presented to the IWC Scientific Committee (unpublished). 10 pp. [Available at http://www.iwcoffice.org]
M-0415	Calambokidis et al., 2012	Calambokidis, J., Laake, J.L. and Klimek, A. 2012. Updated analysis of abundance and population structure of seasonal gray whales in the Pacific Northwest, 1998-2010. Paper SC/M12/AWMP2 presented to the Scientific Committee of the International Whaling Commission. [Available at http://www.iwcoffice.org/]
M-0416	Calambokidis et al., 2017	Calambokidis, J., Laake, J. and Pérez, A. 2017. Updated analysis of abundance and population structure of seasonal gray whales in the Pacific Northwest, 1996-2015. Paper SC/A17/GW/05 presented to the IWC Scientific Committee (unpublished). 68 pp. [Available at http://www.iwcoffice.org]
M-0417	Clapham and Zerbini, 2015	Clapham, P.J., Zerbini, A.N., 2015. Are social aggregation and temporary immigration driving high rates of increase in some Southern Hemisphere humpback whale populations? Mar. Biol. 162, 625–634. https://doi.org/10.1007/s00227-015-2610-3
M-0418	Cooke et al., 2018	Cooke, J.G., Taylor, B.L., Reeves, R. & Brownell Jr., R.L. 2018. *Eschrichtius robustus* western subpopulation. [Online]. The IUCN Red List of Threatened Species 2018: e.T8099A50345475. Available: https://www.iucnredlist.org/species/8099/50345475
M-0419	Cooke et al., 2013	Cooke J.G., Weller D.W., Bradford A.L., Sychenko O., Burdin A.M. and Brownell, R.L. Jr. 2013. Population assessment of Sakhalin gray whale aggregation. Paper SC/65a/BRG27 presented to the IWC Scientific Committee (unpublished). 12 pp. [Available at http://www.iwcoffice.org]
M-0420	Cooke et al., 2017	Cooke, J.G., Weller, D.W., Bradford, A.L., Sychenko, O., Burdin, A.M., Lang, A.R., Brownell, J.R., R.L. 2017. Population assessment update for Sakhalin, gray whales. with reference to stock identity. Paper SC/67a/NH11 presented to the IWC Scientific Committee (unpublished). 8 pp. [Available at http://www.iwcoffice.org]
M-0421	Cooke, 2018	Cooke, J.G. 2018. Abundance estimates for western North Pacific gray whales for use with stock structure hypotheses of the Range-wide Review of the Population Structure and Status of North Pacific gray whales. Paper SC/67b/ASI presented to the IWC Scientific Committee (unpublished). 14 pp. [Available at http://www.iwcoffice.org]

M-0422	DeWoody et al., 2016	DeWoody, J. A., N. B. Fernandez, A. Brüniche-Olsen, J. D. Antonides, J. M. Doyle, P. San Miguel, R. Westerman, C. Godard-Codding, and J. W. Bickham. 2016. Novel single nucleotide polymorphisms from functional genes in the gray whale (*Eschrichtius robustus*) genome provide a powerful genotyping platform. Paper SC/66b/DNA04 presented to the International Whaling Commission Scientific Committee. 57 pp. [Available at http://www.iwcoffice.org]
M-0423	DeWoody et al., 2017a	DeWoody, J. A., N. B. Fernandez, A. Brüniche-Olsen, J. D. Antonides, J. M. Doyle, P. San Miguel, R. Westerman, V. V. Vertyankin, C. Godard-Codding, and J. W. Bickham. 2017a. Characterization of the gray whale (*Eschrichtius robustus*) genome and a genotyping array based on single nucleotide polymorphisms in candidate genes. Paper SC/67a/SDDNA02 presented to the IWC Scientific Committee (unpublished). 2 pp. [Available at http://www.iwcoffice.org]
M-0424	DeWoody et al., 2017b	DeWoody, J. A., N. B. Fernandez, A. Brüniche-Olsen, J. D. Antonides, J. M. Doyle, P. San Miguel, R. Westerman, V. V. Vertyankin, C. Godard-Codding, and J. W. Bickham. 2017b. Characterization of the gray whale (*Eschrichtius robustus*) genome and a genotyping array based on single nucleotide polymorphisms in candidate genes. Biological Bulletin 232: 186–197.
M-0425	D'Intino et al., 2013	D'Intino, A.M., Darling, J.D., Urbán R, J., Frasier, T.R., 2013. Lack of nuclear differentiation suggests reproductive connectivity between the "southern feeding group" and the larger population of eastern North Pacific gray whales, despite previous detection of mitochondrial differences. J. Cetacean Restor. Manag. 13, 97–104.
M-0426	Durban et al., 2017	Durban, J.W., Weller, D.W., and Perryman, W.L. 2017. Gray whale abundance estimates from shore-based counts off California in 2014/2015 and 2015/2016. Paper SC/A17/GW/06 presented to the IWC Scientific Committee (unpublished). 4 pp. [Available at http://www.iwcoffice.org]
M-0427	Frasier et al., 2011	Frasier T.R., Koroscil S.M., White B.N. and Darling J.D. 2011. Assessment of population substructure in relation to summer feeding ground use in the eastern North Pacific gray whale. *Endangered Species Res*. 14:39-48.
M-0427a	Harlin-Cognato et al., 2006	Harlin-Cognato, A., J. W. Bickham, T. R. Loughlin, and R. L. Honeycutt. 2006. Glacial refugia and the phylogeography of Steller's sea lion (*Eumatopias jubatus*) in the North Pacific. Journal of Evolutionary Biology 19:955-969.
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M-0429	Huey, 1928	Huey, L.M. 1928. Notes on the California gray whale. Journal of Mammalogy, 9: 71-75.

M-0430	Ilyashenko, 2011	Ilyashenko V.Yu. 2011. Gray whale re-inhabits former species area. Paper SC/63/BRG24 presented to the IWC Scientific Committee (unpublished). 10 pp. [Available at http://www.iwcoffice.org]
M-0431	IWC, 2006	International Whaling Commission. 2006. Report of the Scientific Committee. Journal of Cetacean Research and Management 8:Supplement 2006.
M-0432	IWC, 2012	International Whaling Commission. 2012. Report of the Scientific Committee. 11-23 June, Panama City, Panama. IWC/64/Rep1. 130 pp. [Available from http://www.iwcoffice.org/]
M-0433		NO EXHIBIT
M-0434	IWC, 2014a	International Whaling Commission. 2014a. Report of the 2014 IWC Scientific Committee. Bled, Slovenia.
M-0435	IWC, 2014b; SC/65b/Rep08	International Whaling Commission. 2014b. Report of the Workshop on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales. Paper SC/65b/Rep08 presented to the IWC Scientific Committee (Unpublished). 49 pp. [Available at http://www.iwcoffice.org/]
M-0436	IWC, 2017	International Whaling Commission. 2017. Report of the Third Workshop on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales, 18-20 April 2016, La Jolla, California, USA. *Journal of Cetacean Research & Management* 18 (Supplement):643-671
M-0437	IWC, 2018a	International Whaling Commission. 2018. Report of the 2018 IWC Scientific Committee. 24 April-6 May 2018, Bled, Slovenia. [Available from http://www.iwcoffice.org/]
M-0437a	IWC, 2018b; SC/67B/REP07	International Whaling Commission. 2018b. Fifth Rangewide workshop on the Status of North Pacific Gray Whales. Paper SC/67B/REP07 presented to the IWC Scientific Committee (Unpublished). [Available at http://www.iwcoffice.org/]
M-0438	Kanda et al., 2010	Kanda N., Goto M., Ilyashenko V.Yu. and Pastene L.A. 2010. Preliminary mtDNA analysis of gray whales from Japan and Russia. Paper SC/62/BRG5 presented to the IWC Scientific Committee (Unpublished). 8 pp. [Available at http://www.iwcoffice.org]
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M-0442	Lang and Martien, 2012	Lang, A.R. and Martien, K.K. 2012. Update on the use of a simulation-based approach to evaluate plausible levels of recruitment into the Pacific Coast Feeding Group of gray whales.

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M-0449	Mead and Mitchell, 1984	Mead J.G. and Mitchell E.D. 1984. Atlantic gray whales. pp. 33–53. *In*: M.L. Jones, S.L. Swartz, and S. Leatherwood (eds.), *The Gray Whale* Eschrichtius robustus. Academic Press, Orlando, Florida.
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M-0451	Meschersky et al., 2015	Meschersky I.G., Kuleshova M.A., Litovka D.I., Burkanov V.N., Andrews R.D., Tsidulko G.A., Rozhnov V.V., Ilyashenko V.Yu. 2015. Occurrence and distribution of mitochondrial lineages of gray whales (*Eschrichtius robustus*) in Russian Far Eastern Seas. *Biology Bulletin 42: 34–42.*
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M-0455	Omura, 1974	Omura, *H.* 1974. Possible migration route of the gray whale on the coast of Japan. *Sci. Rep. Whales Res. Inst., Tokyo* 26: l-14.
M-0456	Omura, 1984	Omura, H. 1984. History of gray whales in Japan. pp. 57-77. *In:* M.L. Jones, S.L. Swartz and S. Leatherwood (eds.) *The Gray Whale,* Eschrichtius robustus. Academic Press Inc., Orlando Florida. xxiv+600pp.
M-0457	Perrin et al., 1994	Perrin, W.F., G.P. Donovan, and J. Barlow (eds.). 1994. Gillnets and cetaceans. Report of the International Whaling Commission, Special Issue 15, 629 pp.
M-0458	Phillips et al., (2011)	Phillips, C. D., T. S. Gelatt, J. C. Patton, and J. W. Bickham. 2011. Phylogeography of Steller sea lions: relationships among climate change, effective population size, and genetic diversity. Journal of Mammalogy 92:1091-1104.
M-0459	Reeves et al., 2008	Reeves R.R., Smith T.D. and Josephson E.A. 2008. Observations of western gray whales by ship-based whalers in the 19th century. *J. Cetacean Res. Manage.*10:247-256.
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M-0461	Scheinin et al., 2011	Scheinin, A.P., Kerem, D., Macleod, C.D., Gazo, M., Chicote, C.A., Castellote, M., 2011. Gray whale (Eschrichtius robustus) in the Mediterranean Sea: anomalous event or early sign of climate-driven distribution change? Mar. Biodivers. Rec. 4, 1–5. http://dx.doi.org/10.1017/S1755267211000042.
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M-0463	Shpak et al., 2013	Shpak, O.V., D. M. Kuznetsova, and V. V. Rozhnov. 2013. Observation of the Gray Whale (*Eschrichtius robustus*) in the Laptev Sea. *Biology Bulletin*, 40: 797–800.
M-0464	Tyurneva et al., 2012	Tyurneva O.Yu, Yakovlev Yu.M. and Vertyankin V.V. 2012. Photographic identification study of gray whales (*Eschrichtius robustus*) offshore northeast Sakhalin Island and southeast Kamchatka Peninsula, Russia: 2002-2011. Paper SC/64/BRG22 presented to the IWC Scientific Committee (unpublished). 13 pp. [Available at http://www.iwcoffice.org]

M-0465	Urban et al., 2012	Urbán R.J., Weller D., Tyurneva O., Swartz S., Bradford A., Yakovlev Y., Sychenko O., Rosales N. H., Martínez A. S., Burdin A. and Gómez-Gallardo U.A. 2012. Report on the photographic comparison of the western and Mexican gray whale catalogues. Paper SC/64/BRG13 presented to the IWC Scientific Committee (unpublished). 6 pp. [Available at http://www.iwcoffice.org]
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M-0467	Weller et al., 1999	Weller D.W., Wursig B., Bradford A.L., Burdin A.M., Blokhin S.A., Minakuchi H. and Brownell R.L., Jr. 1999. Gray whales (*Eschrichtius robustus*) off Sakhalin Island, Russia: Seasonal and annual patterns of occurrence. Marine Mammal Science 15:1208-1227.
M-0468	Weller et al., 2002	Weller, D.W., Burdin A.M., Wursig B., Taylor B.L. and Brownell R.L., Jr. 2002. The western gray whale: A review of past exploitation, current status and potential threats. *J. Cetacean Res. Manage.* 4:7-12.
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M-0470	Weller et al., 2011	Weller D.W., Klimek A., Bradford A.L., Calambokidis J, Lang A.R., Gisborne B., Burdin A.M., Szaniszlo W. and Brownell R.L., Jr. 2011. Movements of western gray whales from the Okhotsk Sea to the eastern North Pacific. Paper SC/63/BRG6 presented to the IWC Scientific Committee (unpublished). 5 pp. [Available at http://www.iwcoffice.org]
M-0471	Weller et al., 2012	Weller, D.W., Klimek A., Bradford A.L., Calambokidis J., Lang A.R., Gisborne B., Burdin A.M., Szaniszlo W., Urbán J., Gómez-Gallardo Unzueta A., Swartz S., Brownell R.L., Jr. 2012. Movements of gray whales between the western and eastern North Pacific. Endang. Species Res. 18:193–199.
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M-0473	Weller et al., 2013	Weller D.W., Bettridge S., Brownell R.L., Jr., Laake J.L., Moore J.E., Rosel P.E., Taylor B.L. and Wade P.R. 2013. Report of the National Marine Fisheries Service gray whale stock identification workshop. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFSC-507

JOHN W. BICKHAM

CURRICULUM VITAE

Address: John W. Bickham
Professor Emeritus
Department of Wildlife & Fisheries Sciences
Texas A&M University
College Station, TX 77843
Mobile: 1-979-777-2873
email: Bickham@tamu.edu

Mailing Address:
31526 Lower Oxbow Trace
Fulshear, TX 77441

Degrees: University of Dayton, Dayton, Ohio, B.S. 1971
University of Dayton, Dayton, Ohio, M.S. 1973
Texas Tech University, Lubbock, Texas, Ph.D. 1976

Thesis and Dissertation:
M.S. Thesis: A cytosystematic study of the Clemmys complex.
Ph.D. Dissertation: Chromosomal banding and phylogenetic relationships of vespertilionid bats.

Major Interest:
Molecular Genetics, Genomics, Cytogenetics, Marine Mammals, Molecular Systematics, Evolutionary Toxicology, Ecotoxicology

Professional Positions:

2013-present	Professor Emeritus, Department of Wildlife and Fisheries Sciences, Texas A&M University
2012-2016	Principal Scientist, Battelle Memorial Institute
2006 - 2012	Professor, Department of Forestry and Natural Resources, Purdue University
2006 - 2011	Director, Center for the Environment, Purdue University
1986 - 2006	Professor of Wildlife and Fisheries Sciences, Texas A&M University
1983 - 1986	Associate Professor of Wildlife and Fisheries Sciences, Texas A&M University
1976 - 1983	Assistant Professor of Wildlife and Fisheries Sciences, Texas A&M University

Society Affiliations:
American Society of Mammalogists
Southwestern Association of Naturalists
Texas Society of Mammalogists

Honors: President, Southwestern Association of Naturalists 1985-1987.

Distinguished Performance Award - Graduate Teaching, Texas A&M University System 1985.
Distinguished Professor Award, Association of Graduate Wildlife and Fisheries Scientists, Texas A&M University 1986.
Southwestern Association of Naturalists, Donald W. Tinkle Research Excellence Award, 1990.
Member of the Board of Governors, Southwestern Association of Naturalists, 1977-present.
Best Paper Award, Texas Chapter of the Wildlife Society, for a paper in J. Wildl. Manage. (1994) with D. L. Ellsworth, et al.
Distinguished Performance Award – Research, Texas Agricultural Experiment Station 2005
President, Texas Society of Mammalogists, 2006 (president-elect) – 2007
Award of Appreciation received from the Alaska Eskimo Whaling Commission at the annual meeting in Barrow, Alaska February 2008 for my participation in the Scientific Committee of the International Whaling Commission and my efforts in helping to obtain a 5-year quota for the harvest of bowhead whales (8-ft plate of baleen with scrimshaw).
Honorary member, Texas Society of Mammalogists, bestowed February 2009

Editorial Experience:

Managing editor of the Southwestern Naturalist 1982- 1984.
Associate Editor of the Journal of Mammalogy 1989-1992.
Presently a member of the review board for *Ecotoxicology*.

University Administrative Experience:

Purdue

Director the Center for the Environment 2006-2011.

Texas A&M

Member of the Executive Committee of the Faculty of Genetics, 1980-82, 1984-86. Vice-chairman of the Faculty of Genetics 1985. Graduate Advisor and Chairman of the Graduate Affairs Committee, Department of Wildlife and Fisheries Sciences, 1988-1989. Chairman of the departmental Tenure and Promotion Committee, 1993-1995. Member of Texas A&M University Laboratory Animal Care Committee 2002-2005.

International Administrative Experience:

Member of the US delegation to the Scientific Committee of the International Whaling Commission, 2003 to present.
US team leader for the US Department of State "US-China EcoPartnership" 2011-2012.
Independent International Consultant to BP in Azerbaijan. I advised BP's environmental program regarding their offshore environmental monitoring program in the Caspian Sea. 2007 to 2009.

Administrative Workshops

Engagement Academy for University Leaders, Virginia Tech University, June 22-26, 2009, Roanoke, VA.

Private Sector Administrative Experience:

Principal Scientist, Battelle Memorial Institute, Houston Texas, 2012 to 2016.
Vice President for Research (and co-founder), LGL Ecological Genetics, Inc., Bryan, Texas 1990-1995.

Courses Taught:

Texas A&M University:
WFS 302, Natural History of the Vertebrates. A 3-credit undergraduate course designed as an introductory vertebrate zoology course for both science and non-science majors.
WFS 401, General Mammalogy. A 3-credit undergraduate course designed to be an important foundation course in wildlife science. The study of structure, function, phylogeny, classification, biology, and economic relationships of mammals.
WFS 601, Vertebrate Systematics. A 3-credit graduate course designed to be an introduction to systematic theory, practice, and methodology.
WFS 602, Vertebrate Cytosystematics. A 3-credit graduate course that covers applications of cytogenetic techniques to evolutionary studies of vertebrates.

Purdue University
FNR 396B Ecological Genetics of our Natural Resources. A 1-credit graduate seminar on natural resource genetics.

Graduate Students Completed (Texas A&M):

Mike W. Haiduk, M.S., 1979.
Thesis: A Comparative analysis of karyology and hyoid morphology of the Chelydridae (Reptilia: Testudines).
Presently Associate Professor, Lamar University.

Jack W. Sites, Jr., Ph.D. (Co-chair with J. R. Dixon), 1980.
Dissertation: Chromosome, allozyme, and morphometric variation in three cytotypes of the *Sceloporus grammicus* complex. Presently Professor, Brigham Young University.

Robert H. Dean, M.S, 1980.
Thesis: Selected aspects of the ecology of the Central American mud turtle, *Staurotypus salvinii.*

Timothy W. Houseal, Master of Science, 1980.
Thesis: Geographic variation in the yellow mud turtle, *Kinosternon flavescens* from the central and southwestern United States, and northern Mexico.

John L. Carr, M.S., 1981.
Thesis: Phylogenetic implications of chromosomal variation in the Batagurinae (Testudines: Emydidae). Presently Professor, Department of Biology, and Associate Curator, Museum of Natural History, The University of Louisiana at Monroe.
Presently Assistant Profess, NE Louisiana St. Univ.

Robert C. Dowler, Ph.D., (Co-chair with D. J. Schmidly)1982.
Dissertation: Genetic interactions among three chromosomal races of the *Geomys bursarius* complex (Rodentia: Geomyidae). Presently Professor, Angelo State University.

Mark D. Engstrom, Ph.D. (Co-chair with D. J. Schmidly), 1984.
Dissertation: Chromosomal, morphological, and allozymic variation in the *Oryzomys melanotis* species complex.
Presently Vice President for Research, Royal Ontario Museum, and Professor, University of Toronto.

Priscilla K. Tucker, Ph.D. 1984.
Dissertation: Sex chromosome-autosome translocations in the leaf-nosed bats, family Phyllostomidae.

Presently Professor, University of Michigan.

Karen McBee, Ph.D. 1985.
Dissertation: Chromosomal aberrations in resident small mammals at a petrochemical waste dump site: A natural model for analysis of environmental mutagenesis.
Presently Professor, Oklahoma State University.

David W. Burton, M.S. 1986.
Thesis: Heterochromatin and DNA content in *Geomys attwateri* and *G. breviceps* (Rodentia: Geomyidae).

Scott W. Ballinger, M.S. 1987.
Thesis: Allozymic and mitochondrial DNA analysis of sympatric white-tailed and mule deer in West Texas.
Presently Associate Professor of Pathology, University of Alabama, Birmingham.

Samuel F. Lockwood, M.S. 1989.
Thesis: Flow cytometric analysis of DNA content in spawning and coastal samples of Arctic cisco (*Coregonus autumnalis*).

James N. Derr, Ph.D. (Co-chairman with D. J. Schmidly) 1990.
Dissertation: Genetic interactions between two species of North American deer, *Odocoileus virginianus* and *Odocoileus hemionus*. Presently Professor, Texas A&M University.

Thomas E. Lee, Jr., Ph.D. 1992.
Dissertation: Mitochondrial DNA and allozyme analysis of pronghorn populations in North America.
Presently Associate Professor, Abilene Christian University.

Juan Carlos Morales-Muciño, Ph.D. 1992.
Dissertation: Molecular systematics of the tree bats, genus *Lasiurus*.
Presently Program Officer, Systematic Biology, National Science Foundation.

Luis A. Ruedas, Ph.D. 1992.
Dissertation: Genome size evolution in the Class Mammalia. Presently Associate Professor at Portland State University.

Michael J. Smolen, Ph.D. 1992.
Dissertation: Variation in the chromosomes of five species of pocket gophers in the genus *Geomys* as detected by differential staining, and the phylogenetic implications.

James C. Cathey, M.S. 1993.
Thesis: Sequence analysis of a zinc-finger gene for the examination of paternal lineages and introgressive hybridization in North American deer.
Presently Assistant Professor and Extension Wildlife Specialist, Texas A&M University.

Thomas Barret Lyne, Ph.D. (Co-chair with K. W. Brown) 1995.
Dissertation: The impact of environmental pollution on the genetic integrity of indigenous species and the application of biosassays in risk assessment. Presently working in the private sector.

Stirling J. Robertson, M.S. 1996
Thesis: A phylogenetic study of *Lasiurus* (Chiroptera: Vespertilionidae) using the Zfx/Zfy loci. Presently Ph.D. student, Florida Institute of Technology.

Jeffrey K. Wickliffe, M.S. 1997
Thesis: Cell cycle perturbations in *Peromyscus* and *Microtus* inhabiting sites contaminates with radioactive and nitroaromatic waste. Presently

Assistant Professor, Tulane University.

Yigong Lou, Ph.D. 1998

Dissertation: Genetic variation of pronghorn (*Antilocapra americana*) populations in North America. Presently Postdoctoral Researcher, Stanford University.

Donnell S. Frank, M.S. (Co-chair with M. Mora) 1999

Thesis: Chlorinated pesticides, polychlorinated biphenyls, and dioxins in colonial nesting waterbirds of Galveston Bay, Texas.

William James Rogers, Ph.D. 1999

Dissertation: Development and application of an integrated model for ecological risk assessment employing the spatial habitat equivalency method. Presently Professor and Associate Dean of Academic Environmental Health and Safety, West Texas A&M University.

Robert G. Trujillo, MS 2001

Thesis: Macrogeographic variation of nuclear Microsatellite loci in an endangered species, *Eumetopias jubatus*. (See below).

Daniel Musquiz, MS (Co-chair with M. Mora) 2003

Thesis: Cave and Cliff Swallows as indicators of exposure and effects of environmental contaminants on birds from the Rio Grande, Texas.

Alyson Baker, MS 2003

Thesis: Variation of Mitochondrial Control Region Sequences of Steller Sea Lions, Eumetopias jubatus: The Three-Stock Hypothesis.

Carol D. Swartz, Ph.D. (Co-chair with K. C. Donnelly) 2004

Dissertation: Integrating environmental sampling and wildlife biomonitoring in exposure and effects assessment: genotoxins at multiple levels of biological organization. Presently works for Integrated Laboratory Systems, Incorporated.

Cole W. Matson, Ph.D. 2004

Dissertation: Integrating environmental sampling and wildlife biomonitoring in exposure and effects assessment: genotoxins at multiple levels of biological organization. Presently Executive Director, Center for the Environmental Implications of NanoTechnology, Duke University.

Robert G. Trujillo, Ph.D. 2005

Phylogenetics of the genus Scotophilus (Chiroptera:Vespertilionidae): perspectives from the nuclear and mitochondrial genomes. Presently Deputy Director – Ecosystem Analysis, Planning, Watershed, & Air Southwestern Region, US Forest Service.

Devra D. Hunter, M.S. 2005

Did bowhead whales (*Balaena mysticetus*) from the Bering-Chukchi-Beaufort Seas undergo a genetic bottleneck? A Test Using Nuclear Microsatellite Loci.

Jason M. Sweny, M.S. 2005

A comparison of diversity in the ZFY gene in two species of pinnipeds with different breeding strategies.

Megan A. Sitzlar, M.S. (Co-chair with M. Mora) 2005
P450 aromatase alterations and DNA damage as avian pollution biomarkers in Cliff and Cave Swallows breeding near the Rio Grande region, Texas.

Ryan M. Huebinger, Ph.D. 2007
Genetic Relationships and Evolutionary History of Extant Bowhead Whale Populations, *Balaena mysticetus.* Presently Postdoctoral Instructor, University of Texas Southwestern Medical Center.

Graduate Students Completed (Purdue):

Caleb D. Phillips, Ph.D. 2008
Systematics, molecular evolution, and phylogeography of Steller sea lions, *Eumetopias jubatus*. Presently Assistant Professor, Texas Tech University.

Brian Rinner, MS, 2009
Evolutionary Toxicology of the Invasive Eastern Mosquitofish (*Gambusia holbrooki*) in Azerbaijan.

Geoff Laban, PhD. 2011
The effects of silver nanoparticles on fathead minnow (*Pimephales promelas*) embryos.

Former Postdoctoral Research Associates

Dr. Steven M. Carr. Presently Professor, Memorial University, St. John's, Newfoundland, Canada.

Dr. Christopher W. Theodorakis. Presently Associate Professor, Southern Illinois University Edwardsville

Dr. Dmitri V. Politov. Presently at Vavilov Institute of General Genetics, 3 Gubkin St., GSP-1, Moscow 119991, Russia

Dr. Cole W. Matson. Presently Associate Professor, Baylor University, Waco Texas.

Dr. Ryan Huebinger. Presently Instructor, University of Texas Southwestern Medical Center.

International Agreements

Purdue University and the Chinese Academy of Sciences. September 10, 2010 to September 9, 2015, LOA between Purdue University, Discovery Park, Center for the Environment and the Chinese Academy of Sciences, Institute of Applied Ecology establishes a "China-US Joint Research Lab on Sustainable Ecosystem."

Purdue University and the Azerbaijan National Science Foundation. April 2, 2011 to April 1, 2016, LOA between Purdue University, Discovery Park, Center for the Environment and the National Science Foundation of Azerbaijan to promote collaborative research projects, seminars, and training courses.

Purdue University and Zhejiang University. July 20, 2011 to July 19, 2016, LOA,

Purdue University, Discovery Park, Energy Center and the Center for the Environment and the State Key Laboratory of Clean Energy Utilization to establish the creation of the Clean Energy Research Initiative.

Publications (Nos. 167 and 211 are books)
Google Scholar Citations 9,838; h-index 57, i10-index 173

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1. Bickham, J.W. and J. A. MacMahon. 1971. Feeding habits of the western whiptail *Cnemidophorus tigris*. Southwestern Nat., 17:207-208.

1975

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1976

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DNA evidence for historic population size and past ecosystem impacts of gray whales

S. Elizabeth Alter[†‡], Eric Rynes[§], and Stephen R. Palumbi[†]

[†]Department of Biological Sciences, Hopkins Marine Station, Stanford University, 120 Oceanview Boulevard, Pacific Grove, CA 93950; and [§]Department of Genome Sciences, University of Washington, Seattle, WA 98195

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Ecosystem restoration may require returning threatened populations of ecologically pivotal species to near their former abundances, but it is often difficult to estimate historic population size of species that have been heavily exploited. Eastern Pacific gray whales play a key ecological role in their Arctic feeding grounds and are widely thought to have returned to their prewhaling abundance. Recent mortality spikes might signal that the population has reached long-term carrying capacity, but an alternative is that this decline was due to shifting climatic conditions on Arctic feeding grounds. We used a genetic approach to estimate prewhaling abundance of gray whales and report DNA variability at 10 loci that is typical of a population of ≈76,000–118,000 individuals, approximately three to five times more numerous than today's average census size of 22,000. Coalescent simulations indicate these estimates may include the entire Pacific metapopulation, suggesting that our average measurement of ≈96,000 individuals was probably distributed between the eastern and currently endangered western Pacific populations. These levels of genetic variation suggest the eastern population is at most at 28–56% of its historical abundance and should be considered depleted. If used to inform management, this would halve acceptable human-caused mortality for this population from 417 to 208 per year. Potentially profound ecosystem impacts may have resulted from a decline from 96,000 gray whales to the current population. At previous levels, gray whales may have seasonally resuspended 700 million cubic meters of sediment, as much as 12 Yukon Rivers, and provided food to a million sea birds.

cetacean | coalescence | effective population size | genetic diversity | historic abundance

Studies of ecologically important marine populations from corals (1) to pelagic predators (2) suggest that many current marine ecosystems are far from their natural states because of anthropogenic disruption. Detecting and measuring the impacts of such changes is complicated because information about past marine population abundance is generally difficult to obtain (3). However, knowledge of past abundances can be important for managing and restoring ecologically important populations recovering from overexploitation, such as those of many baleen whale species. Information about past population sizes of baleen whales can be derived from the level of genetic variation in current populations, because genetic diversity increases with long-term effective population size and can be relatively unaffected by moderate short-term changes in census size. Genetically determined past population sizes for Atlantic humpback, minke, and fin whales are surprisingly high (4), prompting the need for further exploration of results from other species and expanded genetic data sets.

Using genetic data to assay past populations depends on the balance between genetic drift reducing variation at individual loci and mutation increasing it. The relationship between genetic diversity and population size also varies with population subdivision, natural selection, changes in population size over time, and departures from perfectly random mating. Because the impacts of these factors generally vary across the genome, measuring patterns of genetic variation among multiple loci allows more accurate inference of past population sizes than is possible with a single locus. The International Whaling Commission suggested five areas for expanding and improving genetic approaches to inferring past population sizes of whales (5): (*i*) using multiple unlinked nuclear loci, (*ii*) confirming locus-specific substitution rates, (*iii*) estimating overall variance in abundance estimates, (*iv*) considering the long-term nature of population estimates, and (*v*) analyzing the effect of unsampled, "ghost" populations. Here, we concentrate on a single species, the gray whale (*Eschrichtius robustus*), and expand previous analyses to include measurements of diversity and mutation rate at many loci. In addition to using multiple loci, we consider the long-term nature of population estimates and analyze the effect of unsampled, ghost populations.

Gray whales were extensively hunted in the 19th century and currently persist as an eastern Pacific population assumed to have fully recovered from whaling, and a western Pacific population that remains critically endangered. For eastern gray whales, the presumption of full recovery is based on recent census counts of between 18,000 and 29,000 (6), including particularly low population estimates in 1999–2001 that roughly match model-based, prewhaling estimates of 19,480–35,430.[¶] This presumed recovery has resulted in diminished management concern for eastern gray whales. For example, the recovery factor, a parameter used in marine mammal management to calculate acceptable human-induced mortality (7), has been increased for eastern gray whales compared with all other baleen whales by a factor of 10 (8), a change that will effectively slow, but not prevent, full recovery.

However, other interpretations of gray whale population dynamics suggest there has been no demographic plateau. Instead, the low population estimates in 1999–2001 may have resulted from recent climate change in the Bering Sea (9). Although population models that incorporate the 1999–2001 decline support the idea that this population has reached its carrying capacity,[¶] models that do not include data from these years find some support for an equilibrium population size (N_{eq}) of up to 70,000 (10). Recent resurgence of calving rates to pre-1999 levels[‖] and new calving locations (11) also suggest this population has not yet reached its typical long-term abundance but can continue to grow if current ocean conditions permit.

Author contributions: S.E.A. and S.R.P. designed research; S.E.A. performed research; S.E.A., E.R., and S.R.P. analyzed data; and S.E.A., E.R., and S.R.P. wrote the paper.

The authors declare no conflict of interest.

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Data deposition: The sequences reported in this paper have been deposited in the GenBank database (accession nos. EF043286–EF043340).

[‡]To whom correspondence should be addressed. E-mail: sealter@stanford.edu.

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Table 1. Number of haplotype samples (n), substitution rates, SE of substitution rates, Θ per generation, effective population size (N_e), and census size (N) for each marker

Marker	n	Substitution rate, bp^{-1}·year^{-1}	SE of substitution rate	Θ gen^{-1}	N_e	N
ACTA	72	5.00×10^{-10}	2.47×10^{-11}	0.001527	51,464	162,625
BTN	72	4.50×10^{-10}	3.07×10^{-11}	0.000717	24,165	76,360
CP	76	5.00×10^{-10}	2.78×10^{-11}	0.000726	24,468	77,319
ESD	72	3.50×10^{-10}	2.63×10^{-11}	0.002557	86,177	272,320
FGG	72	1.50×10^{-10}	1.05×10^{-11}	0.001697	57,193	180,730
G6PD*	30	3.50×10^{-10}	2.54×10^{-11}	0.000026	876	2,769
PLP*	52	4.00×10^{-10}	1.61×10^{-11}	0.000870	29,321	92,655
LACTAL	72	1.00×10^{-9}	8.75×10^{-11}	0.000417	14,054	44,410
WT1	80	4.00×10^{-10}	2.60×10^{-11}	0.000488	16,447	51,972
Cyt b†	42	4.00×10^{-9}	1.34×10^{-10}	0.001012	34,107	107,778

Values of Θ are given by using a scale in which the average substitution rate is 4.79×10^{-10} substitutions bp^{-1}·year^{-1} based on seven autosomal nuclear introns; Θ values reported for X-linked introns and mitochondrial markers have been scaled by additional factors as described in the text. N_e was calculated by using the lower value for generation time, 15.5 years.
*Located on chromosome X.
†Located on the mitochondrion.

To evaluate the hypothesis of demographic recovery and assess historical population size, we measured genetic variation among eastern Pacific gray whales to calculate long-term effective population size and estimate long-term census size. We conclude that the long-term population size of gray whales in the North Pacific was probably 3- to 5-fold larger than it is today but that this estimate likely measures the eastern and western gray whale stocks together. These data imply that the gray whale population could continue to grow, unless anthropogenic changes to ocean ecosystems are severe enough to lower the capacity of the North Pacific ecosystem to support a typical population size.

Results

Genetic Variation and Mutation Rates at Multiple Loci. We sequenced amplified gene segments for seven autosomal introns, two X-linked introns, and the mitochondrial marker cytochrome *b* from up to 42 individuals from the eastern Pacific gray whale population, and estimated substitution rates for these markers [see *Materials and Methods* and supporting information (SI) *Methods*, including SI Table 2]. The average rate of substitutions across autosomal nuclear introns was 4.8×10^{-10} substitutions per base pair per year^{-1} (ranging from 1.5×10^{-10} to 10×10^{-10}) (Table 1).

We used the coalescent analysis program LAMARC (12) to estimate genealogies from individual sequences and calculate the genetic diversity parameter, $\Theta = 4N_e\mu$, where N_e is the effective population size and μ is the average mutation rate. We combined data from all loci into a joint-likelihood analysis. The overall maximum-likelihood point estimate of Θ was 0.001021, with 95% confidence intervals ranging from 0.000925 to 0.001130.

Variance of Effective and Census Population Sizes. To calculate the effective population size N_e, we divided the joint maximum likelihood estimate of Θ by estimates of generation time ranging from 15.5 to 22.28 years (13, 14), and by four times the average autosomal substitution rate (μ), after applying scaling factors described in *Materials and Methods*. Generation time range was calculated as the median age of 54 sexually mature females (13) and as the mean period elapsing between the birth of a parent and the birth of offspring (14).

We calculated the average long-term effective population size of gray whales to be on average 34,410 with 95% confidence limits of 31,175 and 38,084. However, census size of animal populations is typically higher than effective size because not all adults successfully breed. We converted effective size N_e into total census estimates (N) by multiplying by a conservative 2:1 ratio of total adults to breeding adults (15) and the ratio of total population size to total adults, estimated between 1.58 and 1.78 (13, 16) based on census and fisheries data.

By using the relationship $\Theta = 4N_e\mu$, and the conversion factors above, we computed 95% confidence intervals on census size N by randomly sampling 10,000 times from uniform distributions of Θ (0.000925–0.001130), generation time (15.5–22.28 years), and the ratio of census population size to effective population size (3.2–3.6). This procedure gives 95% confidence limits of 78,500–117,700 with a mean of 96,400 (Fig. 1), or 3.5–5.3 times today's census population size. This range of values incorporates uncertainty in measures of genetic diversity, uncertainty in mutation rates among loci, and uncertainties in generation time and juvenile abundance.

Testing for a Prewhaling Population Bottleneck. Genetic data provide population size estimates potentially averaged over thousands of generations or more. Thus, the genetically estimated gray whale population size might be higher than at the start of

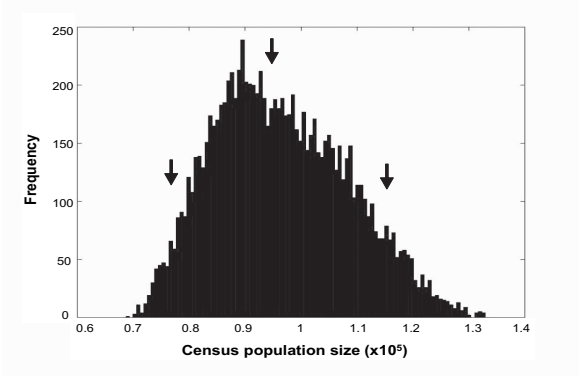

Fig. 1. Bootstrap simulations to estimate variance in historical census population size. Distribution of historical census population size estimates based on 10,000 bootstrap replicates using 95% confidence intervals for the joint estimate of Θ across all introns and cytochrome *b*, and a range of generation times (15.5–22.28 years), effective/census ratios, and juvenile proportions representing the range of values found in the literature. The arrows represent upper and lower 95% confidence intervals and the mean value.

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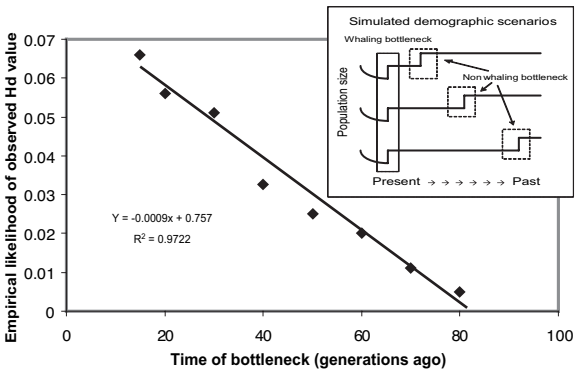

Fig. 2. Simulation of demographic bottlenecks. Shown is the likelihood of the observed parameter *Hd* (haplotype diversity) given a bottleneck scenario beginning 15–80 generations ago. A linear regression was used to determine the generation at which the likelihood falls below 0.01 (73 generations ago or ≈1,100–1,600 years).

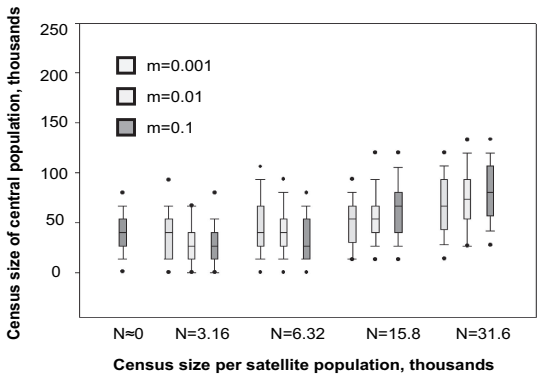

Fig. 3. Simulation of migration from satellite populations. The census size of the central population increases with migration to and from a satellite population, as the size of the satellite population approaches that of the main population and as migration rate increases (*m*, proportion of migrants per generation). Box plots show median values and 25th and 75th percentiles, whiskers show 10th and 90th percentiles, and dots represent 5th and 95th percentiles across 100 simulated data sets per scenario.

commercial whaling if a large population decline occurred before the mid-1800s. Tests for departure from neutral distributions of alleles within populations and segregating sites (Tajima's *D*, Fu and Li's *D**, Fu's *F*) (SI Table 3) showed no evidence for loci under selection, or for significant population growth or decline. A separate way to estimate past population dynamics is to use coalescent analysis (12, 17). However, the low average mutation rate across whale introns and the large gray whale population size lengthen the time period over which our data provide useful views of population changes. Coalescent analyses performed on our intron data set show no long-term growth or decline, but lack the power to detect relatively recent population swings.

However, loci with relatively high mutation rates and more sensitivity to genetic drift are more useful for testing for changes in population size, so we used current mitochondrial DNA haplotype diversity in gray whales to examine the effects of different bottleneck scenarios. We carried out coalescent simulations of bottleneck events at a variety of times before the onset of commercial whaling, to test whether such an event could explain differences between genetic and historic estimates (see *Materials and Methods*).

We simulated a prewhaling census size change from 96,000 to 22,000, approximately the difference between genetic estimates and average census size today, varying the bottleneck time from 15 generations to 10,000 generations ago. We then tested for significant reductions in mitochondrial haplotype diversity in simulated vs. current populations. These tests show that haplotype diversity (*Hd*) significantly declines for all bottlenecks occurring longer ago than 73 generations, or ≈1,100–1,600 years ago (Fig. 2). These analyses are therefore inconsistent with the hypothesis that a bottleneck from 96,000 to 22,000 animals further back in time than 1,100–1,600 years can explain the difference between our genetic estimate and prior estimates of historic abundance: such a bottleneck would have eroded haplotype diversity well below the current value.

Quantifying the Effects of Population Structure. A final consideration is population structure, because genetic diversity among subpopulations can inflate N_e. In general, estimates of effective population size exceed real population size in this situation by a factor of $\approx 1/(1 - F_{ST})$, where F_{ST} is the proportion of genetic variance distributed spatially (ref. 18, equation 2.7 based on ref. 19). Available data show no observable structure within the eastern Pacific gray whale population (reviewed in ref. 20). To further confirm this result, we collected data from six microsatellite loci for the same whales used in this study and estimated the probabilities of one population ($K = 1$) versus multiple populations ($K > 1$) by using STRUCTURE, version 2 (21). No population subdivision is apparent in our data, suggesting that our estimate of genetic diversity is not inflated by current population substructure.

However, two other populations may have contributed genetic diversity to the eastern Pacific population in the past: the western Pacific population (16) and an extinct Atlantic population (22). A recent study comparing mitochondrial control region data between the eastern and western Pacific gray whale populations indicates an F_{ST} value of 0.087 between these two populations (23), potentially inflating our estimate of population size in the eastern population by about a factor of ≈9.5% [$1/(1 - 0.087) = 1.095$]. However, this formulation assumes the populations are at migration–drift equilibrium, which is unlikely to be true for gray whales. To capture the complex contribution of potentially nonequilibrium migration scenarios to current-day genetic diversity, we constructed a series of population simulations to estimate the impact of migration from partially isolated western and Atlantic gray whales on genetic diversity in eastern gray whales. Our basic question was whether periodic migration from small satellite populations could significantly increase genetic diversity in a central population.

We simulated a set of scenarios likely to be realistic given the appearance and disappearance of biogeographic barriers over the past 200,000 years (SI Fig. 4). Migration between the eastern and western Pacific populations is allowed during the last glaciation (18–70 kya), and the Little Ice Age (400–750 ya) when sea ice or lower sea level may have blocked migration through the Bering Sea (24). Arctic migration between the eastern Pacific and the Atlantic is assumed to have been possible only during interglacial, warm periods, most recently during the Sangamonian Interglacial period (114–131 kya).

Simulations with a variety of migration rates were conducted by using effective population sizes as input values, but in the following, we converted these effective sizes to estimated census size by using the conversion factors described above. Simulations of an eastern population with an effective size of 11,500 (corresponding to a census size of 40,000) and small populations in the western Pacific and Atlantic (census size, 3,000–6,000 each) show no impact on the genetic diversity of the eastern Pacific (Fig. 3). Large satellite populations, however, can increase the genetic diversity of the eastern population. Of course, at these large sizes (approximate census size of 30,000) (Fig. 3), the western and Atlantic populations contain a substantial fraction

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of the global population. Simulations also indicate that increased diversity in the eastern population is much more likely to have been caused by immigration from the western Pacific population than the Atlantic. Gene flow from a large Atlantic population alone increases genetic diversity values in the present eastern Pacific population by <10% (data not shown).

Discussion

Levels of genetic variation in eastern Pacific gray whales are higher than expected, and suggest that the long-term, effective population size has been typically between 31,175 and 38,084 breeding adults. When we adjust our estimated effective size for nonreproductive adults and for juveniles (which are included in census data), the long-term average of 78,500–117,700 is 3- to 5-fold higher than the current number of gray whales (≈22,000) (6) and is larger than most model-based estimates of gray whale abundance before whaling.[¶]

Sources of Uncertainty. These estimates involve two major levels of analysis, the estimate of effective size from genetic diversity and the estimate of census size from effective size. In the use of genetic diversity to measure effective size, genetic variation and subsequent estimates of long-term effective population size differ among loci, and are affected by many evolutionary forces, such as selective sweeps, population expansions and bottlenecks, variance in reproductive success, stochastic retention of genetic diversity, population structure, and mutation rates. Although most of these factors are likely to decrease estimates of effective population size, stochastic effects, mutation and population structure can potentially increase it. As in other genetic studies of wild populations, such as chimpanzees (25), we have attempted to control for these three factors by measuring effective size across independent loci, estimating mutation rate independently for each locus, and by accounting for population structure.

Because data from multiple unlinked loci independently assay past population patterns, analyzing large numbers of loci greatly increases the accuracy of estimates of Θ, even when the number of individuals sampled is moderate (26). Among the nine polymorphic loci we examined, genetically based population census estimates vary from 44,000 to 272,000, but exceed current census estimates in all cases. Only in the X-linked intron *G6PD*, in which no variation was observed, is the genetic estimate of long-term abundance less than the current population size (Table 1).

Different loci potentially have different mutation rates, so we independently measured mutation rates for each locus. Prior genetic measurement of whale populations relied on variation in the mitochondrial control region, which has a complex pattern of molecular evolution (4). In contrast, for whale introns the relationship between divergence time and genetic distance is largely linear (SI Figs. 5 and 6). The most critical fossil date used to calibrate substitution rates, the divergence between right whales and other mysticetes, is well supported. This time point represents the earliest well dated split within mysticetes and thus has a large impact on the relationship between genetic distance and divergence. Fossil dates (26–30 Mya) for this split are concordant with molecular clock estimates (27.3 ± 1.9 Mya) (ref. 27 and ††), suggesting this time point is a robust anchor for our mutation calibrations. Our calculated rate of intron evolution is similar to that of other mammals after taking into consideration the large size and low metabolic rate of whales (28).

Because the amount of genetic data varies between markers, our average rate might differ slightly if we calculated a rate by using data from all loci in the same analysis. This approach generates a slightly lower rate [$4.15 \times 10^{-10} \pm 0.3 \times 10^{-10}$ (SE) $\text{bp}^{-1}\,\text{year}^{-1}$] (SI Fig. 6). Because a lower mutation rate will result in higher estimates of N_e, we used the higher rate obtained from averaging across loci in our analysis (4.8×10^{-10} $\text{bp}^{-1}\,\text{year}^{-1}$). In our LAMARC analysis, the estimate of Θ for each genetic marker is scaled by that marker's relative mutation rate. This allows us to use an average mutation rate to calculate overall census size estimates from LAMARC's output.

Ecological counts include nonreproductive adults and juveniles observed from shore, so to compare our results to published census data we must correct for these parts of the population. The ratio of adult population to effective population has been estimated as >2 for many mammals (15): models of the relationship between population size and extinction risk, including those for whales, often assume ratios of 2–10 (29). In the absence of a direct estimate of this parameter from lifetime measures of reproductive success in males and females, we assumed the most conservative ratio of 2. Juvenile abundance can be more confidently estimated from census data (13, 16).

We estimated overall variance by incorporating uncertainty in both the generation of effective size from diversity and the generation of census size from effective size through a Monte Carlo sampling method. This approach gave us confidence intervals that ranged from 76,000 to 118,000. Other sources of uncertainty exist, such as (*i*) variance in reproductive success among adults, (*ii*) impact of selection at individual loci, and (*iii*) swings in population size over time. However, each of these factors, if known in detail and taken into account, would tend to increase our estimates of the ratio of census to effective population size, and would increase our calculated long-term census population size by some unknown amount.

Long-Term Nature of Population Estimates. Genetic data provide long-term estimates of average effective population size, and there are many population trajectories throughout the past that could give rise to a particular effective population size today. Until reconstructions of whale population size in different past time periods become available, the single value of long-term size we provide should be treated cautiously. In particular, it is possible that the population sizes of whales just before whaling might have been lower than their long-term sizes. Although no direct evidence is available to evaluate this hypothesis, such a population trajectory could explain the discrepancies between historical and genetic views of whale abundance (4).

We explored this possibility with simulations of gray whale population bottlenecks from our estimated census size of 96,000 down to 22,000 individuals. Simulations show that such a decline would rapidly erode mitochondrial haplotype diversity. Current data would be able to detect this erosion if the prewhaling bottleneck had happened more than 1,100–1,600 years ago (73 generations).

Two possibilities remain. First, a decline in gray whale numbers from 96,000 to 22,000 might have occurred over the past 1,100–1,600 years. If this happened before western whaling began in the 19th century, then both long-term genetic estimates and traditional estimates of gray whale abundance just before whaling could be correct. A second possibility is that a population much larger than 96,000 collapsed to 22,000 further back in time. Analysis of gray whale genetic diversity from ancient samples may clarify these possibilities, and allow the exploration of other possible population trajectories.

The Influence of Population Structure on the Results. Although there are many demographic events that reduce genetic variability, there are a few that increase it. Balancing selection can increase diversity, but is unlikely to be operating across all of the multiple loci we analyzed, and there is no signature of excess high-frequency alleles in our data (SI Table 3). More likely might be that undetected, nonequilibrium population migration could

††Fordyce, R. E. (2002) *J Vertebr Paleontol* 22(Pt 3, Suppl):54 (abstr.).

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increase the apparent genetic diversity of whale populations. Accounting for past population structure is complex, given a potentially infinite number of past migration scenarios. We simulated a set of scenarios in which genetic diversity might have been injected into the eastern Pacific population from the western Pacific population when it was larger, or from the Atlantic before that population became extinct. Our simulations suggest that small populations in the western Pacific or in the Atlantic would not have appreciably increased genetic diversity in the eastern population. However, historical migration from a large western Pacific population could partially explain high genetic diversity in the eastern Pacific.

As a result, our long-term estimate of 96,000 gray whales was probably distributed between the eastern and western populations. Very few data are currently available on historical abundance and whaling effort in the western Pacific stock (20), but it is possible that this population was substantially larger than it is now. Future analysis of these two populations using multiple nuclear loci and the IM approach used by Won and Hey (25) to investigate ancestral and effective sizes in chimpanzees might be a profitable way to address these issues.

Implications for Management. Conservation efforts have resulted in a steep decline in extinction risk for eastern Pacific gray whales, but our results suggest that full demographic recovery has not occurred and that this population remains depleted. Mean census counts of ≈22,000 (8) are 28–56% of the minimum genetic long-term estimates, assuming up to half the population have typically been western. Because marine mammal populations <50–70% of historic population size are considered depleted (7), a cautionary response to these data would be to consider the eastern Pacific gray whale as a depleted stock. Such a designation could change the allowable human-caused mortality of this stock under the U.S. Marine Mammal Protection Act from ≈417 animals a year to ≈208, assuming the recovery factor (7) used in calculating potential biological removal (7, 8) changes from 1.0 (8) to 0.5 (7, 30). Currently, an aboriginal take of 125 animals per year is allowed by the International Whaling Commission (8, 30).

For gray whales, historic population data help clarify population trends. Models that incorporate census data from 1999–2000 indicate that gray whales have reached their carrying capacity (7), but other interpretations suggest that high mortality in 1999–2000 represented an ephemeral episode due to climatic shifts (9). Genetically determined long-term population estimates support the hypothesis that the current population has not fully recovered and will continue growing if ecological conditions permit.

An important question for current whales is whether carrying capacity has declined over time. If this is the case, gray whales may be depleted relative to historical numbers but may have reached carrying capacity today. Ecological surveys of gray whale feeding areas on the Bering Sea shelf suggest that this area alone could support ≈90,000 whales annually (see *SI Methods*). However, recent evidence suggests that gray whale feeding habitat may be declining as Arctic benthic prey populations are reduced because of changing climate in the Bering Sea (9). Although additional survey data will be critical to determining whether carrying capacity has been reached, our estimate of typical gray whale abundance suggests that recent problems in gray whale feeding, including reports of thin adults or high calf mortality, may result from changing conditions in northern feeding grounds.

Ecosystem-Wide Impacts of Gray Whale Depletion. In addition to implications for management, these data are a first step toward quantification of the ecosystem effects of whale population depletion in the North Pacific. Gray whales are important ecological structuring agents in Bering Sea benthic marine communities (31, 32). Because they are bottom feeders that suck up mouthfuls of sediment, study of feeding gray whales shows $\approx 1.2 \times 10^8$ m^3 of sediment were annually resuspended by the eastern Pacific gray whale population of the early 1980s (33, 34). Assuming a population size then of ≈16,000 individuals, a population of 96,000 gray whales would rework $\approx 7.2 \times 10^8$ m^3 in a summer, ≈12 times larger than the sediment transport load of the largest river emptying into the Bering Sea, the Yukon River (35, 36). Decreased sediment reworking could dramatically change nutrient recycling, and create shifts in benthic species dominance (32).

Similarly, feeding by gray whales provides nutrient subsidies from benthic marine communities to terrestrial ones, including food subsidies for at least four species of seabirds that feed on benthic crustaceans brought to the surface by gray whale feeding (37). The number of birds attending the foraging activities of a single gray whale averages ≈11, although the number of plumes used per bird and the use of plumes from different whales are not known. If this average is representative across the summer season, we calculate that a population of 96,000 whales could provide food subsidies to 1.03 million birds. The quantitative impact of these subsidies on sea bird reproduction or fitness is currently unexplored. In addition, gray whales may have provided an important food source for predators and scavengers such as orcas (38) and California condors (39).

More numerous gray whales in the past may not have fed only on the Bering and Chukchi shelves, the areas in which the majority of individuals feed today. As gray whale populations have increased, more and more are observed feeding in other coastal locations including Oregon, Washington, British Columbia, and southeast Alaska (e.g., ref. 41). If feeding in other areas was common, the ecological impact of diminished gray whale populations would not be restricted to the Arctic.

Overall, these simple calculations of gray whale impact do not fully document the likely ecological impact of whales; they merely suggest the order of magnitude of effects of gray whales on their environment. Further research on ecological subsidies of whales to seabirds, sediment and nutrient effects, and ecological shifts of whales during population expansion are critically needed to better understand how marine ecosystems have been impacted by reduced whale populations.

Conclusions

Genetic-based abundance data suggest that gray whale populations were typically larger than they are today: the whole Pacific population likely numbered three to five times the current population. These numbers suggest the eastern Pacific population, even if it historically accounted for only half of the entire Pacific population, should be considered depleted and should regain higher management protection. Recently observed changes in the eastern Pacific gray whale population are unlikely to be the result of this population reaching its long-term carrying capacity; rather, these changes may have been transient or they may represent first responses to altered ecological conditions and reduced carrying capacity in the Bering Sea and other habitats (9). Ocean nutrient cycling, sediment transport, and ecological subsidies may have been far different in the past when gray whales were more abundant. Although restoring gray whales to their full former abundance in the North Pacific may be unrealistic because of such large-scale environmental changes in critical feeding areas, an improved knowledge of past abundance allows a more comprehensive assessment of the ecological impacts of gray whale population decline. Historic data have been eliminated from much of conservation management (7, 30, 41). However, our data suggest that such information can provide a critical context for evaluating population trends and in determining the potential ecosystem impacts of ecologically important threatened and endangered species.

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Materials and Methods

Estimating Genetic Population Parameters. The diversity parameter Θ was calculated by using LAMARC (12), by jointly estimating Θ across multiple loci while incorporating relative μ and N_e values for each locus. Among genomic regions (seven autosomal nuclear introns, two X-linked introns, and cytochrome *b*), we applied scaling factors of 4 and 4/3 to our mitochondrial and X chromosome N_e values, respectively, and computed Θ by using a scale in which the average relative mutation rate among autosomal loci is unity. These two sets of scaling factors allowed us to calculate the population's Θ from a multidimensional likelihood surface constructed from all loci. To ensure model convergence, we performed each LAMARC analysis 15 times, using three different random number seeds and five different trial values for Θ. For each gene, we performed 10 MCMC searches of 31,000 iterations each followed by two searches of 1,001,000 iterations each, sampling every 20th genealogy estimate after discarding the first 1,000 estimates of each search.

Substitution rate was estimated by comparing pairwise genetic distance between 4 and 14 species of baleen whales and their respective divergence times (27). We used the program MODELTEST (42) to determine the appropriate mutational model, and PAUP* to generate pairwise genetic distances (43).

Bottleneck Simulations. We used SIMCOAL (44) to simulate a sequence of 523 bp for 42 individuals, the length of the control region segment we obtained, and used a mutation rate of 5×10^{-8} bp^{-1} $year^{-1}$, which is the mutation rate necessary to obtain the same average effective size of eastern North Pacific gray whales for control region data as we found for intron data. We used an empirically determined transition bias of 0.96 and a rate heterogeneity parameter of 0.8. The empirical likelihood of haplotype diversity (*Hd*) under each demographic model was calculated as a one-tailed test [see Belle *et al.* (45)] and decreases as the time of bottleneck becomes more ancient (Fig. 2). Linear regression shows that a likelihood of 0.01 is obtained under a bottleneck occurring 73 generations ago.

Migration Between Subpopulations. To test the effect of immigration from satellite populations on effective population size of females, we used SIMCOAL (44) to simulate a central population with migration of varying levels from satellite populations of varying sizes, and calculated the ratio between $N_{e(f)}$ of the central population computed with and without migration. The central population was assigned an $N_{e(f)}$ of 5,000 individuals, corresponding to the estimated effective size of the female population today. We simulated immigration rates of 0.001, 0.01, and 0.1 (proportion of immigrants per generation) and satellite populations of sizes 500, 1,000, 2,500, and 5,000.

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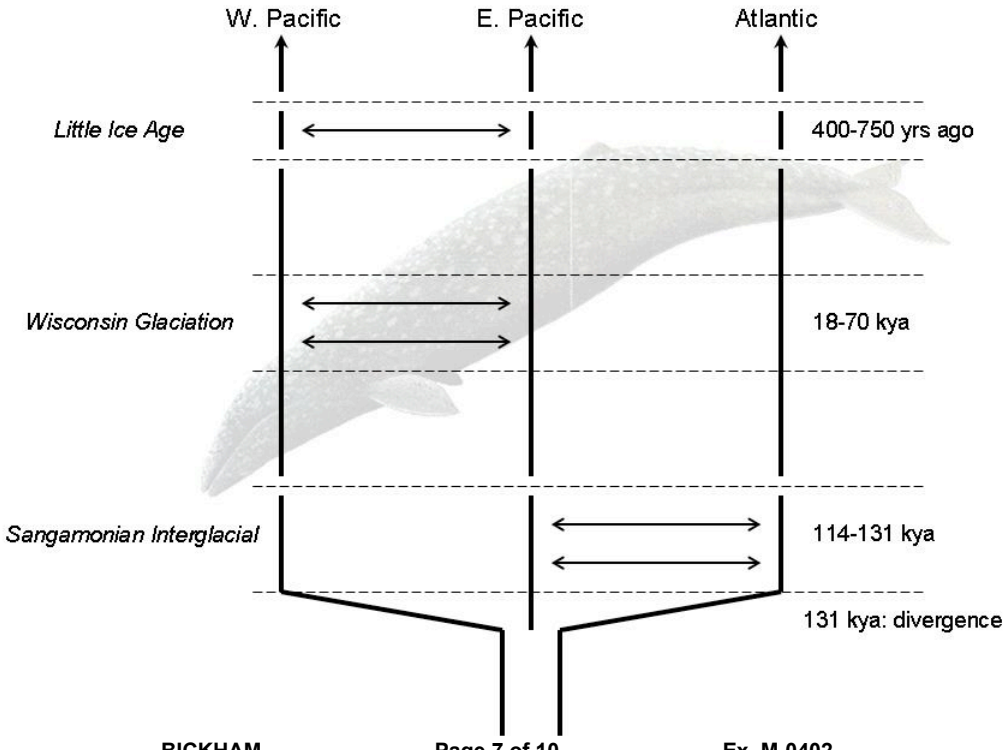
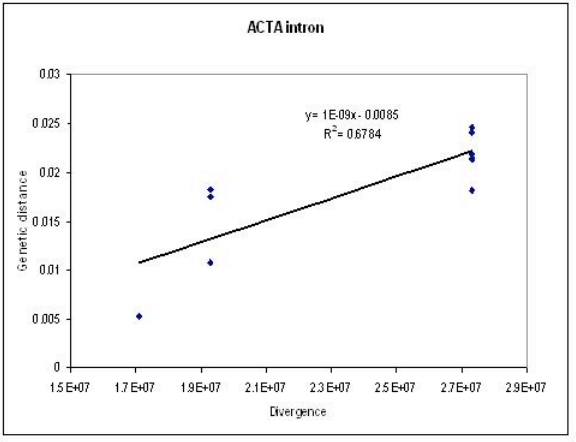
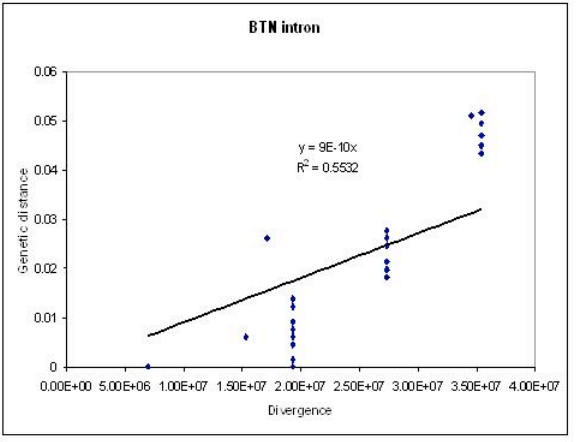
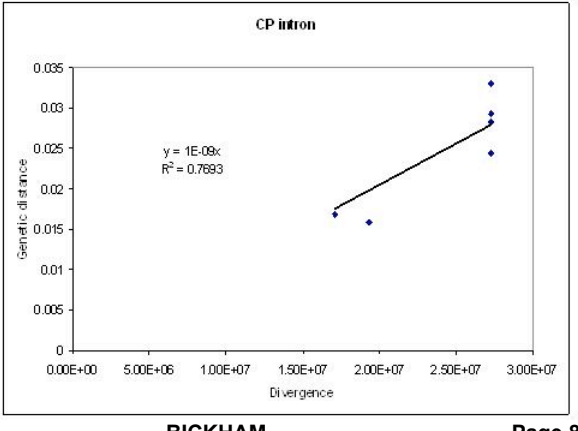
Migration scenario used for simulations




ACTA intron
y= 1E-09x - 0.0085
R² = 0.6784
Genetic distance
Divergence
0.03
0.025
0.02
0.015
0.01
0.005
0
1.5E+07
1.7E+07
1.9E+07
2.1E+07
2.3E+07
2.5E+07
2.7E+07
2.9E+07


BTN intron
y = 9E-10x
R² = 0.5532
Genetic distance
Divergence
0.06
0.05
0.04
0.03
0.02
0.01
0
0.00E+00
5.00E+06
1.00E+07
1.50E+07
2.00E+07
2.50E+07
3.00E+07
3.50E+07
4.00E+07


CP intron
y = 1E-09x
R² = 0.7693
Genetic distance
Divergence
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
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5.00E+06
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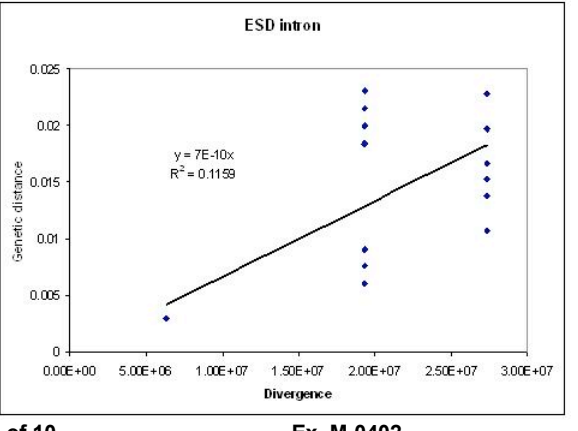
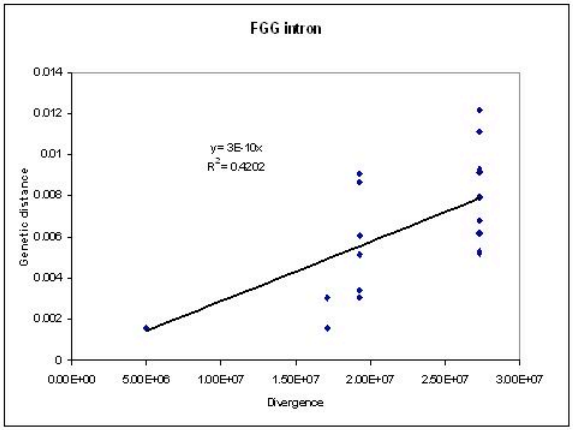
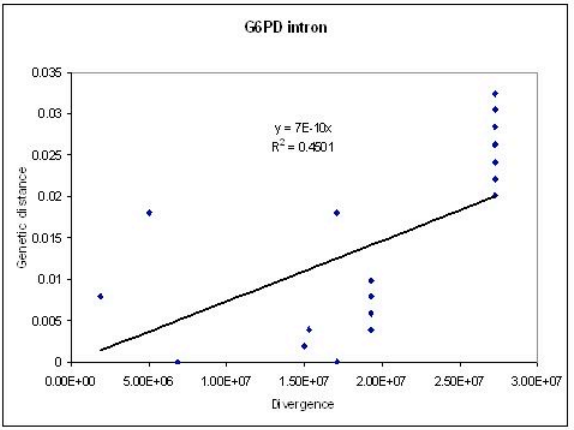
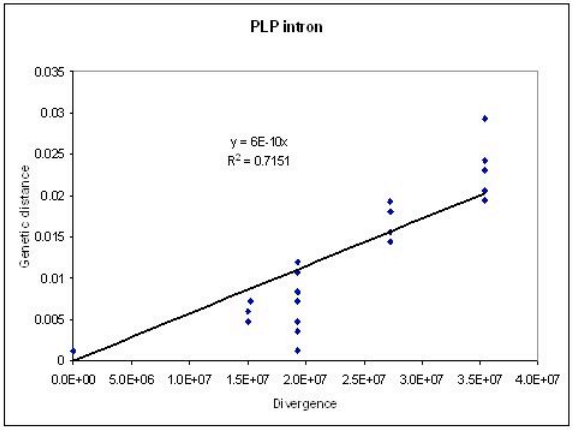
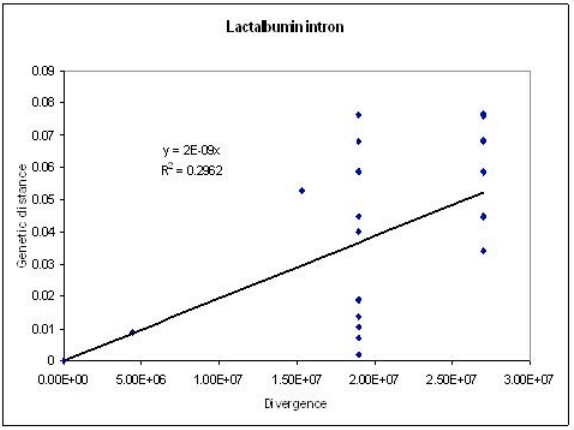
2.00E+07
2.50E+07
3.00E+07

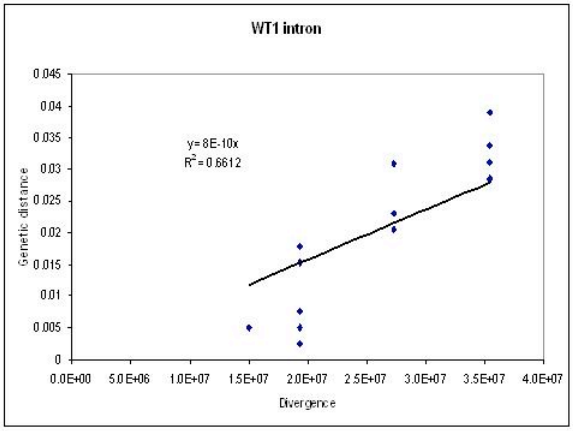

ESD intron
y = 7E-10x
R² = 0.1159
Genetic distance
Divergence
0.025
0.02
0.015
0.01
0.005
0
0.00E+00
5.00E+06
1.00E+07
1.50E+07
2.00E+07
2.50E+07
3.00E+07

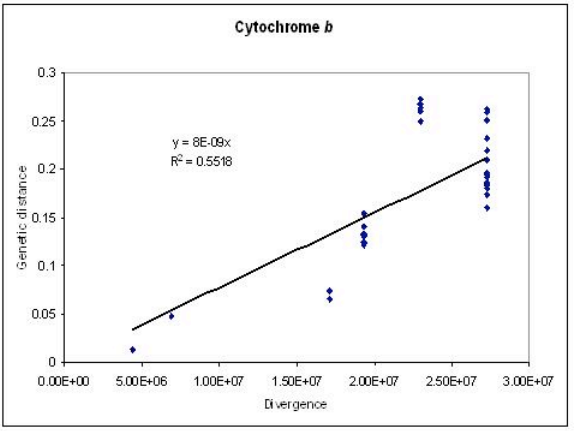

FGG intron
y= 3E-10x
R2= 0.4202
Genetic distance
Divergence

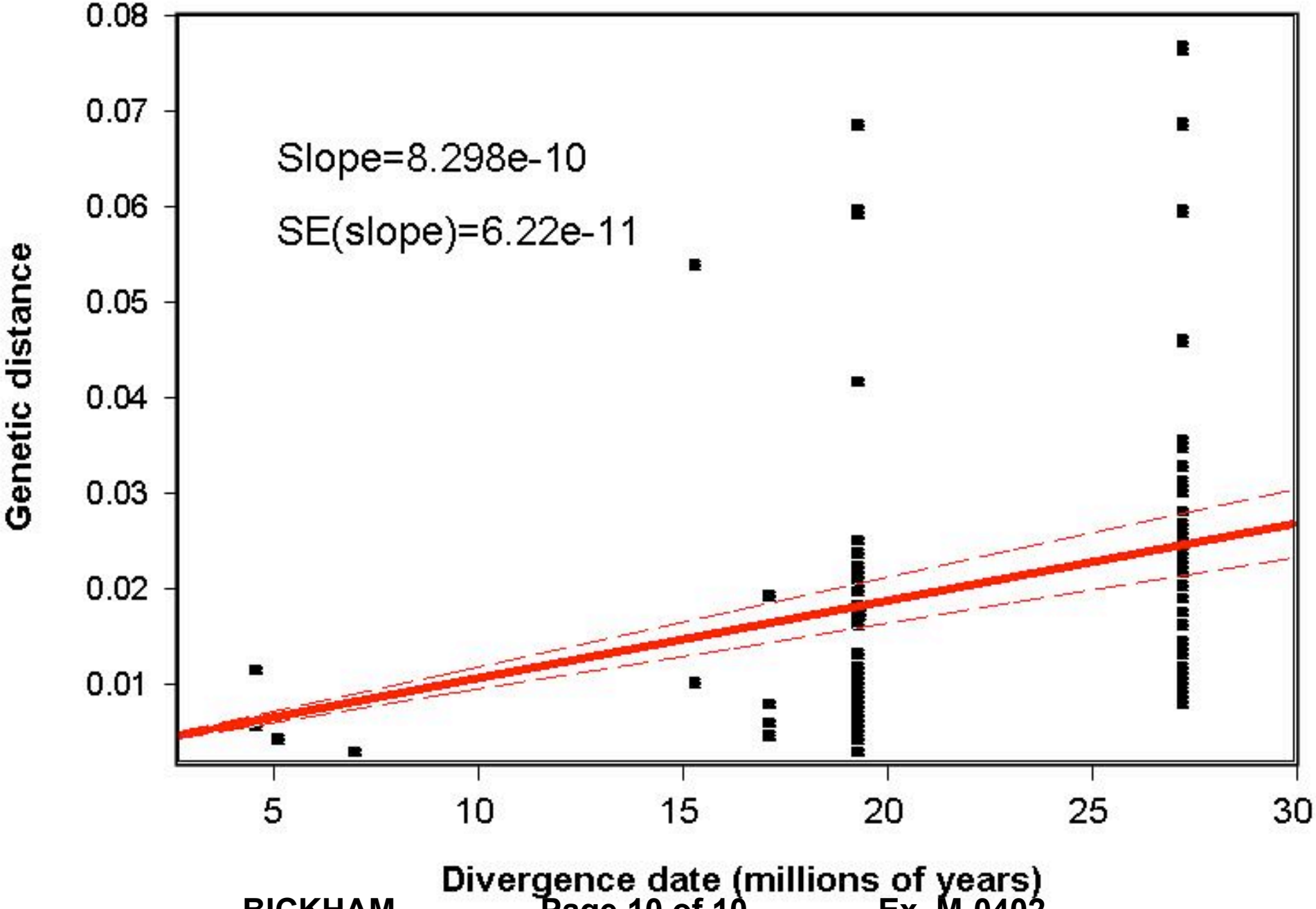

G6PD intron
y = 7E-10x
R2 = 0.4501
Genetic distance
Divergence


PLP intron
y = 6E-10x
R2 = 0.7151
Genetic distance
Divergence


Lactalbumin intron
y = 2E-09x
R2 = 0.2962
Genetic distance
Divergence


WT1 intron
y= 8E-10x
R2 = 0.6612
Genetic distance
Divergence


Cytochrome b
y = 8E-09x
R2 = 0.5518
Genetic distance
Divergence


0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Genetic distance
Slope=8.298e-10
SE(slope)=6.22e-11
5
10
15
20
25
30
Divergence date (millions of years)

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Pre-Whaling Genetic Diversity and Population Ecology in Eastern Pacific Gray Whales: Insights from Ancient DNA and Stable Isotopes

S. Elizabeth Alter[1]*¤, Seth D. Newsome[2], Stephen R. Palumbi[1]

1 Department of Biological Sciences, Hopkins Marine Station, Stanford University, Pacific Grove, California, United States of America, **2** Department of Zoology and Physiology, University of Wyoming, Laramie, Wyoming, United States of America

Abstract

Commercial whaling decimated many whale populations, including the eastern Pacific gray whale, but little is known about how population dynamics or ecology differed prior to these removals. Of particular interest is the possibility of a large population decline prior to whaling, as such a decline could explain the ~5-fold difference between genetic estimates of prior abundance and estimates based on historical records. We analyzed genetic (mitochondrial control region) and isotopic information from modern and prehistoric gray whales using serial coalescent simulations and Bayesian skyline analyses to test for a pre-whaling decline and to examine prehistoric genetic diversity, population dynamics and ecology. Simulations demonstrate that significant genetic differences observed between ancient and modern samples could be caused by a large, recent population bottleneck, roughly concurrent with commercial whaling. Stable isotopes show minimal differences between modern and ancient gray whale foraging ecology. Using rejection-based Approximate Bayesian Computation, we estimate the size of the population bottleneck at its minimum abundance and the pre-bottleneck abundance. Our results agree with previous genetic studies suggesting the historical size of the eastern gray whale population was roughly three to five times its current size.

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* E-mail: ealter@york.cuny.edu

¤ Current address: Department of Biology, York College, City University of New York, Jamaica, New York, United States of America

Introduction

Commercial whaling in the 19th and 20th centuries resulted in greatly reduced population sizes in many species, with dramatic impacts on marine ecosystems (e.g. [1]). Despite widespread scientific and public interest in the recovery of whale stocks and the ecological impacts of removal, little is known about how whaling may have altered basic aspects of population ecology including abundance, foraging grounds, migration patterns, or population substructure [2,3].

Of particular interest is the estimation of historic abundance immediately prior to whaling. Genetic diversity in many whale populations is too high to match pre-whaling population sizes estimated from whaling and commercial records, producing a striking discrepancy between historic abundance in baleen whales estimated from historical records versus genetic data (e.g. [4,5]). For example, mitochondrial data from three baleen whale species in the North Atlantic produced estimates 6 to 20 times larger than previous estimates based on historical data [4]. Many potential explanations for this discrepancy have been suggested [6]. For example, abundances estimated from historical data could be too low if whaling records were lost, biased or falsified, or if parameters (such as struck-and-lost rate) used to calculate the numbers of whales killed from these records are inaccurate. On the other hand, abundances from genetic data could be too high if the mutation rate used is too low, if few genetic markers were used, if population structure is not accounted for, if generation time is underestimated, or if balancing selection was occurring at the genetic loci used to calculate population size. Many of these factors have been and continue to be investigated as sources of error (see [6,7]).

However, the discrepancy between historic and genetic estimates can also be explained by a single scenario: populations of whales were much larger in the past, but declined substantially before whaling began. Under this scenario, both genetic and historic inferences could be correct. However, this hypothesis has proven difficult to test, as it requires estimation of prehistoric population dynamics.

Ancient DNA sequences allow direct estimation of changes in genetic diversity over time, and can greatly improve the reconstruction of historic population dynamics, particularly when demographic histories are complex [8,9]. Temporally-spaced genetic data can improve statistical power to detect bottlenecks relative to modern data alone, even when relatively few ancient samples are available [10]. Demographic reconstruction using ancient sequences has yielded insight into historic population ecology and the context of declines in organisms such as bison [11], woolly mammoths [12], and tuco tuco [13], and has the

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potential to provide information about the historical demography of whales before whaling. Ancient genetic data can be particularly powerful when combined with stable isotope data, which can reveal information about feeding ecology from the same population [14,15].

In this study, we investigate the pre-whaling genetic diversity, population dynamics and feeding ecology of the eastern Pacific gray whale using ancient and modern DNA sequences and stable isotope data. Eastern gray whales represent a useful case study for investigating historic population dynamics and in particular the discrepancy between genetic and historical data, because both genetic diversity and historical records have been examined in depth [5,16,17]. According to historic records, eastern Pacific gray whales originally numbered around 15,000–20,000 individuals before whaling [16]; modeling based on census data extends these numbers to 19,500–35,500 individuals [18]. Intensive whaling from 1850 to 1874 and subsequently from the turn of the century until the 1930s reduced this population to some unknown fraction of its former size. In contrast, estimates from multilocus genetic data are consistent with a much higher original population size (78,000–116,000 individuals) [5].

A pre-whaling bottleneck in gray whales could have several potential causes. Because they feed in Arctic and subarctic benthic environments, gray whales are thought to be relatively sensitive to changes in climate, and climatic events such as the Medieval Warm Period (ca. 900–1200 AD) or Little Ice Age (ca. 1300–1850 AD) could have caused a population decline. The nature of the relationship between gray whale populations and climate-sensitive ecosystem features such as sea ice, freshwater input to nearshore benthic ecosystems and benthic species composition is poorly understood [19,20]. However, recent calving rates have been shown to be negatively correlated with ice cover extent, indicating population growth is faster when ice cover is reduced and feeding habitat is extended [20]. Indigenous hunting of gray whales has been occurring for at least 5000 years around the Pacific Rim and could have reduced gray whale populations below original levels. Though it has always been assumed that hunting using traditional techniques had minimal impact on whale abundance [21], the actual effects of indigenous hunting have not been quantified. A final possibility is that killer whales (*Orcinus orca*), the major predator on gray whales, may have increased or switched to feeding primarily on gray whales (e.g. [1]).

The accurate inference of population dynamics from ancient sequences requires multiple, well-dated samples from a single population, and depends on a number of assumptions related to the coalescent including random selection of individuals from a panmictic population [22]. We utilized whale bones excavated from dated archaeological sites on the Makah and Quilleute tribal reservations, dated 150–3500 years before present (ybp). To detect a pre-whaling bottleneck, we used genetic data from these dated ancient samples along with a modern gray whale dataset in two different and complementary analyses: 1) serial coalescent simulations with approximate Bayesian computation to determine posterior probability distributions for demographic parameters; and 2) a Bayesian MCMC method [8], which uses a coalescent approach to compare the likelihood of different histories.

In addition to investigating genetic diversity of modern and ancient samples, we used stable isotope analysis to investigate how feeding ecology may have changed since whaling, particularly around the Olympic peninsula and Vancouver Island. Today, most gray whales feed in the Bering, Chukchi and Beaufort Seas, though a small number of "summer residents" are known to feed near Vancouver Island and other locations in the Pacific Northwest (e.g. [23]). Abundant bones found in archaeological sites around the Chukchi peninsula (e.g. [24]) suggest the majority of gray whales fed in the Bering Sea and northward in the past. However, the larger population size of gray whales before whaling may also have resulted in alternative foraging habitats or strategies. In particular, productive areas in the Pacific Northwest including the inlets and sounds of Vancouver Island may have supported sizeable feeding populations [25]. Stable isotope analysis, particularly carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$), can be used to distinguish between marine foraging areas on a broad geographic scale (reviewed in [15,26]), and thus can be used to determine whether the ancient gray whales from the Pacific Northwest represented a local feeding group. Because the samples used in this study come from the same region as the modern feeding agreggation of gray whales in the Pacific Northwest, we compared stable isotope ($\delta^{13}C$ and $\delta^{15}N$) values between ancient and modern samples to determine whether ancient samples were derived from individuals representing a local feeding subpopulation.

Materials and Methods

Samples

Modern mitochondrial control region sequences from 120 eastern Pacific and 45 western Pacific gray whales were obtained from NCBI [17]. These datasets are comprised of samples from both stranded individuals across the migratory route (eastern Pacific) and biopsies (western Pacific) across numerous years. Subsequent sampling in the eastern Pacific population [3] found essentially the same distribution of mitochondrial haplotypes as in [17], suggesting this dataset contains a reasonable representation of the haplotype distribution in the population. Forty-two of these samples were reamplified and sequenced in our laboratory and sequenced blind in both directions (see [27] for methods), and sequences were compared with those from NCBI. Subsamples of 40 whale bones were collected from previously excavated sites in Northwest Washington (USA) from the Makah and Quilleute Tribal Reservations, including the Ozette site [28], a shell midden deposit on the Makah Tribal Reservation, and a shell midden on the Quilleute Tribal Reservation (Table 1, Figure 1). Excavations took place between 1971 and 2005. All bones were dated based on previously-established site provenience [28] or AMS-^{14}C dating at Lawrence Livermore National Laboratory (Livermore, CA) after correction for the marine reservoir (North Pacific surface reservoir) [29,30,31].

DNA Extraction, Amplification and Sequencing

DNA extraction and amplification were performed under strict ancient DNA contamination control measures (see "Authentication" below). The surface of each sample was removed via sanding and ca. 0.1–0.3 g of bone was removed using a dremel tool. Each subsample was ground into a fine powder and incubated overnight at 55°C with 1.25 mL of extraction buffer (0.5 M EDTA at pH 8.0, 0.5% SDS and 0.5 mg/mL proteinase K) in a 1.5 mL tube. DNA was extracted using Qiaquick DNA Extraction columns (QIAGEN) according to manufacturer's instructions.

We amplified four overlapping fragments of the mitochondrial control region sized 180–250 bp (Table 2). First, a 182 bp fragment was amplifed using primers F22 and R258 as described in [32] and sequenced to determine species identity. We amplified all samples identified as gray whales at three additional fragments. Amplification conditions were as follows: 0.1 μM each primer, 2.5 mM $MgCl_2$, 0.2 mM dNTP, 1.5 mg/mL spermidine, 2.5 μL DNA template, and 1.25 U Amplitaq Gold (Applied Biosystems). Amplifications were performed on a BioRad cycler with the

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Table 1. Ancient samples: sampling locations, units and dates in calendar years based on direct radiocarbon dating of bones (samples in italics) or of associated shell middens.

Sample	Site	Date (ybp)
BAL4	45CA24B70	300–500
BAL5	45CA24B70	150–250
BAL6	45CA24B70	370–490
BAL12	45CA24B70	300–400
BAL15	45CA24B70	300–500
BAL16	45CA24B70	300–500
BAL17	45CA24B70	150–250
BAL18	45CA24B70	280–370
BAL19	45CA24B70	150–250
BAL20	45CA24B70	150–250
BAL21	45CA24B70	260–380
BAL23	45CA24B70	310–420
BAL24	45CA24B70	430–520
BAL25	45CA24B70	320–420
BAL28	45CA400	2450–2690
BAL37	45CA23	660–880

45CA24B70 = Ozette site; 45CA400 = Shell midden deposit; 45CA23 = Shell midden on Quilleute Indian reservation.
doi:10.1371/journal.pone.0035039.t001

Table 2. Primers used in the ancient DNA analysis (5′-3′ direction).

Primer name	Sequence	Reference
dlpF22	CCACCATCAGCACCCAAAGC	[32]
dlpR258	TGCTCGTGGTGTARATAATTGAATG	[32]
ERdlpF1	CCCATAGTARTTAGTATTCCCCTGTG	This study
ERdlpR1	CACAGGGGAATACTAAYTACTATGGG	This study
ERdlpF2	CTTCACTACGGAAGTTAAAGCCCG	This study
ERdlpR2	CGGGCTTTAACTTCCGTAGTGAAG	This study
ERdlpF3	CAGCATGCCGCGTGAAACCAGCAACCC	This study
ERdlpR3	GGGTTGCTGGTTTCACGCGGCATGCTG	This study
ERdlpF4	GCAGGGATCCCTCTTCTCGCACCGG	This study
ERdlpR4	CCGGTGCGAGAAGAGGGATCCCTGC	This study

doi:10.1371/journal.pone.0035039.t002

following profile: initial denaturation at 95°C for 12 minutes, 40 cycles of 94°C/30 s, 55°C/30 s, 72°C/40 s, and a final extension at 72°C for 10 minutes.

We purified all succesful amplification products using Qiaquick columns (QIAGEN). All purified products were sequenced in both directions on an ABI 3100 Genetic Analyzer. A subset of 20% of amplification products were cloned (with a minimum of 8 sequences per product) to determine whether exogenous ampli-

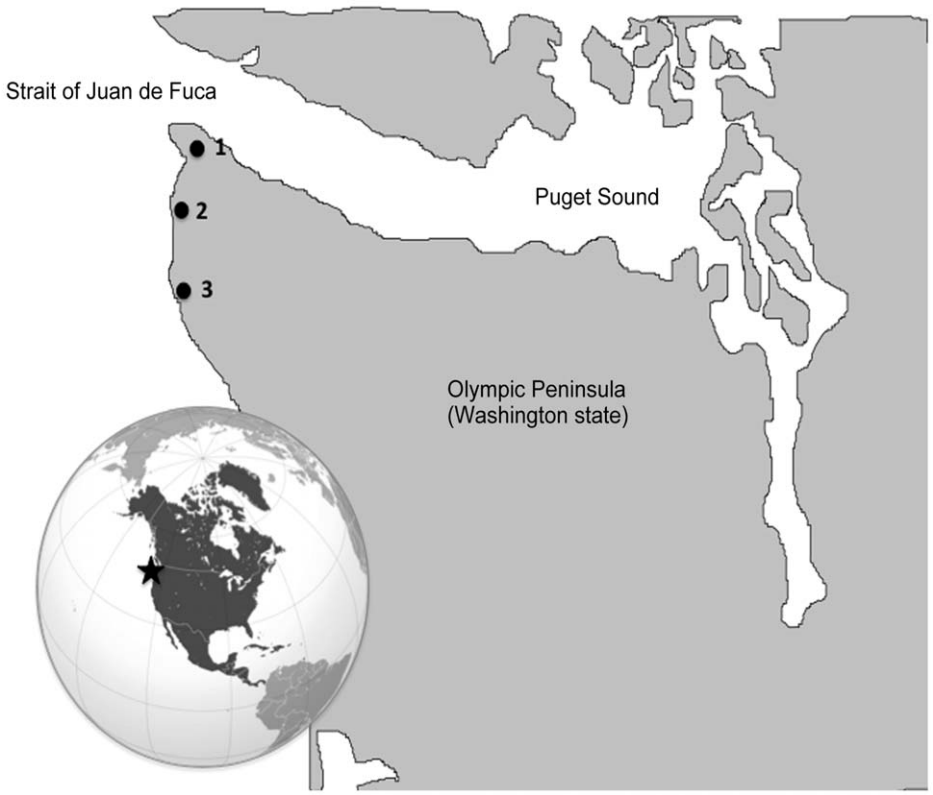

Figure 1. Sampling locations for archaeological material on the Olympic Peninsula, Washington state, USA. 1 = Shell midden deposit on Makah Tribal Reservation (45CA400); 2 = Ozette site (45CA24B70); 3 = Shell midden deposit on Quilleute Tribal Reservation (45CA23). Samples were excavated between 1971 and 2005 [28].
doi:10.1371/journal.pone.0035039.g001

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cons were present, using ABI Topo kit. Sequences were cleaned, edited and aligned in Sequencher 4.0 (GeneCodes).

Authentication

Ancient DNA extraction and pre-PCR procedures were performed under strict controls to minimize contamination risk and controls were included at each step to monitor contamination. Primers were designed specifically for cetaceans, and laboratories in which extractions and PCR were performed had never had any modern whale or cetartiodactyl DNA or tissues in the facilities. Ancient DNA extraction and pre-PCR procedures took place in a specialized facility, spatially isolated from facilities in which PCR, cloning and sequencing take place. The ancient DNA facility is equipped with positive airflow to prevent/minimize exogenous contaminants from entering the room, and overhead UV lamps to destroy non-target DNA. No researchers are permitted to enter the clean room within 24 hours of contact with facilities in which PCR occurs. Prior to extraction of DNA from ancient material, all surfaces were cleaned with Alconox detergent and a bleach solution (10–30%), and room, materials (including tubes, tips, pipettors, and foil) and reagents (excluding proteinase K) were UV-irradiated overnight. Extractions and PCR set-up were performed in a Class II laminar flow hood. Samples were stored in separate airtight plastic bags until use. Each sample represents a different individual because subsamples came from the same complete skeletal element, had different ^{14}C dates, or were from different sites.

All extractions and amplifications included negative controls at a ratio of one control for every four samples. Multiple, overlapping amplifications with different primer pairs were used to confirm all SNPs. Amplifications were repeated for 20% of samples. As described above, 10% of amplified fragments were cloned and sequenced to determine the extent of contamination by exogenous DNA. In addition, 25% of gray whale samples were re-extracted and amplified independently by a separate laboratory. New gray whale haplotypes were deposited in NCBI with corresponding sample names (Accession numbers JQ910911–JQ910926).

Genetic Diversity

Ancient sequences were aligned to previously published control region sequences for both eastern and western Pacific gray whales [17] using Sequencher 4.0 (GeneCodes). Haplotype diversity (*Hd*), the genetic diversity parameters Watterson's *?* and nucleotide diversity (π), and Tajima's D were estimated using DnaSP v.5 [33]. We measured genetic differentiation between sample sets using F_{ST} [34], and derived 95% confidence intervals from 20,000 bootstrap replicates using the program Arlequin v. 3.1 [35].

Coalescent Simulations and Demographic Analyses

To explore whether bottlenecks could result in observed patterns, we used a rejection-based approximate Bayesian computation (ABC) approach [36] with serial coalescent simulations. We simulated a range of demographic histories (including population bottlenecks of different sizes/timing and various pre-bottleneck sizes) and used an ABC framework to compare observed and simulated values of summary statistics to estimate the posterior probability distributions of demographic parameters. In these simulations, population size parameters were estimated in terms of female effective size (N_{ef}), or the number of breeding females. To relate these estimates to previously published figures, we converted between effective female size and census size using three steps (see [4,5] for additional details and rationale): 1) female effective size is converted to effective size (N_e) by multiplying by 2 to account for males; 2) effective size (N_e) is converted to all adults (N_T) by multiplying by 2, and 3) Adult population (N_T) is converted to census size (N), or the total number of individuals in the population including juveniles, by multiplying by 1.5.

We varied demographic scenarios as follows. The time of the bottleneck was varied from 1–100 generations ago, prebottleneck size was varied from $N_{ef} = 3333$–19,333 (equivalent to N = 20,000–116,000) in the past, and minimum abundance at the bottleneck was varied from $N_{ef} = 17$–1667 (equivalent to N = 100–10,000 individuals) (Figure 2). The range of original abundance employed in the simulations was derived from today's census size and an analysis of genetic diversity in nuclear introns of gray whales [5], and the range of bottleneck sizes was derived from the highest [18] and lowest [37] estimates available in the literature. Simulations use a generation time of 15.5 years, equal to the median age of reproductive females [38]. The molecular substitution model used (HKY+G) was selected using the program MODELTEST using Akaike Information Criterion (AIC) [39]. A range of mutation rates from $4.00–8.00\times10^{-8}$ bp^{-1} yr^{-1} were employed based on the analysis of [27], which used cytochrome-b data to calibrate rate of substitution in the control region of gray whales. The method used to derive this rate, which is 2 to 4.4-fold faster than the phylogenetically derived rate (e.g. [40]), has been found to be consistent with results obtained in subsequent studies of mammalian rates [41,42,43]. To test the sensitivity of results to mutation rate, we also repeated the analysis using rates derived from Bayesian MCMC analysis of ancient and modern data (see below). We chose sample sizes and ages of samples to reflect our empirical dataset. Simulations were generated in Bayesian Serial SIMCOAL [44,45] and rejection-based ABC was implemented in the statistical package R version 2.0 following the algorithm described in [13]. We performed 1,000,000 simulations with 1000 acceptances. We used five summary statistics (π_{modern}, $\pi_{ancient}$, F_{ST} (ancient-modern comparison), Hd_{modern} and $Hd_{ancient}$) to estimate posterior likelihoods for three parameters: 1) bottleneck time in

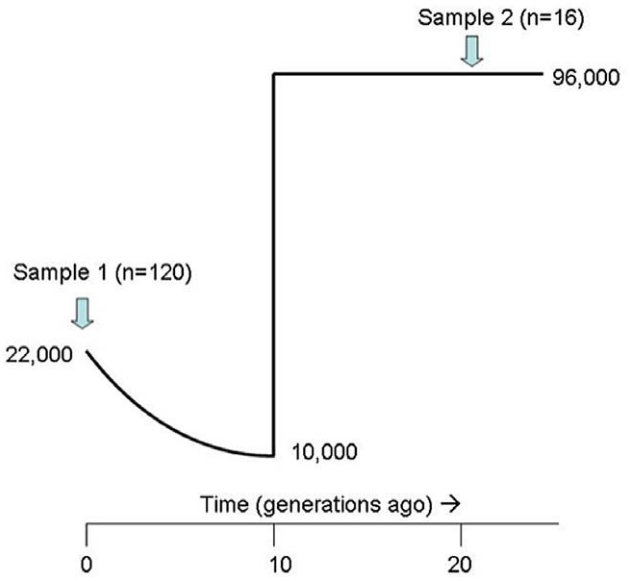

Figure 2. Simulated demographic scenario. The size of the ancient population is assumed to range from 20,000–116,000 (census size). The modern population is assumed to have a census size of 22,000. The size and timing of the bottleneck (pictured here at 10,000 individuals and 10 generations ago) were varied between 100–10,000 (census size) and 1–100 generations ago.
doi:10.1371/journal.pone.0035039.g002

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generations (t_{bot}); 2) minimum size of population ($N_{ef(bot)}$); and 3) pre-bottleneck abundance ($N_{ef(prebot)}$).

In addition, all ancient and 120 modern sequences were used to compare the likelihood of different demographic scenarios in a Bayesian MCMC analysis as implemented in BEAST v 1.5.3. MODELTEST [39] was used to determine the best-fitting substitution model. Based on these results, analyses were run using the HKY+G substitution model with a relaxed molecular clock (uncorrelated lognormal) in order to allow rates to vary among branches [46], and 30,000,000 iterations after a burn-in of 100,000 iterations, with sample ages used in the calibration and a uniform prior on mutation rate of $4.00–8.00\times10^{-8}$ bp^{-1} yr^{-1}. We selected the numbers of iterations and burn-in steps to ensure model convergence, and averaged results over five replicate runs. Both geneaologies and model parameters were sampled every 3000 iterations. Mixing and convergence were determined to be adequate based on the effective sample sizes (ESS) of each parameter, as evaluated in Tracer v. 1.3. We compared the following demographic models: constant population size, exponential growth, and Bayesian skyline plot (BSP) using 10 temporal groups. We compared support for models by calculating Bayes factors using the harmonic means of sampled marginal likelihoods for each model [47]. Additionally, BEAST v1.5.3 was used to assess levels of post-mortem DNA damage and take account of this damage in demographic analyses (see [48]). The potential for such damage to confound demographic analyses is an important consideration in assessing the ability of ancient or historical sequences to shed light on past population processes (e.g. [49]). However, Rambaut et al. [48] showed through simulations that when damage was measured and accomodated in aDNA analyses, evolutionary parameters and demographic reconstructions were correctly recovered.

Finally, we also evaluated past population dynamics using the Bayesian skyline plot (BSP) method of Drummond et al. [8]. In this method, a sample of gene sequences (including sequences sampled at different points in time) is used to estimate effective population size through time, using an MCMC sampling procedure. The method produces credibility intervals that incorporate both phylogenetic error and uncertainty inherent in reconstructing the coalescent process. However, using limited sequence data from a single locus can reduce the power of this method to detect population dynamics in the past [22]. To determine whether our ancient samples were adequate for detecting the signature of a bottleneck in Bayesian demographic analyses, we repeated the analyses on simulated datasets with identical ancient sampling but known demographic histories. We analyzed two demographic scenarios in which bottlenecks were assumed to have occurred at 800 or 1200 ybp (reducing the population from 96,000 individuals to 22,000). All other parameters (such as mutation rate and generation time) were identical to those used in the demographic simulations described above.

Stable Isotope Analysis

In addition to assessing the stable isotope composition ($\delta^{13}C$ and $\delta^{15}N$) of all ancient gray whale samples, we collected bone fragments from modern gray whale bones for the purpose of comparison. Fourteen gray whale bones were analyzed from the USNM collection, Smithsonian Institution. The majority of the USNM samples come from animals harvested in the 1960s and 70s at a California whaling station across different years [38], and are therefore likely represent a random subsample of the population. Bone fragments were demineralized in 0.5 N hydrochloric acid (HCl) for ~12–15 hr at 5°C. The resulting material was treated repeatedly with a chloroform/methanol (2:1) mixture to remove lipids and then lyophilized. Dried samples (~0.5 mg) were sealed in tin boats and analyzed using a Carlo-Erba elemental analyzer interfaced with a Finnegan Delta Plus XL mass spectrometer (Geophysical Laboratory, Carnegie Institution of Washington). Results are expressed as δ values, $\delta^{13}C$ or $\delta^{15}N = 1000[(R_{sample}/R_{standard})\text{-}1]$, where R_{sample} and $R_{standard}$ are the $^{13}C/^{12}C$ or $^{15}N/^{14}N$ ratios of the sample and standard, respectively. The standards are Vienna-Pee Dee Belemnite limestone (V-PDB) for carbon and atmospheric N_2 for nitrogen. Units are expressed as parts per thousand or per mil (‰). Within-run standard deviation of an acetalinide standard was $\leq$0.2‰ for both $\delta^{13}C$ and $\delta^{15}N$ values. As a control for the quality of collagen, we measured the [C]/[N] ratio of each sample; weight percent [C]/[N] ratios of all bone collagen samples were 2.8–3.2, within the theoretical [C]/[N] ratio of unaltered collagen [50]. We applied a correction to all carbon isotope values to account for the global decrease in the ^{13}C proportion of atmospheric carbon dioxide (i.e., "Suess Effect"), due largely to fossil fuel burning, over the last 150 years. Based on ice core records [51], we applied a time-dependent $\delta^{13}C$ correction to historic samples (1912–1975) of -0.005 per mil/year between 1860 and 1960 (n = 1), and -0.022 per mil/year since 1960 (n = 13). This resulted in relatively minor (mean = -0.3‰) $\delta^{13}C$ corrections for the modern samples since most of them (12/14, ~85%) were collected prior to 1970.

Results

We extracted and amplified DNA from 38 of 40 samples. Alignment of control region sequence with baleen whale sequences from NCBI showed that 16 of the 38 sequences grouped with gray whales (remaining sequences grouped with humpack, blue or sperm whales). No exogenous contaminants or mismatches were detected in any of the cloned sequences or sequences from independently extracted specimens. Blind resequencing of a subset (25%) of modern sequences did not yield any sequence discrepancies with NCBI data. Only genetic data from gray whales (383 bp) were used for the remaining analyses.

Genetic Diversity

The level of haplotype diversity across ancient samples (Hd = 0.933) was comparable to that found in modern Eastern samples (Hd = 0.948) and higher than that of modern Western samples (Hd = 0.700) (Table 3). Nine haplotypes were obtained from the sixteen gray whale samples, including three haplotypes previously unobserved in either the eastern or western Pacific populations. These unique haplotypes differed by four (one individual), two (one individual) and one (two individuals) base pair changes from known haplotypes. All but one of these changes were transitions. Values of $\Theta(S)$ and nucleotide diversity (π) were also similar across modern and ancient eastern Pacific samples. Tajima's D values were nonsignificant for all three sets of samples.

Both a haplogroup network constructed using TCS [52], and a neighbor-joining tree constructed using PAUP* [53] show that ancient samples are not distributed randomly across the distribution of modern eastern Pacific samples, but cluster in one part of the network or tree (Figure 3a, 3b). Significant differences in haplotype frequencies were observed between each pair of samples ($p<0.001$). The observed F_{ST} value between modern eastern and ancient eastern was 0.1004 (95% CIs: 0.0640–0.1344). The difference between modern western samples and ancient sequences ($F_{ST} = 0.2794$) was greater than the difference between modern eastern and western sequences ($F_{ST} = 0.1125$).

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Table 3. Summary statistics (±SD) for ancient Eastern Pacific (EP) samples, Modern EP, and modern Western Pacific (WP) samples.

	N	N(H)	Hd	π	θ(S)	Tajima's D
Ancient EP	16	9	0.933±0.035	0.0130±0.0016	0.0127±0.0053	−0.031
Modern EP	120	30	0.948±0.007	0.0191±0.0009	0.0189±0.0041	0.906
Modern WP	45	10	0.700±0.049	0.0187±0.0012	0.0190±0.0045	1.392

N = number of samples; N(H) = number of haplotypes; *Hd* = haplotype diversity, *θ(S)* = Watterson's theta [76]; *π* = nucleotide diversity [77]. Values of Tajima's D were nonsignificant for all samples (p>0.10).

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Coalescent Simulations and Demographic Analyses

Posterior density curves and prior distributions for the three parameters of interest are shown in Figure 4. The maximum a posteriori estimate was for a bottleneck time 6 generations ago (90% highest posterior density interval (HPD) = 5–60 generations). Estimates for minimum abundance ($N_{(ef)bot}$) and pre-bottleneck abundance ($N_{(ef)prebot}$) were translated from units of female effective size ($N_{(ef)}$) to census size (N) using conservative factors to account for sex ratio, the ratio of breeding adults to all adults and the ratio of juveniles to adults [5]. This resulted in maximum a posteriori estimates of N_{bot} = 9,070 (90% HPD = 3,750–9,740) and N_{prebot} = 100,670 (90% HPD:59,940–111,550).

Bayesian MCMC methods as implemented in BEAST can also be used to measure mutation rates directly when ancient data are available [54]. These methods can produce upwardly biased estimates of mutation rates in populations that deviate from simple demographic histories, especially in cases where population bottlenecks have occurred or population structure is or was pronounced [55], as is likely to be the case for the population considered here. However, in order to test the sensitivity of the ABC analysis to a range of rates, we implemented this method to derive control region rates. The Bayesian MCMC method gives a rate of 0.032–0.194 (95% HPD; mean 0.11) substitutions/site/My when applied to this dataset, a wide range that overlaps with the full range of rates used in this study. This broader range of mutation rates with a higher mean value produces a wider range of Ne values with smaller MLEs, resulting in MLEs of N_{bot} = 8,890 (90% HPD = 2,500–9,610) and N_{prebot} = 69,890 (90% HPD:41,220–109,210), and T_{bot} = 13 (90% HPD = 9–68).

We used ancient and modern sequences to compare the likelihood of different demographic scenarios in a Bayesian MCMC analysis. A Bayes factor analysis of sampled marginal likelihoods for each model indicated some support for the Bayesian skyline plot (BSP) model over the demographic models of constant or exponential growth (BF>2). The skyline population trend is also consistent with a recent decline (Figure 5). BSP analyses using simulated datasets showed broad declines that were consistent with the bottleneck dates simulated (e.g. roughly 1200 ybp). However, for both the real dataset and simulated datasets, confidence intervals are extremely wide and the skyline plots do not successfully recreate the most recent fine-scale population dynamics over the past ~150 years (population bottleneck followed by regrowth). The mean rate of post-mortem damage estimated in BEAST was 2.37×10^{-8} errors per base pair (95% highest posterior density interval: 6.99×10^{-12}, 7.25×10^{-8}). This estimated rate is lower than several other D-loop datasets derived from samples of comparable (though generally older on average) age, such as ox (4–8 kya, HPD: 3.87×10^{-7}–8.57×10^{-4}), moa (1–6 kya, HPD: 1.75×10^{-5} to 3.58^{-3}), and musk ox (0–44 kya, HPD: 9.81×10^{-8}–1.91×10^{-3}) [56].

Stable Isotope Analyses

Ancient gray whales had significantly higher mean $\delta^{13}C$ values (ANOVA or pooled T-test, $p<0.05$) than the modern whales (Figure 6); there were no differences in mean $\delta^{15}N$ values. The mean (±SE) $\delta^{13}C$ value for Suess corrected modern (n = 14) and ancient (n = 16) gray whales was −13.7 (±0.2) and −13.1 (±0.1) respectively. The mean (±SE) $\delta^{15}N$ values for modern and ancient samples were 14.2 (±0.2) and 14.7 (±0.2), respectively. For modern samples, for which age and sex were sometimes known, no obvious effects were observed based on these factors (though small sample size prevents a thorough analysis).

Discussion

Ancient gray whale sequences show high genetic diversity, but this diversity is not randomly distributed with respect to today's haplotype distribution (Figure 3). There are at least two potential causes for this non-random distribution: past population structure, and a large demographic bottleneck that resulted in the reshuffling of haplotype frequencies.

Population structure in the past could result in significant genetic differences between modern and ancient whales. All ancient samples were collected from the same geographic area (the Olympic Peninsula) and were likely caught in or outside of the Strait of Juan de Fuca, raising the possibility that this area might have harbored a genetically unique population in the past. This possibility is particularly worth exploring because a small subset of the modern gray whale population uses the Strait of Juan de Fuca and Puget Sound as a summer feeding ground, whereas the large majority of gray whales travel north to the Bering Sea and northward to feed [25]. Photoidentification data shows that at least some of these individuals return year after year to the area to feed (Calambokidis et al. 2002). Though an earlier genetic study found no evidence that these animals represented a unique population [23], a more recent analysis detected slight but significant differentiation between the southern feeding aggregation and the gray whale population as a whole [57].

To explore pre-whaling feeding ecology and test the hypothesis of population structure in the past, we investigated the stable isotope signature of the ancient whales and a set of modern gray whale bones from the USNM collection. We presume the USNM whales, which were mostly collected at a whaling station near Richmond, California in the 1970s, represent a random subset of the population because whales were taken in different years along their central migration route, and thus would carry the isotopic signature of the primary northern feeding grounds. Gray whales are unique among large cetaceans in that they migrate and feed close to shore, typically <80 km [38], and therefore we would not expect distance from shore to be a confounding factor in interpreting isotopic results. If in fact the ancient whales represented a genetically distinct resident aggregation in the past, the most likely scenario is that these whales were feeding in the Strait of Juan de Fuca and Puget Sound, which would result in different isotopic signature due to differences in foraging latitude. Phytoplankton and dissolved organic matter $\delta^{13}C$ and $\delta^{15}N$ values are negatively correlated with latitude in the northeast Pacific Ocean [58,59,60]; temperate latitude systems (e.g., California Current) have higher isotope values by ~1–2% than high latitude

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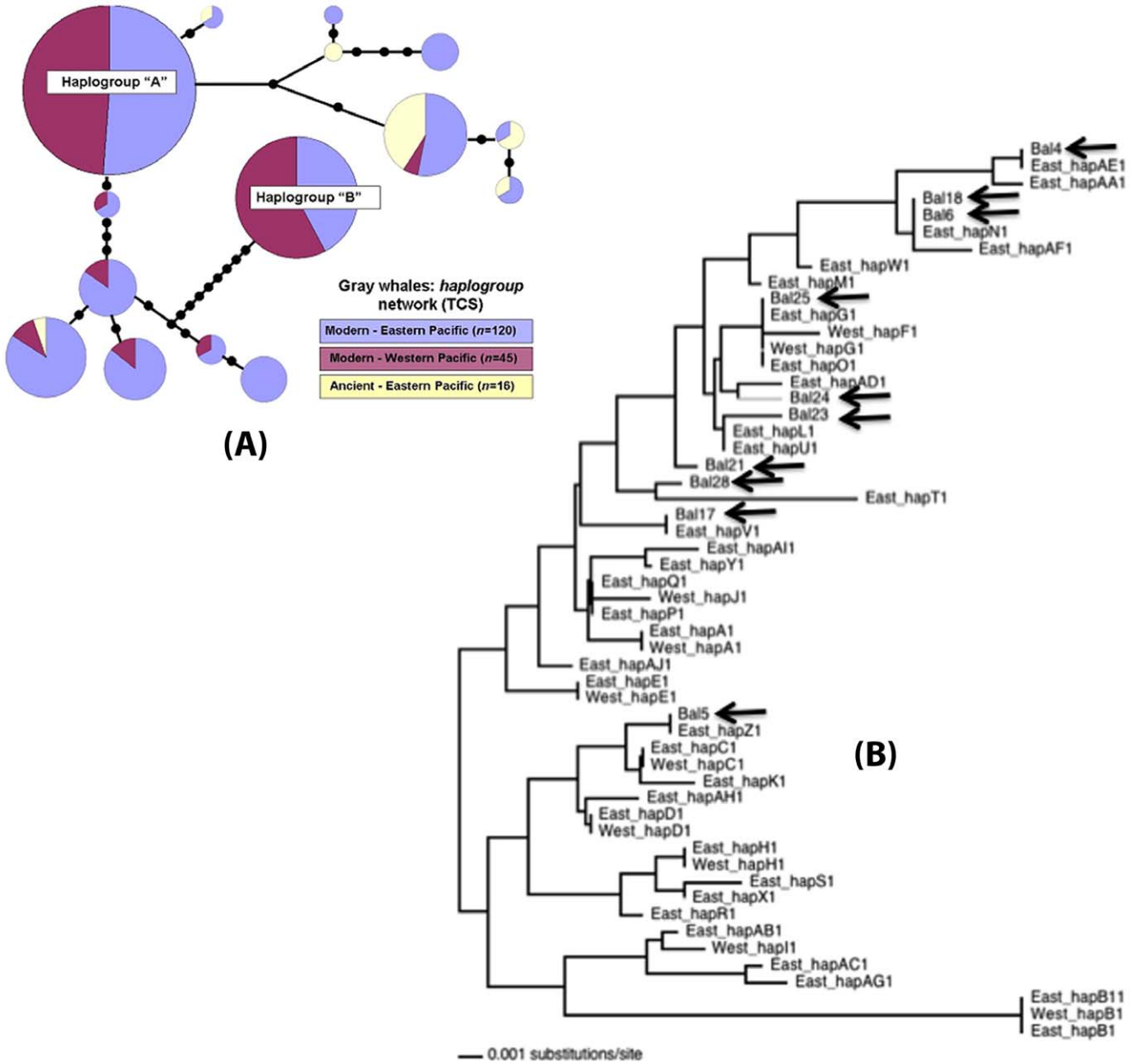

Figure 3. Phylogenetic network and tree constructed from modern and ancient gray whale haplotypes. (**a**) Haplogroup network for ancient eastern Pacific and modern eastern and western Pacific samples (constructed in TCS [52]). Haplogroups were defined by grouping together sequences with one or zero differences. (**b**) Neighbor-joining (midpoint-rooted) tree using ancient and modern haplotypes from PAUP* [53]. The HKY85 model [75] was used to correct genetic distances. Ancient samples have the prefix BAL and are denoted with an arrow. Each haplotype is represented only once in the tree.
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systems (e.g., Bering Sea). As such these isotopes have been used extensively to examine differences in foraging latitude in modern and ancient marine mammals [14,15,61,62], After correcting for the Suess effect, we found slight but significant differences in mean $\delta^{13}C$ values between the two groups; mean $\delta^{15}N$ values were not significant. Assuming ancient and modern groups forage at similar trophic levels, the overall isotopic pattern is in agreement with that expected if ancient Ozette gray whales foraged in lower latitude waters than the modern group, which is known to forage at high latitudes in the Bering Sea. Thus, it remains possible that at least a subset of these whales were occasional summer residents in the area, particularly in light of the recent analysis by [57]. However, the small observed isotopic differences in $\delta^{13}C$ and $\delta^{15}N$ and small sample sizes suggest that drawing a firm conclusion about geographic structure from these isotopic data would be premature. Finally, it is also possible that the ancient whales from Ozette represent a genetically unique population, due to structuring along another ecological axis other than feeding. Further tests of the hypothesis of population structure in the past will require additional ancient samples from this region and new locales.

We tested the second possible cause for nonrandom distribution of ancient haplotypes, a demographic bottleneck, using serial coalescent simulations and rejection-based Approximate Bayesian Computation approach. We selected demographic scenarios used

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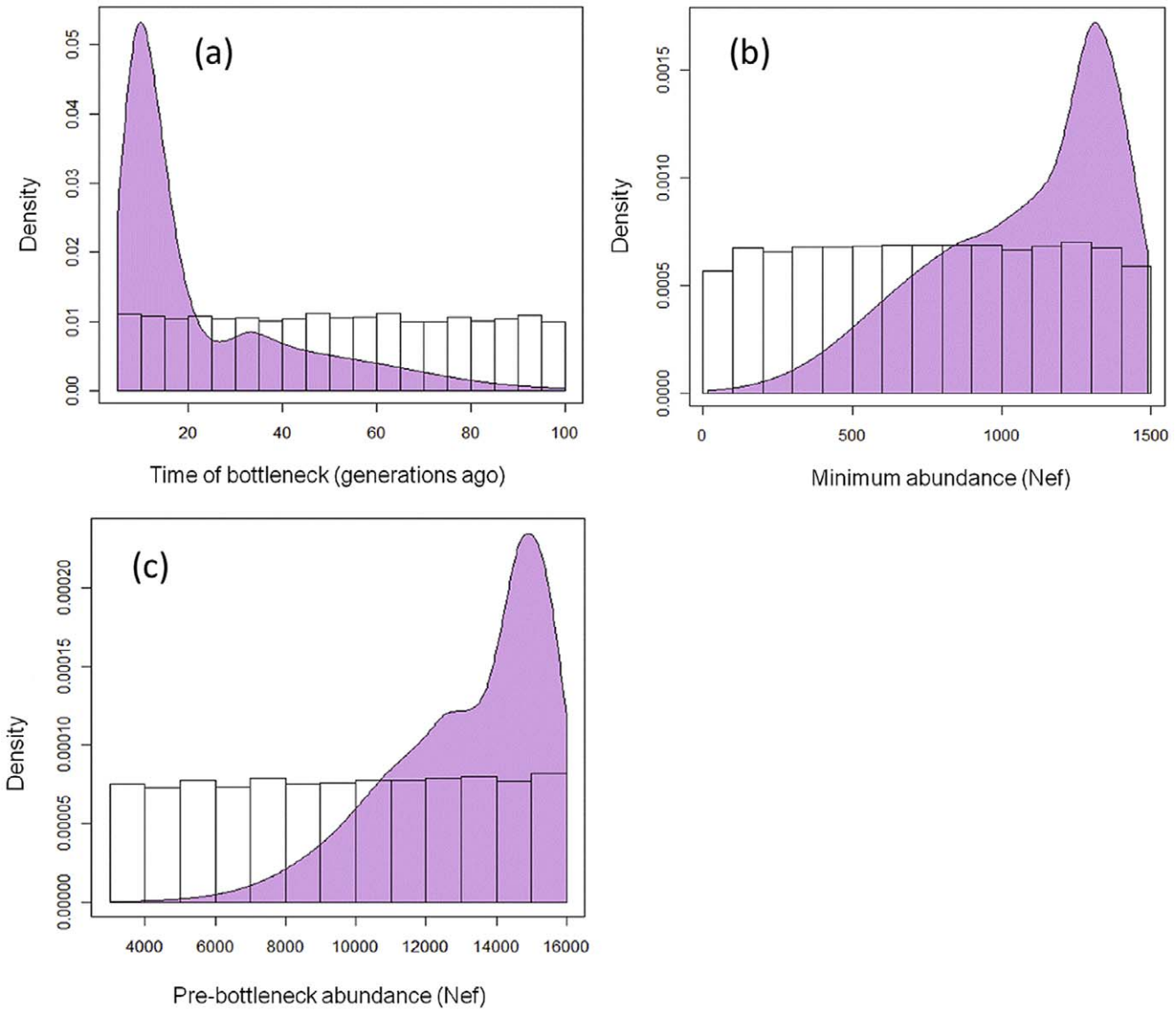

Figure 4. Posterior density distributions for Approximate Bayesian Computation results. Based on ancient eastern Pacific and modern eastern samples (shaded area) and prior uniform sampling distributions based on one million iterations for (a) time of bottleneck in generations (t_{bot}); (b) minimum female effective population size at bottleneck ($N_{ef(bot)}$); and (c) pre-bottleneck female effective population size ($N_{ef(prebot)}$).
doi:10.1371/journal.pone.0035039.g004

in coalescent simulations by using a range of values of population size in the past and today from census [63] and genetic data [5], and exploring potential bottleneck dynamics that might have occurred in the interim. These analyses demonstrate that a subset of demographic scenarios are most likely to produce the observed summary statistics in modern and ancient samples. In particular, the observed F_{ST} value can result from a bottleneck followed by rapid population growth. Simulations demonstrate that, as expected, more severe bottlenecks create higher F_{ST} values. Results indicate highest support for a population bottleneck that between 5–60 generations ago (90% HPD), with a maximum likelihood estimate of 93 years or 6 generations, which roughly corresponds to the end of the central period of commercial whaling (Figure 4). Little is known about the size of the gray whale population during the height of industrial whaling around 1890, though it is known that the population was determined to be "commercially extinct" [16]. Previous estimates vary from 150 based on visual census [37] to 10,000 based on population models [18]. Simulation results give an MLE of 9,070 (90% HPD: 3,750–9,740), much closer to the latter value. This larger estimate is in agreement with the rapid growth of the gray whale population during the last half of the 20th century, and brings estimates of pre-whaling abundance from whaling records (which reflect whales killed in addition to the number of individuals remaining at the bottleneck) into slightly closer alignment with those from genetics. The posterior distribution of pre-bottleneck census size (MLE = 100,670, 90% HPD:59,940–111,550) is higher than those estimated from whaling records, and corresponds to the distribution of 96,000 (78,000–116,000) previously estimated from a separate genetic dataset (nine nuclear introns and cytochrome-*b*; [5]).

In addition to the simulation approach, we used a Bayes factor analysis to determine which demographic model (constant, exponential growth, or Bayesian skyline plot) provided the best

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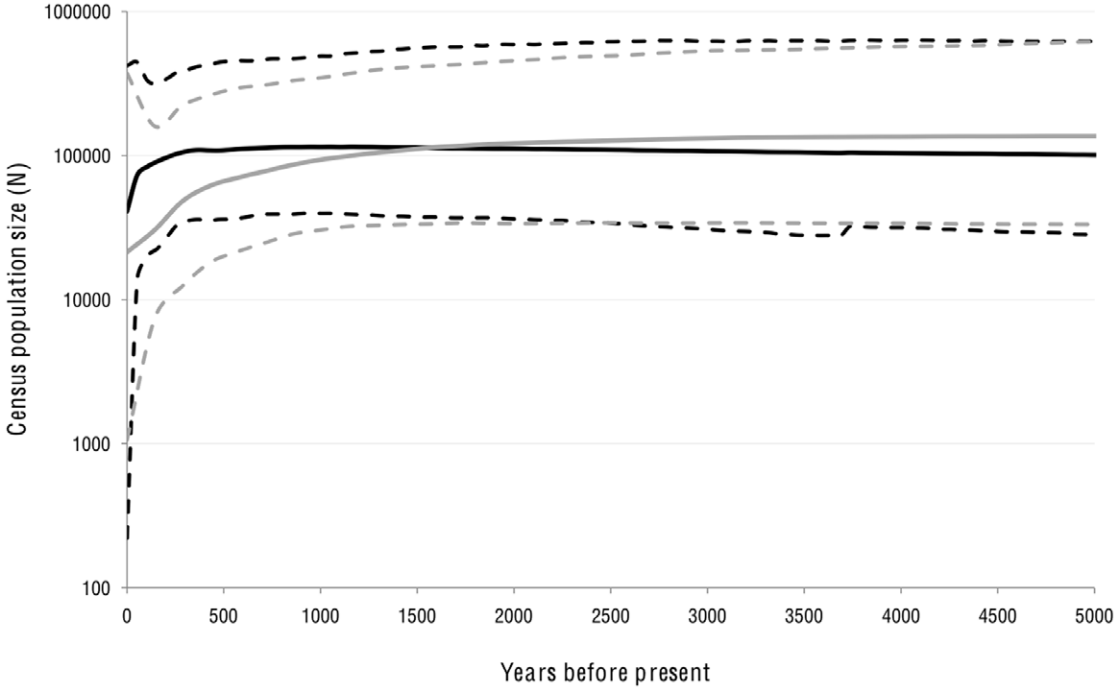

Figure 5. Bayesian skyline plots using empirical ancient and eastern Pacific modern datasets. (black solid line = median; black dashed lines = 95% highest posterior density intervals (HPDIs)), and for a simulated dataset in which bottleneck from 96,000 to 22,000 individuals occurred 1200 ybp (gray solid line = median; gray dashed lines = 95% HPDIs). BSP results were averaged across five replicate runs. NB: The BSP analysis used here assumes a single panmictic population.
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fit to the data. The BSP provided a better fit than the other two models (BF>2), suggesting a population decline. The skyline plot analyses based on modern and ancient control region sequences are consistent with a recent decline, and there is no indication of an earlier major decline. Though the possibility remains that our dataset violates the assumption of panmixia, previous studies indicate that skyline plots are relatively robust to such violations [8,11]. The BSP analysis also successfully reconstructed earlier

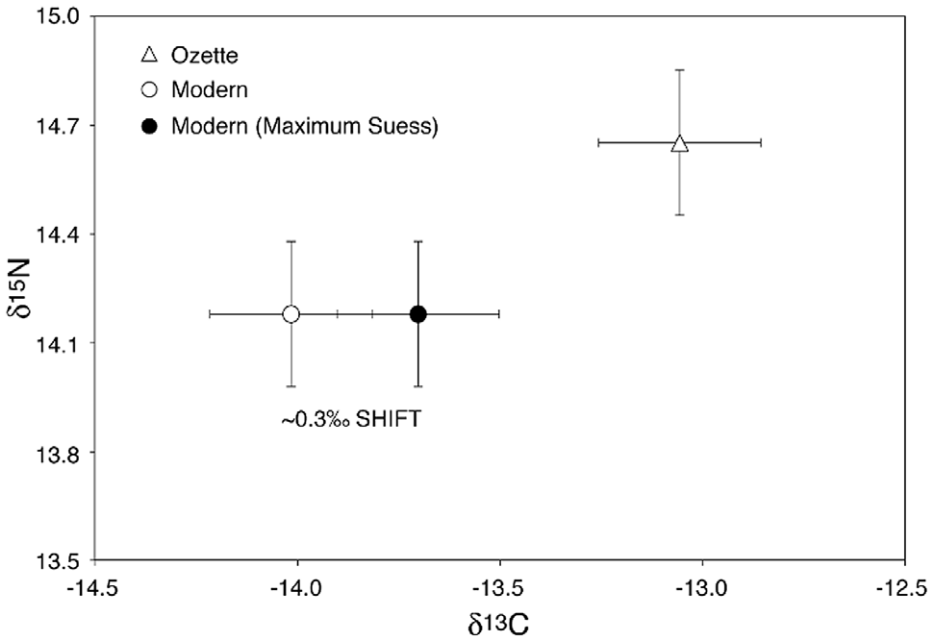

Figure 6. Mean stable isotope values for modern (USNM), modern corrected (USNM (maximum Suess)) and ancient (Ozette) samples; error bars represent standard errors. No significant overall difference between ancient and modern samples is observed once modern samples are corrected for the Suess effect. The Suess effect results in an average shift in $\delta^{13}C$ of 0.3%.
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hypothetical declines in simulated datasets using the same sample size and age distribution as in our empirical dataset, indicating that if a decline from 100,000 to 20,000 individuals occurred earlier in the Holocene, we would expect to detect it with our dataset. However, in both cases credibility intervals are large due to small ancient sample size and uncertainty inherent in the coalescent process and phylogenetic reconstruction, limiting the inferences we can draw from these results. In addition, previous analyses of ancient DNA datasets using Bayesian skyline plots (e.g. [8,11]) and bowhead whales [64] indicate that this methodology was unable to reconstruct very recent declines or bottlenecks. Additional loci and ancient samples would be needed to gain enough statistical power to quantify very recent bottlenecks with confidence.

Estimating demographic parameters from genetic data requires the estimation of evolutionary rates and other uncertain factors. Recent studies have suggested mtDNA mutation rates estimated from phylogenetic data are inappropriate for intraspecific studies because of time dependency of molecular rates (older calibration points produce slower clock rates) [54,65]. In this study, we addressed this problem by using a range of evolutionary rates derived from intraspecific calibration of the control region based on variation at a linked locus [27]. This method utilizes more recent calibration points and is thus better able to detect multiple hits/homoplasy, a common feature of the mammalian control region that may contribute to differences between pedigree-based and phylogenetic rate estimates [66]. Bayesian MCMC methods have been used to measure mutation rates directly when ancient data are available [54], but simulation studies found these methods can overestimate the true rate for populations in which bottlenecks have occurred or those with pronounced structure [55] (however, it is important to note that some of the simulation scenarios used in the latter study included non-representative sampling). In addition, a recent study found that some ancient DNA datasets, including bowhead whale, produced artifactual rate estimates as a result of low information content among other factors including sequence ages [67]. For this reason, we consider the range of rates derived from intraspecific calibration [27] to be the best available estimates for use in this analysis, in the absence of a molecular rate curve [46] for baleen whale species.

Additional uncertainties in the estimates of total population size (N) arise from other parameters needed for the analysis, including the ratio of breeding adults to total adults (Ne/N), generation time, the sex ratio and the ratio of juveniles to adults. While gray whale-specific estimates exist for the latter two values, Ne/N is very poorly known for most species [68]. A review of empirical studies suggested that the number of breeding individuals in a population is typically an order of magnitude below the total number (averaging 0.10–0.11), and that Ne/N rarely falls above 0.5 in natural populations [69]. Theoretical analyses suggest that Ne/N approaches 0.5 in most populations with constant size [70]. Factors that can reduce Ne/N include uneven sex ratios, population bottlenecks and variance in reproductive success (e.g. [71,72]). In this analysis, we used a conservative estimate of Ne/N (0.5), which will produce smaller estimates of total population size; however, it is important to recognize the additional uncertainty introduced by this calculation. While empirical and theoretical studies indicate that this value is unlikely to be an underestimate for gray whales, it is possible that the true Ne/N ratio might be much smaller. Likewise, generation time is difficult to measure with precision in wild populations, and may not necessarily be stable across evolutionary time scales. In this analysis, we use a standard definition of generation time, calculated as the mean age of reproductive females, assuming no decline in fecundity with age [68]. A decline in fecundity with age would reduce the estimated generation time, causing a proportional increase in the population size estimated from genetic data. If, on the other hand, the average generation time of gray whales across the last several thousand years was greater than estimated here (for example if whaling caused average generation time to decrease), it would cause a proportional reduction in DNA-based N_e estimates. These caveats regarding life history parameters underscore the uncertainties associated with inferring population size and dynamics from genetic data, which have been discussed in depth in previous works (e.g. [6,7,73]).

Overall, the genetic evidence presented here supports the hypothesis that gray whales experienced a major population decline, and that this reduction occurred recently. Stable isotope results show only very slight differences between ancient and modern whales, indicating the hypothesis of population substructure in the past around the area of the Olympic peninsula/Vancouver Island remains a possibility and warrants further investigation using larger sample sizes. Though our ability to infer what was surely a complex demographic history is limited by the number of ancient samples available and large uncertainties associated with the coalescent and evolutionary processes, these first ancient data for gray whales demonstrate the value of paired genetic and isotopic studies of ancient samples, showing that a population bottleneck can result in significant genetic differentiation between ancient and modern samples without requiring spatial structure. Both demographic simulations and coalescent analyses indicate that genetic data are consistent with a recent bottleneck and a pre-bottleneck size of >ca. 60,000. Recent models of gray whale carrying capacity during the Pleistocene suggest that enough benthic habitat existed to support a population of this size [74]. Future exploration of the impacts of population structure (particularly between eastern and western populations) and analysis of whaling records may be informative regarding the unresolved discrepancy between whaling estimates and genetic estimates of historic abundance. Understanding the causes and extent of the decline in marine species is important to their future management and aids in reconstructing the past states of ocean ecosystems. The analyses presented here corroborate an emerging body of evidence demonstrating historic baselines for many marine populations much larger than previously estimated.

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Author Contributions

Conceived and designed the experiments: SEA. Performed the experiments: SEA SDN. Analyzed the data: SEA SND. Contributed reagents/materials/analysis tools: SEA SDN SRP. Wrote the paper: SEA SDN SRP.

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BY ROY C. ANDREWS.

MARCH, 1914.

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I.—THE CALIFORNIA GRAY WHALE (*RHACHIANECTES GLAUCUS* COPE).

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MEMOIRS

OF THE

AMERICAN MUSEUM OF NATURAL HISTORY.

THE CALIFORNIA GRAY WHALE (*RHACHIANECTES GLAUCUS* COPE).

ITS HISTORY, HABITS, EXTERNAL ANATOMY, OSTEOLOGY AND RELATIONSHIP.

By Roy C. Andrews.

Plates XIX–XXVII and 22 Text Figures.

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HISTORY, HABITS AND EXTERNAL ANATOMY.

Foreword.

The present paper is the first of a series of monographs which are in course of preparation upon the large Cetaceans of the Pacific Ocean. The collection of specimens and field studies upon this group began in 1908 upon the coasts of Vancouver Island and southeastern Alaska and has since been carried on along the shores of Japan and Korea.

It was originally intended to embody all the results of these investigations in a single volume but continued field work and many interruptions have so delayed the assembling of the vast amount of data secured that it has seemed advisable to bring out the material upon each genus or species as fast as it is prepared for publication.

Acknowledgments.

It gives me the greatest pleasure to acknowledge the generosity and assistance of the President and Directors of the Toyo Hogei Kabushiki Kaisha (Oriental Whaling Co., Ltd.) of Osaka, Japan. Not only did these gentlemen freely extend the courtesies of their ships and stations but presented to the Museum the skeletons of the whale which forms the subject of the present paper. At all times the officers and employees of the Toyo Hogei Kaisha assisted me in every way possible, and it was entirely through their efforts that field studies and the collection of specimens was made possible.

To the untiring efforts of my friend Mr. D. Ogiwara, formerly an officer of the whaling company, much of the success of my two expeditions to Japan is due. Mr. Ogiwara, who is deeply interested in the advancement of science, not only rendered great practical assistance but always stood ready to give me the benefit of his sound advice and intimate knowledge of Japanese business methods.

Mr. T. Shibuya, Manager of the Shimonoseki branch of the Toyo Hogei Kaisha, was of the greatest assistance in many ways, especially in securing the two skeletons of *Rhachianectes* which were shipped to America.

Mr. Kondo, the station master at Ulsan, Korea, and Mr. T. Matsumoto, his assistant, deserve the greatest thanks not only for contributing materially to my study but also for making my stay in their home most enjoyable as well as profitable.

Thanks are also due to Messrs. Oto, Iku Kita, E. J. Kitson and S. Reed for assistance in various ways.

Captain H. G. Melsom of the S.S. 'Main' was my constant companion at Ulsan. Not only did he entertain me frequently upon his ship but contributed much information from his vast store of knowledge and long experience with Gray Whales. Captain Melsom was the first whaleman to learn to take "Devilfish" in Korean waters and it was he who laid the foundation for the winter fishery which has been so successfully prosecuted there by the Japanese for the last fifteen years. Captains Johnson and Hurum also entertained me frequently and gave me much valuable information.

Sincere thanks are due to Mr. Chas. L. Bernheimer of New York City for generous financial assistance during the field work upon which this paper is based.

During the years 1880–1882, Dr. J. A. Allen began work upon an extensive monograph of the Cetacea. A vast amount of material was examined and numerous plates were prepared by the well known artist, Mr. J. H. Blake. Because of ill health, however, this work was later abandoned and has remained in manuscript to the present day with the exception of the portion relative to *Eubalæna glacialis*, which was published in 1908.[1] Dr. Allen has very kindly offered me the use of this material and so far as possible it will be combined with the results of my own research. For the present paper the only available portion was that of the "general history" from the years 1868 to 1879. It is also a pleasure to acknowledge Dr. Allen's invaluable assistance and advice in preparing this paper for the press.

Dr. F. W. True has not only read portions of the manuscript but has devoted considerable time to an examination with me of the fossil genera of baleen whales in relation to *Rhachianectes*, and I was thus afforded the benefit of his thorough knowledge of this difficult material. For his never-failing kindness I wish to express my sincere appreciation. My thanks are also due to Dr. W. K. Gregory for much advice and many valuable suggestions.

My mother, Mrs. C. E. Andrews, kindly prepared the table of percentage measurements and assisted me in other ways, and to her my sincerest thanks are extended.

The photographs of the skull and skeleton were made by Mr. Julius Kirschner, the Museum photographer.

Introduction.

Knowledge of the habits and external anatomy of the California Gray Whale has rested almost exclusively upon the observations of Captain C. M. Scammon made nearly forty years ago. Shortly after the publication of his book 'The Marine Mammalia,' in 1874, the Gray Whale fishery began to decline and for several years was conducted only in a desultory manner by a number of Portuguese upon the shores of Lower California. During the past twenty years the species had been lost to science and many naturalists believed it to be extinct.

While studying Cetaceans upon the coast of Japan in 1910, the writer learned from the Japanese whaling company of the existence of an animal known as the *Koku kujira* or "Devil-fish," which formed the basis of their winter fishery upon the southeastern shore of Korea.

The descriptions indicated that the *Koku kujira* would prove to be none other than the lost California Gray Whale and I determined to investigate it at the earliest opportunity. Consequently, during the winter of 1911–12, I returned to the Orient and spent the months of January and February at the station of the Toyo Hogei Kaisha at Ulsan, a small village on the southeastern coast of Korea, forty miles north of Fusan.

During this time fifty or more Gray Whales were taken and it was possible to make a careful study of the habits and external characters of the species. Skeletons of two adult individuals were also secured, one of which was sent to the American Museum of Natural History in New York City and the other to the U. S. National Museum at Washington, D. C.

These are the first skeletons of this species to be preserved in any American Museum and are, moreover, the only *complete* specimens in the world.

The British Museum of Natural History, South Kensington, England, contains a skeleton and a second is to be found in the Imperial Museum of Tokyo, Japan. There is also one skull of the Gray Whale from California in the United States National Museum.

[1] Bull, Amer. Mus. Nat. Hist., Vol. XXIV, Art. XVIII, pp. 277–329, pls. xix–xxiv.

The study of this animal has been especially interesting since it was almost an untouched field. The fact that the most diligent search of the literature of the subject discloses only 23 titles, and that the great majority of these papers are either short notices or compilations, indicates how little this whale, which is among the most remarkable of all large Cetaceans, has been studied.

General History.

"The California Gray whale was first introduced into scientific literature by Professor Cope in 1868 [1] under the name *Agaphelus glaucus*. For our first knowledge of its characters, however, we are indebted to Dr. W. H. Dall whose manuscript notes, outline figures and specimens of baleen transmitted by him to the Museum of the Essex Institute (now the Museum of the Peabody Academy of Science), Salem, Mass., formed the basis of Professor Cope's description. Dr. Dall's notes and figures were based upon an examination of two specimens, and though very incompletely indicating the characters of the species, were sufficient to show it to be one not previously described.

"Shortly afterward the external characters were quite fully given by Captain Scammon together with a detailed account of the habits, habitat and products, and of the California coast whaling of which it formed the chief basis. Captain Scammon's account was accompanied by two rough figures of the animal. At the same time the species was made the basis of a new genus (*Rhachianectes*) by Prof. Cope.[2] Captain Scammon's account was substantially republished in 1871 in the 'Overland Monthly' magazine,[3] and in 1874 was incorporated into his 'Marine Mammals' [4] with, however, much additional matter and new and creditable illustrations. In 1871 Pechuel-Losch gave a short account and figure of the animal in his 'Wale und Walfang' [5] but added nothing of importance to its history as given by Scammon in 1869. In 1870 Professor Van Beneden thus refers to the genus *Rhachianectes:* 'Si ce genre ne repose pas sur une balénoptère mutilée, c'est-à-dire qui a perdu sa nagoire dorsale, c'est une des plus belles découvertes qui aient été faites depuis bien longtemps en Cétotologie." [6]

"In view of Scammon's history of the species, the doubt here expressed has a strange aspect, but happily he later had abundant opportunity of satisfying himself that his doubt was groundless and it was also his good fortune to publish in 1877 the first description and figure [7] of the skull of the 'California Gray' from photographs, transmitted by Dr. O. Finsch." [8]

In 1879, Professor Cope examined at San Francisco, a "schooner-load of bones" of this species brought from Scammon's Lagoon, Lower California, to be ground up and sold as fertilizer and says: "Having examined a large number of the bones I can complete the characters of the genus *Rhachianectes*,[9] which have been but imperfectly known. The cervical vertebræ are all

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[1] Proc. Acad. Nat. Sci. Phila., 1868, pp. 225–227.
[2] *Ibid.*, 1869, pp. 15, 40–49, figs. 7, 8.
[3] Vol. VI, No. 2, Feb. 1871, pp. 118–125.
[4] The Marine Mammals of the North-western Coast of North America, by Charles M. Scammon, 1874.
[5] Das Ausland, 1871, pp. 1185–1186.
[6] Ostéographie des Cétacès, livr. 8, 1870, p. 235.
[7] Bull. de l'Acad. de Belgique, 2me Sér., T. XLIII, 1877, pp. 92–96, pl. 1.
[8] J. A. Allen, manuscript notes.
[9] Professor Cope's original reference to the genus, embraced in four lines, is as follows: "This genus is now first characterized. Its only known species I originally united with Agaphelus Cope, but the form of the scapula is so different that it must be distinguished. While that of Agaphelus is identical with that of Balænoptera, it is in the present genus quite like that of Balæna." — Proc. Acad. Nat. Sci. Phila., 1869, p. 15.

distinct, and the second and third at least enclose a vertebral canal. A first rib (the only one not broken up) has two heads; two other short ribs, perhaps first and second, are united distally into a broad sheet of bone. It is uncertain how far the union of these ribs is constant. The scapula has both coracoid and acromion. The orbital process of the frontal is of medium width, somewhat as in some species of *Megaptera*." [1]

A. W. Malm [2] described in 1883 fragments of the skeleton of *Rhachianectes* secured by the 'Vega' Expedition and figured parts of the skulls of several individuals.

In 1886 Charles H. Townsend published in the 'Bulletin of the United States Fish Commission' a brief report upon the condition of the Gray Whale fishery at that time along the coast of California and remarks: "Of the eleven whaling stations mentioned by Scammon as established along the coast ten or twelve years ago, only five remain...." In commenting upon the numbers of the Gray Whale, he says: "At the San Simeon station in December, 1885, I could see whales blowing almost every hour during the day. From the elevated 'look-out,' or observation station, on shore an extensive stretch of ocean could be examined with the telescope. During my stay, and for a short time afterward, covering a period of fully a month, Mr. Clark counted forty whales passing southward. Many of these were too far off shore to be pursued by the three boats that were daily cruising outside during the season, and a few may have been other species than gray whales, but counting the forty whales actually seen in December and doubling that number to include those that passed at night during the same period, we have eighty whales per month easily accounted for. Doubling this number again to include those which pass within sight of the lookout station in January (for the 'down season' lasts two months), we have one hundred and sixty whales as the number that may readily be seen at the present time from one point alone during the 'down season.' What proportion this number bears to the number passing off shore would be hard to say, but it is certainly less than half, since the whales near the coast are mostly females seeking bays and lagoons in which to bring forth their young, which would leave the males and young whales unaccounted for.

"These safe and obviously low estimates, and the above table showing the actual catch during the past three seasons, afford a very fair showing for a species so scarce in 1880 that only one individual could be captured, and indicate a tendency towards its re-establishment while unmolested in its breeding resorts." [3]

In the 'American Naturalist' for 1888, John Dean Caton [4] gave a popular compiled account of the Gray Whale and its habits, and twelve years later F. E. Beddard [5] very briefly described a skeleton of this species in the British Museum.

The last contribution to our knowledge of this interesting animal was made by Dr. F. W. True [6] in 1904. Dr. True summarized the existing facts relative to the external and internal anatomy of *Rhachianectes glaucus* with enlightening critical comments and also presented detail measurements and photographs of the Monterey skull in the National Museum.

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[1] American Naturalist, Vol. XIII, Oct. 1879, p. 655.
[2] Bihang K. Sven. Vet. Akad. Handl., Vol. VIII, No. 4, 1883, pp. 17–37.
[3] Bull. U. S. Fish. Comm., Vol. VI, 1886, pp. 346–350, pls. vi, vii.
[4] American Naturalist, Vol. XXII, 1888, pp. 509–514.
[5] A Book of Whales, 1900, pp. 168–170.
[6] Smiths. Contrib. to Knowledge, Vol. XXXIII. The Whalebone Whales of the Western North Atlantic, 1904, pp. 287–292, pl. 47 and pl. 49, fig. 3.

Life History.

Migration.— The Gray Whales begin to appear at Ulsan, southeast Korea, about the end of November on their southward migration. Single pregnant females come first and a little later both males and females are seen but the latter considerably outnumber the former. About January 1, schools of from ten to fifteen males, with perhaps one or two females, appear, the female always leading. From the 7th to the 25th of January, when the migration is completed, only males are present, the females all having passed.

In November and December, when the females are taken, almost every individual will be found to be carrying young nearly ready for birth. As these would necessarily be delivered within two or three weeks after passing Ulsan, the birth must occur in the bays among the numerous small islands at the extreme southern end of the peninsula. Indeed Captain H. G. Melsom, who has hunted Gray Whales for fifteen years along the Korea coast, has often observed them in this vicinity, but because of the abundance of other and more valuable species, they are not killed at this time by the Japanese. When travelling southward the whales are always hurrying straight ahead as though anxious to arrive at the breeding grounds and are never accompanied by small calves; upon the northward migration, however, young have been seen following their parents.

The "Devilfish" again arrives at Ulsan, travelling north, about the middle of March and by the 15th of May they have all passed by. Although the greater portion of the herd goes straight northward, Captain Melsom reports that during the end of April and first week of May he has observed many Gray Whales in Broughton Bay, Korea; these animals seemed to be feeding and had apparently broken the migration by a sojourn in the bay.

A comparison of these observations upon the Korea whales and those made by Scammon on the California coast is interesting. It shows that the breeding grounds of the two herds are in very nearly the same latitude and that their migration dates correspond closely. In regard to this Scammon writes: "The California Gray whale is found only in north latitudes, and its migrations have never been known to extend lower than 20° north. It frequents the coast of California from November to May. During these months the cows enter the lagoons on the lower coast to bring forth their young, while the males remain outside along the seashore. The time of gestation is about one year. Occasionally a male is seen in the lagoons with the cows at the last of the season, and soon after both male and female, with their young, will be seen working their way northward, following the shore so near that they often pass through the kelp near the beach. It is seldom they are seen far out at sea. This habit of resorting to shoal bays is one in which they differ strikingly from other whales. In summer they congregate in the Arctic Ocean and Okhotsk Sea. It has been said that this species of whale has been found on the coast of China and about the shores of the island of Formosa, but the report needs confirmation.[1]

"In October and November the California Grays appear off the coast of Oregon and Upper California, on their way back to their tropical haunts, making a quick, low spout at long intervals; showing themselves but very little until they reach the smooth lagoons of the lower coast, where, if not disturbed, they gather in large numbers, passing and repassing into and out of the estuaries,

[1] From personal observation and the statements of the whalers, I doubt if the Gray Whales migrate far south of the peninsula of Korea. During my own travels along the China and Formosa coasts, I have neither seen nor heard of Gray Whales. R. C. A.

or slowly raising their colossal forms midway above the surface, falling over on their sides as if by accident, and dashing the water into foam and spray about them. At times, in calm weather, they are seen lying on the water quite motionless, keeping one position for an hour or more. At such times the sea-gulls and cormorants frequently alight upon the huge beasts. The first season in Scammon's Lagoon, coast of Lower California, the boats were lowered several times for them, we thinking that the animals when in that position were dead or sleeping, but before the boats arrived within even shooting distance they were on the move again" (*l. c.*, pp. 22–24).

As yet it is impossible to state whether or not the Korea and California herds mingle in the north during the summer. Information gathered from the whalers tends to show that a large part of the former herd summers in the Okhotsk Sea and the latter in Bering Sea and further north. Individuals of the two herds may mingle and interbreed during their sojourn in the north, but it is probable that whales which have been born near either the Korea or California coasts will find mates among the members of their own herd during the southward migration and return annually to their birth place. It is quite conceivable that the case of the Gray Whale may be analogous to that of the Fur Seal where it has been shown conclusively that members of the American and Japanese herds do not mingle in the north although separated by comparatively few miles of water at certain times of the year.

Period of gestation and rate of growth.— Because of its regular annual migrations the period of gestation of this species can be more nearly determined than in the case of most other large whales, and appears to be about one year. Mating probably takes place in the south during December or early January, and the calf is ready for delivery the following year.

As stated above (see 'Migration'), the females which appear at Ulsan, Korea, travelling southward are nearly all bearing calves almost ready for birth. Upon the return journey the females are accompanied by young calves, and Capt. H. G. Melsom writes that he killed on March 13 and 14, 1912, at Chan Chien Dogo (near Broughton Bay), Korea, upon their northward migration, two females bearing fœtuses 7 and 10 inches long, respectively. These fœtuses were probably not more than $2\frac{1}{2}$ months old, which would indicate that the mating had taken place late in the previous December and that the calves would be delivered the following December or January when the whales returned to the south. A female 1300 cm. (42′ 8″) in length taken at Ulsan, Korea, on January 8, 1912, contained a fœtus 476 cm. (15′ $7\frac{1}{2}$″) long, and ready for birth; it would certainly not have been carried more than a week or ten days longer.

Whether or not the females again mate immediately after giving birth to their young it is impossible to state, but from Scammon's observations, quoted below, I believe it to be unlikely and that calves are born but once in two years.

Scammon says that the period of gestation is about one year, and remarks: "This statement is maintained upon the following observations: We have known of five embryos being taken from females between the latitudes of 31° and 37° north, on the California coast, when the animals were returning from their warm winter haunts to their cool summer resorts, and in every instance they were exceedingly fat, which is quite opposite to the cows which have produced and nutured a calf while in the lagoons; hence we conclude that the animals propagate only once in two years" (*l. c.*, p. 23, note).

Mr. C. H. Townsend, writing in 1886 of the San Simeon (Cal.) station, says: "Unlike Monterey, this station depends almost entirely for its business upon the gray whales, which pass southward with great regularity from December until February. The 'up season,' lasting until

April, is also profitable at San Simeon, but the catch there consists chiefly of males, the females keeping farther off shore when passing northward with their young. During the last ten years Captain Clark has seen but one female accompanied by young in the vicinity of his station. At San Simeon, and all the whaling establishments situated south of it, females exceed the other sex in numbers during the 'down run' and most of them contain well-developed young. At this place and at San Luis Obispo, the nearest neighboring station, I saw four young whales lying on the beach, which had been taken from females killed in the vicinity during that season (December, 1885). Their average length was about 12 feet; the largest, which I sketched, being 17 feet long, and from an adult nearly 40 feet in length. They were probably within two weeks of the time of birth when the parent animals were killed" (*l. c.*, pp. 347–348).

From the above data it may be safely affirmed that the length at birth of the majority of Gray Whales is between 12 and 17 feet. When the females go north in March on the Korea coast, the calves which have been born near the end of the previous December accompany them, and by the time they reach Ulsan are about twenty-five feet in length, This makes a growth of nine or ten feet during a little less than three months. This may seem extraordinary, but it is quite in accord with what apparently takes place in all baleen whales. Without doubt the rate of growth for the calf is very rapid during the first few months after birth and until sexual maturity is reached.

Thirty-two feet is the minimum length for Gray Whales taken at Ulsan, and individuals of this size must certainly have been born during the previous winter. Thus, accepting 14 feet as the average length at birth, we get a growth of 18 feet during a little less than one year.

How long the young nurse is problematical but it must be considerably less than one year because, so far as I am aware, nursing calves or females have not been taken at Ulsan on the southward migration, and some would certainly have been brought in if the suckling period was not over before the animals reached that point upon the coast.

Spouting and diving.— The height and form of the spout varies with conditions. Normally the vapor rises vertically ten or eleven feet in a thick column having the width at the summit about twice that at the base (Plate XXIV, Fig. 7). It may, however, reach a height of fifteen feet if the whale is large and has been submerged for a considerable period. The spout is single in the majority of cases, but Captain Melsom asserts positively that at times it is divided like that of a Right Whale. As in all Cetaceans the initial spout after a period of submergence is generally the highest and fullest.

The number of respirations between the dives is fairly regular. When the whale has been below for several minutes upon rising to the surface it will usually blow two or three times before again going down.

When cruising along the shore the animal generally remains submerged seven or eight minutes and blows three times when it reappears. Captain Melsom assures me that when a large female is taking a straight course it will remain below four or five minutes and rise to make three spouts very regularly; at other times a single whale will remain down ten minutes and a school between fifteen or twenty minutes, depending upon circumstances.

When travelling straight ahead and unmolested the Devilfish swim under water for a distance of 300 or 400 fathoms quite regularly and rise to spout three times.

Under normal conditions the animals 'sound' much as do Humpbacks. As soon as the spout has been delivered, the body begins to revolve and as the dive progresses the flukes are

lifted out of the water and drawn slowly under. The flukes are not invariably shown, however, even when sounding; some animals will almost always 'fluke out' and others, not at all. Under no circumstances do the Gray Whales arch the back as strongly as do the Humpbacks nor do the animals raise themselves so far out of the water.

During the 'surface' or 'intermediate' dives only a small part of the back is shown, the motion is forward and downward, and the flukes are never exposed.

Speed.— The Gray Whales are slow swimmers and cannot exceed seven or eight knots per hour even when badly frightened and doing their best to get away. Ordinarily when 'travelling,' and unmolested, they make about three or four knots, and when cruising along the shore perhaps two or three knots per hour.

The Gray Whale is essentially a shore-loving species and on its annual migration always prefers to swim along close to the beach. At times the whales will go in so close to the shore that they are actually rolling in the surf and seem to enjoy being pounded by the breakers. Scammon has observed the same habit in the California animals and says: "About the shoals at the mouth of one of the lagoons, in 1860, we saw large numbers of the monsters. It was at the low stage of the tide, and the shoal places were plainly marked by the constantly foaming breakers. To our surprise we saw many of the whales going through the surf where the depth of water was barely sufficient to float them. We could discern in many places, by the white sand that came to the surface, that they must be near or touching the bottom. One in particular, lay for half an hour in the breakers, playing, as seals often do in a heavy surf; turning from side to side with half extended fins, and moved apparently by the heavy ground-swell which was breaking; at times making a playful spring with its bending flukes, throwing its body clear of the water, coming down with a heavy splash, then making two or three spouts, and again settling under water; perhaps the next moment its head would appear, and with the heavy swell the animal would roll over in a listless manner, to all appearance enjoying the sport intensely. We passed close to this sportive animal, and had only thirteen feet of water" (*l. c.*, p. 24).

Frequently when being hunted the Korea whales would escape by swimming into water so shallow that the ships could not follow them and remaining there until the men had given up the chase.

Food.— Although the stomachs of a great number of Gray Whales were examined carefully I could never discover what constitutes their food. In every case the stomach was more or less filled with dark green water in which the only solid materials were bits of kelp, a little sea weed, and small masses of a light green gelatinous material. The stomachs of two individuals contained a number of small water-worn pebbles and several masses, six to eight inches long, of what appeared to be finely shredded raw meat still connected by its fibers; this was certainly not fish. It is probable that the kelp and sea weed had been taken in with other material, as in the case of the pebbles. The excrement of all the whales had about the consistency of thick cream and was dark green like the water in the stomach.

All the gunners asserted that when the Gray Whales appear at Ulsan on their migrations they are invariably travelling straight ahead and apparently not stopping to feed. This information, combined with the fact that little except water could be found in the stomachs, lends strong support to the theory that upon their annual migrations the Devilfish feed but very little, if at all. If feeding is indulged in, it would seem extraordinary that no specimens have been brought to the station having food, or its remains, in their stomachs. The presence of fæces in the intes-

tines may be due to the fact that these organs had not entirely emptied themselves since the last period of feeding in the north. The green color of the water in the stomach and of the excrement is probably due to bileary secretions.

It is possible that while upon their migrations the whales eat quantities of the jelly fish which are so frequently seen near the kelp fields just off shore. These animals, consisting largely of water, would be very quickly acted upon by the digestive fluids and the lack of solid material in the stomach be thus explained. Captain Melsom has seen Gray Whales in the Okhotsk Sea during the summer which were not travelling but were swimming slowly about.

It is interesting to note that neither Scammon nor Townsend could get any definite information as to the food of the Gray Whales of the California coast. Scammon remarks: "To our personal knowledge, but little or no food has been found in the animal's stomach. We have examined several taken in the lagoons, and in them we found what the whalers called 'sedge' or 'sea-moss' (a sort of sea-cabbage), which at certain seasons darkens the water in extensive patches both in and about the mouths of the estuaries. Whether this was taken into the stomach as food some naturalists doubt, giving as a reason that the whale, passing through the water mixed with this vegetable matter, on opening its mouth would of necessity receive more or less of it, which would be swallowed, there being no other way in which it could be disposed of. The quantity found in any one individual would not exceed a barrelful.

"From the testimony of several whaling-men whom we regard as interested and careful observers, together with our own investigations, we are convinced that mussels have been found in the maws of the California Grays; but as yet, from our own observations, we have not been able to establish the fact of what their principal sustenance consists" (*l. c.*, pp. 24, 25, note).

Townsend says in regard to the food: "The opinion of the men with whom I talked is that it does not feed to any great extent outside of its arctic habitat. It is certainly much thinner on the northward than on the southward run, a male that would yield 30 or more barrels of oil in the down season yielding less than 25 two months later. Whalers admit their ignorance of what constitutes the food of this animal, and can find nothing in its stomach during the breeding season" (*l. c.*, p. 349).

Affection.— The male Devilfish at all times shows strong affection for the female and Captain Melsom tells me that during the migration, when a school of males led by one or two females is found, if one of the latter is wounded, often the former will refuse to leave until she is dead. One day when hunting a pair he wounded the cow and the bull would not leave, keeping close alongside and pushing his head over her body. Later he struck the male with a harpoon but did not get fast and even then it returned and was finally killed. Captain Melsom assures me, however, that if the male is killed the female will seldom remain.

Scammon has recorded instances of the female's love for her young and it was because of her vigorous defense when attacked on the breeding grounds that the name "Devilfish" was gained. The whalemen in Korea, however, where the hunting is done from small ships by the Norwegian method, do not regard the animals as especially dangerous. They seldom lance one from the 'pram,' as is frequently done with Finbacks because the Gray Whales seem to be very sensitive to pain, and as soon as the iron penetrates the body the animal will raise itself in the water, throwing its head from side to side and sometimes lashing about with its flukes and fins.

Attacks by Killers (Orca orca).— The Gray Whales seem to be objects of continual persecution by the Killers; much more so than any of the other large whales. Among the first

eight or nine Devilfish which I examined at Ulsan, three attracted my attention at once because the entire anterior part of the tongue had been torn away. Teeth marks plainly showed in the remaining portion and upon consulting the gunner, Captain Hans Hurum, who had killed them, he told me that it had been done by Killers at the time he shot the whales. Seven Gray Whales were in the school, and shortly after he began to hunt them fifteen Killers appeared. The whales became terrified at once and he had no difficulty in killing three of the seven. When the Orcas gathered about, the whales turned belly up and lay motionless, with fins outspread, apparently paralyzed by fright. A Killer would put its snout against the closed lips of the Devilfish and endeavor to force the mouth open and its own head inside. This extraordinary method of attack was corroborated by Capt. Johnson who had been hunting the same school of Gray Whales, and, moreover, by all the whalemen at the station who had witnessed it upon many other occasions.

Out of the thirty-five Gray Whales which I examined especially, seven had the tongues eaten to a greater or less extent and one had several large semicircular bites in the left lower lip. The Killers do not confine their attention entirely to the tongue for almost every whale which was brought in had the tips and posterior edges of the fins and flukes more or less torn; in several specimens fresh teeth marks were plainly visible where the fin had been 'shredded' as the whale drew it out of the Orca's mouth.

Although none of the Gray Whales exhibited teeth marks on other parts of the body undoubtedly some of them are killed by the Orcas. A female Killer which was brought to the station had several pieces of flesh in its stomach besides a strip of whalebone three inches long; I could not positively identify the latter but believe it to have been from a small Devilfish. A male Killer was taken at the same time by Captain Hurum who told me that in the animal's death flurry it had thrown up two great chunks of flesh.

Captain Melsom brought a Gray Whale to the station one day and I was interested to find the tongue almost gone. He said he had passed a school of Killers in the morning and later, after steaming about fifteen miles, had killed the Devilfish. A short time afterward, a long distance away, he saw the fins of a school of Killers which were coming at full speed straight for the ship. They circled about the vessel and one of them forced open the mouth of the dead whale to get at the tongue. When Captain Melsom fired at the Killer with his Krag rifle the animal lashed out with its flukes, smashing the ship's rail, and disappeared.

As soon as Orcas appear if the Gray Whales are not paralyzed by fright they head for shore and slide in as close as possible to the beach where sometimes the Killers will not follow them. The Devilfish will actually go into such shallow water as to roll in the wash and even try to hide behind rocks. The Orcas are not afraid of the ships and will not leave the whales they are chasing when the vessels arrive, thus giving much assistance to the human hunters.

Captain Johnson, of the 'Rex Maru,' brought to the station at Ulsan a Gray Whale which had been shot in the breast between the fins. He had first seen Killers circling about the whale which was lying at the surface, belly up, with the fins outspread, being absolutely paralyzed by fright. The vessel steamed up at half speed and Johnson shot at once, the iron striking the whale in the breast.

Such is the fear of the Gray Whale that when, as frequently happens, porpoises are playing about a single animal, it will sometimes become terrified, thinking that the Killers have appeared.

I have never personally witnessed it but the gunners tell me that a pod of Gray Whales can

be stampeded much as can a herd of cattle. If three or four ships are near each other when a school of Devilfish are found, they draw together, each vessel going at full speed and making as much noise as possible. The whales at once sound, but as soon as they rise to spout the ships steam at them again. The Devilfish go down once more but do not stay under long, ascending at shorter intervals until finally they are ploughing along at the surface. The animals are 'scared up' as the gunners say, and become terrified to such a degree that everything is forgotten except the desire to get away. It is not always possible to stampede a herd, and often the whales will disappear at the first sound, not rising again until a long distance away. If Killers are about at the time a herd of Gray Whales are being hunted it is very easy for the ships to stampede them.

Even if the Devilfish do exhibit considerable stupidity when danger from Killers threatens, at other times they are the cleverest and most tricky of all large whales. One day the S. S. 'Main,' Captain Melsom, was hunting a Gray Whale in a perfectly smooth sea. The whale had been down for fifteen minutes when suddenly a slight sound was heard near the ship and a thin cloud of vapor was seen floating upward from a patch of ripples which might have been made by a duck leaving the surface. The whale had exposed only the blowholes, spouted, refilled the lungs and again sunk, doing it almost noiselessly. The gunners assert that this is quite a usual occurrence when a single Gray Whale is being hunted.

Diseases.— Most whales are subject to diseases of various kinds and the Devilfish is no exception. One specimen was brought to the station at Ulsan, with all the flesh on the left side of the head badly decomposed and in some places entirely gone, leaving the bone exposed; what remained hung in a soft, green, evil-smelling mass. The whale had evidently suffered considerably from the disease for it was very thin and the blubber dry.

A second specimen had a large swelling on the ventral ridge of the peduncle, which upon being opened, proved to be a large capsular tumor about one foot in depth and of a like diameter.

The skin upon the snout of a third individual was drawn into small circular patches leaving large sections of the blubber exposed.

Size.

The available material relating to the size of *Rhachianectes glaucus* consists of the following: From Korea, records of one hundred and twenty-two specimens taken by the whaling company during 1909–10, and of twenty-three measured by myself in 1912; from California, the measurements given by Scammon and Dall of two specimens taken in Monterey Bay, and the record by Pechuel of one from the Bay of San Simeon.

My own measurements of the total length were taken from the notch of the flukes to the tip of the snout, either along the side of the belly as the animal lay in the water or as each section was drawn upon the cutting wharf. Every whale was also measured by a representative of the company, and as the total length was secured by the Japanese in a way similar to mine it may be assumed that all the Korean specimens are directly comparable.

In the following tables measurements of both males and females are arranged according to size.

Table I. Measurements of 53 females.

Place	Date	Total Length Feet	Total Length Cm.
Ulsan	Dec. 5, 1909	45	1371
"	" 9, "	"	"
"	" 17, "	"	"
"	Jan. 9, "	"	"
"	" 15, "	"	"
"	Dec. 5, "	44	1340
Chan Chien Dogo	" 6, "	"	"
Ulsan	" 28, "	"	"
"	" 18, "	43	1310
"	" 23, "	"	"
"	" 25, "	"	"
"	Jan. 6, 1910	"	"
"	" " "	"	"
"	" 15, "	"	"
"	Dec. 1, 1909	42	1279
"	" 2, "	"	"
"	" 7, "	"	"
Chan Chien Dogo	" 10, "	"	"
Ulsan	" 11, "	"	"
"	" 18, "	"	"
"	" 19, "	"	"
Hidokatsu,	Dec. 20, 1909	42	1279
Chan Chien Dogo	" 22, "	"	"
Ulsan	" " "	"	"
"	" 24, "	"	"
"	" 26, "	"	"
"	Jan. 6, 1910	"	"
Chan Chien Dogo	Dec. 8, 1909	41	1249
"	" 13, "	"	"
"	" 15, "	"	"
"	" " "	"	"
Ulsan	" 21, "	"	"
"	" 27, "	"	"
"	Jan. 6, 1910	"	"
"	" " "	"	"
"	Dec. 26, 1909	40	1218
"	" 4, "	"	"
Chan Chien Dogo	" 7, "	"	"
"	" 11, "	"	"
"	" 16, "	"	"
Ulsan	" 26, "	"	"
"	" 28, "	39	1188
"	Jan. 1, 1910	"	"
"	" " "	"	"
Chan Chien Dogo	Dec. 17, 1909	38	1158
"	" 19, "	"	"
Ulsan	" 31, "	37	1127
"	Jan. 3, 1910	34	1036
"	" 5, "	33	1005
"	" 1, "	32	975
Ulsan, (R. C. A.)	Jan. 9, 1912	43′3″	1317
" "	" 8, "	42′8″	1300
" "	" 10, "	38′1″	1160

Table II.—Measurements of 95 males.

Place	Date	Total Length Feet	Total Length Cm.
Ulsan	Dec. 9, 1909	43	1310
"	" 17, "	"	"
"	" 30, "	"	"
"	Jan. 3, 1910	"	"
"	Dec. 1, 1909	42	1297
"	" 18, "	"	"
"	" 27, "	"	"
"	" 27, "	"	"
"	" 30, "	"	"
"	Jan. 9, 1910	"	"
"	Dec. 1, 1909	41	1249
"	" 4, "	"	"
"	" 22, "	"	"
"	" 29, "	"	"
"	" " "	"	"
"	" 3, "	40	1218
"	" 4, "	"	"
Chan Chien Dogo	" 6, "	"	"
Ulsan	" 8, "	"	"
Chan Chien Dogo	" 15, "	"	"
Chan Chien Dogo	Dec. 18, 1909	40	1218
"	" 18, "	"	"
"	" 19, "	"	"
"	" 20, "	"	"
Ulsan	" 21, 1909	"	"
"	" 27, "	"	"
"	" 29, "	"	"
"	" " "	"	"
"	" " "	"	"
"	" 30, "	"	"
"	" 31, "	"	"
"	" " "	"	"
"	" " "	"	"
"	Jan. 1, 1910	"	"
"	" 12, "	"	"
Oshima, Japan	Feb. 9, 1910	"	"
Ulsan	" 25, "	"	"
"	Dec. 9, 1909	39	1188
"	" 15, "	"	"
"	" 16, "	"	"

Table II.— Continued.

Place	Date	Total Length Feet	Total Length Cm.
Ulsan	Dec. 17, 1909	39	1188
"	" 23, "	"	"
"	" 26, "	"	"
"	" " "	"	"
"	" 29, "	"	"
"	" 30, "	"	"
"	" 30, "	"	"
"	" 31, "	"	"
"	" " "	"	"
"	Jan. 6, 1910	"	"
"	" 9, "	"	"
"	" " "	"	"
"	" 12, "	"	"
"	Feb. 20, "	"	"
Chan Chien Dogo,	Mar. 14, "	"	"
Ulsan	Jan. 6, "	38	1158
"	" 8, "	"	"
"	" 9, "	"	"
"	" " "	"	"
"	" 21, "	"	"
"	Mar. 2, "	"	"
"	Dec. 15, 1909	37	1127
"	" 20, "	"	"
"	" 31, "	"	"
"	Jan. 3, 1910	"	"
"	" 4, "	"	"
"	" 7, "	"	"
"	Feb. 13, "	"	"
"	Dec. 17, "	36	1097

Place	Date	Total Length Feet	Total Length Cm.
Ulsan	Jan. 5, 1910	36	1097
"	" 7, "	"	"
"	" 7, "	"	"
. . .	. . .	. . .	. . .
Ulsan (R. C. A.)	Jan. 13, 1912	41′½″	1250
" "	" 19, "	"	"
" "	" 8, "	40′8½″	1240
" "	" 10, "	"	"
" "	" 21, "	"	"
" "	" 24, "	40′6½″	1235
" "	" 20, "	40′2½″	"
" "	" 9, "	39′5½″	1202
" "	" 11, "	39′1″	1190
" "	" 17, "	"	"
" "	" 16, "	38′9″	1180
" "	" 17, "	"	"
" "	" 8, "	38′5″	1170
" "	" " "	38′1″	1160
" "	" 13, "	"	"
" "	" 9, "	37′6½″	1143
" "	" 14, "	35′7½″	1085
" "	" 10, "	35′3½″	1075
" "	" " "	34′5½″	1050
" "	" 16, "	32′2″	980
. . .	. . .	. . .	. . .
Monterey, Cal. (Scammon)	1865	42	1280
" " (Dall)	——	48	1462
San Diego, Cal. (Pechuel)	——	32	975

Like all baleen whales, the female *Rhachianectes* is larger than the male. The maximum size of the 123 specimens measured by the whaling company was 1371 cm. (45′); this length was reached by four females. The maximum for males was 1310 cm. (43′). A female 1317 cm. (43′ 3″) long and two males each 1250 cm. (41″ ½′) were the largest of the 23 specimens which I measured in 1912. Dall has recorded an unsexed individual 1554 cm. (51′) and a male 1462 cm. (48′) in length. If these measurements are correct Dall's specimens must have been of unusual size for the whalers in Korea assured me that examples longer than 1371 cm. were extremely rare. Measurements of his 1462 cm. whale show such a remarkable disagreement with all other specimens that there must have been some error in either taking or recording the dimensions. My friend Capt. H. G. Melsom, who has spent nearly fifteen years hunting Gray Whales in Korea, tells me that he killed two female whales 49 and 47 feet long, respectively; these are the largest specimens he has ever known killed.

The average length for all females measured by the whaling company and by myself agrees closely and is respectively 1254 cm. (41′ 2″) and 1259 cm. (41′ 4″); for all males it is 1188 cm. (39′) and 1172 cm. (38′ 6″). There can be little doubt that specimens larger than 1371 cm. (45′) are exceedingly rare.

It is difficult to arrive at a satisfactory conclusion as to the length at which *Rhachianectes glaucus* becomes sexually mature, for at present there are few data relative to this subject. Town-

send took a fœtus 518 cm. (17′) long from a female, "about forty feet long," and the only pregnant female which I examined was a specimen 1300 cm. (42′ 8″) in length. The condition of the skeleton proved this animal to be fully adult.

The measurements of length are arranged in tabular form in the following table (Table III).

Table III. Summary of Measurements.

Locality	Average for all specimens of both sexes		Average for all females		Average for all males		Maximum for females	Maximum for males	Minimum for females	Minimum for males
	No. of Whales	Length	No. of Whales	Length	No. of Whales	Length	Length	Length	Length	Length
Korea, measured by R. C. A.	23	cm. 1184 ft. 38′9½″	3	cm. 1259 ft. 41′4″	20	cm. 1172 ft. 38′6″	cm. 1317 ft. 43′3″	cm. 1250 ft. 41′1″	cm. 1160 ft. 38′1″	cm. 980 ft. 32′2″
Korea, measured by Whalers	123	cm. 1213 ft. 39′10″	50	cm. 1254 ft. 41′2″	73	cm. 1188 ft. 39′	cm. 1371 ft. 45′	cm. 1310 ft. 43′	cm. 975 ft. 32′	cm. 1097 ft. 35′5″
California, measured by Scammon, Dall, and Pechuel	4	cm. 1318 ft. 40′8″		—	3	cm. 1239 ft. 40′8″	—	cm. 1462 ft. 48′	—	cm. 975 ft. 32′

Proportions.

In the following tables detail measurements of Korea and California representatives of *Rhachianectes glaucus* will be found. It was possible to take a fairly complete series of measurements of some of the Korea specimens while of others only a few could be secured but all have been presented with the hope that they may be of aid to future students of this species.

In the second table certain of the most reliable measurements have been selected, and their ratios to the total length given, to ascertain the degree of individual variation and to facilitate comparison.

It will be seen upon examination of the table of ratios that there is a greater or less variation in almost all the proportions. The question at once arises as to whether or not this can be due wholly to individual differences or in part to inaccuracy of measurement. The lengths of all specimens were secured while the animals were lying in the water or else were the totals of the different sections as the whales were being "cut in." The length was never taken over the back but usually along the side or breast, and in most cases I believe it to be accurate. In Nos. 2, 9, and 11 there is a possibility of doubt, but none of the ratios of these specimens show unusual variation.

All the measurements, except the total length and the distance from the tip of the snout to the axilla, were secured without difficulty after the sections of the whale had been drawn upon the wharf.

I have included in the table, measurements of the fully grown fœtus No. 1*a*, for as these were taken at leisure with the greatest care there is no doubt as to their accuracy and they furnish a valuable standard for comparison with the adult individuals.

Table IV.— Detail Measurements of Korea and California specimens.

	ULSAN, KOREA																							CALIFORNIA		
	No. 1 Jan. 8 ♀	Foetus No. 1a Jan. 8 ♂	No. 2 Jan. 8 ♂	No. 3 Jan. 8 ♂	No. 4 Jan. 8 ♂	No. 5 Jan. 9 ♂	No. 6 Jan. 9 ♀	No. 7 Jan. 9 ♂	No. 8 Jan. 10 ♂	No. 9 Jan. 10 ♀	No. 10 Jan. 10 ♂	No. 11 Jan. 10 ♂	No. 12 Jan. 11 ♂	No. 13 Jan. 13 ♂	No. 14 Jan. 13 ♂	No. 15 Jan. 14 ♂	No. 16 Jan. 16 ♂	No. 17 Jan. 16 ♂	No. 18 Jan. 17 ♂	No. 19 Jan. 17 ♂	No. 20 Jan. 19 ♂	No. 21 Jan. 20 ♂	No. 22 Jan. 21 ♂	No. 23 Jan. 24 ♂	Seammon Monterey 1865 ♂	Dall Monterey Jan. 1866 ♂	Pechuel San Diego ♂
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
Total length snout to notch of flukes	1300	435	1160	1240	1170	1143	1317	1202	1240	1160	1050	1075	1190	1250	1160	1085	1180	980	1190	1180	1250	1225	1240	1235	1280	1462	975
Tip of snout to eye	250	81	220	227	222	218	244	250	240	....	200	220	225	245	210	220	220	175	232	232	230	230	240	225	229	315	....
" " " " blow-hole (center)	224	74	....	220	210	205	220	....	207	....	....	210	205	232	196	208	215	165	....	210	220	210	235	210	183	145	244
" " " " axilla	....	152	....	....	....	366	390	....	390	365	320	380	....	440	....	350	....	310	....	400	....	415	410	....	335	....	....
Notch of flukes to anus	410	141	370	370	....	363	377	346	335	....	350	355	....	375	335	360	325	280	350	345	355	370	360	365	366	442	....
" " " " dorsal "hump"	485	177	....	450	....	413	....	....	405	373	425	375	350	....	....	....	....	350	....	....	405	....	....	....	....	....	....
Anus to clitoris or penis	....	45	....	....	....	....	....	....	120	....	125	....	....	....	....	....	....	....	....	....	....	....	....	....	142	61	....
" " umbilicus	....	75	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Flukes tip to tip	310	103.5	320	302	....	290	306	....	330	275	300	300	....	302	310	300	320	....	320	....	....	290	320	....	305	267	274
Length right lobe of flukes axially	150	62	....	....	....	155	....	....	....	....	....	175	....	....	....	....	....	....	....	....	....	150	....	....	....	....	....
" left " " " "	....	60	....	....	....	160	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greatest thickness of flukes at insertion	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	22	23	....	....
" breadth " " ant. post	....	40	....	....	....	....	....	....	....	....	106	112	....	....	105	100	95	....	110	....	118	90	....	....	104	....	....
Depth of peduncle just ant. to flukes (on curve)	80	29	76	70	....	68	....	....	75	70	....	80	....	70	....	....	70	....	78	....	....	75	80	80	46	....	....
" " " midway between flukes and anus	....	49	110	....	....	140	....	....	127	135	126	....	....	126	115	114	135	....	130	....	....	150	....	150	....	....	....
Length of pectoral, tip to head of humerus	228	....	240	230	220	222	220	225	230	....	224	220	....	230	....	218	235	180	218	228	240	220	220	235	....	....	....
" " " " " post. insertion	137	67	165	160	145	150	140	160	160	....	156	155	....	165	....	148	155	120	150	160	175	160	150	170	....	....	....
" " " " " ant. "	205	94	....	190	....	190	190	185	180	....	....	....	....	....	....	....	190	....	....	....	....	....	....	....	198	183	153
Greatest breadth of pectoral	75	33	90	94	79	83	85	89	90	....	85	85	....	92	....	82	....	68	85	88	90	85	90	95	87	....	61
Distance from eye to ear	56	24	55	....	....	....	....	....	53	....	52	....	53	62	50	....	50	....	....	50	....	50	....	....	....	....	....
" eye above ear	2[1]	1[1]	....	....	....	....	....	....	5	....	5	....	5	6	5	....	5	....	....	5	....	2	....	....	....	....	....
Length of right blowhole (straight)	25	9	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	21	....	....
" " left " "	25	9	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dist. apart of blowholes anteriorly	7	4.5	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" " " " posteriorly	23	9	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Length of row of baleen (straight)	220	....	203	....	198	190	210	215	....	....	182	200	204	219	185	190	183	155	200	....	200	210	....	200	....	....	....
Longest plate baleen (inside)	40	....	48	....	....	40	46	40	....	....	....	45	....	....	38	36	45	32	45	....	40	38	....	42	46	36	31
Number plates of baleen (one side)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	158	162	148	....	....	....	154	....	....	....	....	....
Number of throat furrows	2	2	2	3	3	2	2	2	2	....	2	2	....	2	3	2	3	2	2	2	4	2	2	2	....	....	....
Length of longest throat furrows	....	59	140	150	165	160	170	....	150	....	165	153	....	165	150	145	150	130	155	160	....	170	170	....	....	....	....
Distance apart anteriorly	15	6	22	....	32	....	....	....	....	....	....	....	....	....	....	19	....	....	....	....	....	....	20	....	....	....	....	....
" " posteriorly	....	16	47	....	50	....	....	....	....	....	....	....	....	....	....	55	....	....	....	....	....	....	50	....	....	....	....	....
Tip of mandible to ant. end of furrows	65	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	75	....	....	....	....	....

[1] Nos. 1 and 1a had the ear above the eye.

It will be seen from the table that the greatest variation appears in the distance from the notch of the flukes to the dorsal "hump" amounting to 11%; this will be discussed later.

The variation of 5.3% in the width of the flukes from tip to tip may in great measure be accounted for by the fact that the tips of the flukes were very frequently injured. The same can be said of the measurement of the pectoral from the tip to the head of the humerus, but in a less degree, for usually one of the flippers, at least, was uninjured and the correct length could thus be secured.

The measurements of the California examples neither conform to each other nor to those from Korea. In Scammon's specimen the distance from the tip of the snout to the blowholes is 14.2% of the total length. This is much less than in any of the Korea whales and, moreover, gives a difference of 3.6% between the measurements from the tip of the snout to the eye and to the blowhole. This can hardly be correct. The same discrepancy is apparent in Dall's figures, but to a greater degree. The ratio to the total length of the tip of the snout to the eye is greater than in any of the Korea specimens, and that from the tip of the snout to the blowholes is much less, the difference between the two being 11.6%. One, or both, of these measurements is certainly incorrect.

Pechuel's figures give the distance from the snout to the blowhole as 25% of the total length, while the greatest in the Korea specimens is 19.5%. It is impossible to account for this discrepancy.

Scammon's measurements from the snout to the axilla, of the flukes from tip to tip, and of the depth of the peduncle just anterior to the flukes, are all at such variance with the Korea specimens that they must either be incorrect or have been taken in quite a different manner from my own. The same is true of Dall's measurements of the flukes from tip to tip and of the length of the fin. These data in reference to the California specimens are, therefore, of little value either for comparison with the Korea examples or with each other.

Table V. — Proportional Measurements of Korea and California specimens.

	ULSAN KOREA													
	No. 1 ♀	No. 1a Fœtus ♂	No. 2 ♂	No. 3 ♂	No. 4 ♂	No. 5 ♂	No. 6 ♀	No. 7 ♂	No. 8 ♂	No. 9 ♀	No. 10 ♂	No. 11 ♂	No. 12 ♂	No. 13 ♂
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
Total length, snout to notch of flukes	1300	435	1160	1240	1170	1143	1317	1202	1240	1160	1050	1075	1190	1250
	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Tip of snout to eye	19.2	18.6	18.9	18.3	18.9	19.0	18.5	20.7	19.3	—	19.0	20.4	18.9	19.6
" " " " blowhole	17.2	17.0	—	17.7	17.9	17.9	16.7	—	16.6	—	—	19.5	17.2	18.5
" " " " axilla	—	34.9	—	—	—	32.0	29.6	—	31.4	31.4	30.4	35.3	—	35.2
Notch of flukes to anus	31.5	32.3	31.9	29.8	—	31.7	28.6	28.7	27.0	—	33.3	33.0	—	30.0
" " " " dorsal "hump"	37.3	40.6	—	36.2	—	36.1	—	—	32.6	32.1	40.4	34.8	29.4	—
Flukes, tip to tip	23.8	23.6	26.0	24.3	—	25.3	23.2	—	26.6	23.7	28.5	27.9	—	24.1
Depth of peduncle just anterior to flukes	6.1	6.6	6.5	5.6	—	5.9	—	—	6.0	6.0	7.6	7.4	—	5.6
" " " midway between flukes and anus	—	11.2	9.4	—	—	12.2	—	—	10.2	11.6	—	—	—	10.0
Fin, tip to head of humerus	17.5	—	20.7	18.5	18.8	19.4	16.7	18.7	18.5	—	20.9	20.4	—	18.4
" " " anterior insertion	15.8	21.6	—	15.3	—	16.6	14.4	15.3	14.5	—	—	—	—	—
" greatest breadth	5.7	7.5	7.7	7.5	6.7	7.2	6.4	7.4	7.2	—	—	7.9	—	7.3

Table V. — Continued.

	ULSAN KOREA										CALIFORNIA				
	No. 14 ♂	No. 15 ♂	No. 16 ♂	No. 17 ♂	No. 18 ♂	No. 19 ♂	No. 20 ♂	No. 21 ♂	No. 22 ♂	No. 23 ♂	Amount of variation in ratios	Average of ratios	Scammon ♂	Dall ♂	Pechuel ♂
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
Total length, snout to notch of flukes	1160	1085	1180	980	1190	1180	1125	1125	1240	1235			1280	1462	975
	%	%	%	%	%	%	%	%	%	%	%[1]	%[1]	%	%	%
Tip of snout to eye	18.1	20.2	18.6	17.8	19.4	19.6	18.4	18.7	19.3	18.2	2.9	19.0	17.8	21.5	——
" " " " blowhole	16.8	19.1	18.2	16.8	——	17.7	17.6	17.1	18.9	17.0	2.8	17.6	14.2	9.9	25.0
" " " " axilla	——	32.2	——	31.6	——	33.8	——	33.8	33.0	——	5.7	32.4	26.1	——	——
Notch of flukes to anus	28.0	33.1	27.5	28.5	29.4	29.2	28.4	30.2	29.0	29.5	5.8	30.4	28.5	30.2	——
" " " " dorsal "hump"	——	——	——	35.7	——	——	32.4	——	——	——	11.0	34.7	——	——	——
Flukes, tip to tip	26.7	27.6	27.1	——	26.8	——	——	23.6	25.8	——	5.3	25.6	23.8	18.2	28.1
Depth of peduncle just anterior to flukes	——	——	5.9	——	6.5	——	——	6.1	6.4	6.4	2.0	6.3	3.5	——	——
" " " midway between flukes and anus.	9.9	10.5	11.4	——	10.9	——	——	12.2	——	12.1	2.8	10.9	——	——	——
Fin, tip to head of humerus	——	20.0	19.9	18.3	18.3	19.3	19.2	17.9	17.7	19.0	4.2	18.9	——	——	——
" " " anterior insertion	——	——	16.1	——	——	——	——	——	——	——	1.3	15.4	15.4	12.5	15.6
" greatest breadth	——	7.5	——	6.9	7.1	7.4	7.2	6.9	7.2	7.6	2.2	7.1	6.7	——	6.2

Color.

Plates XIX and XX.

None of the published descriptions of the color of *Rhachianectes glaucus* which I have been able to find occupy more than three or four lines, or give other than the vaguest impression of the animal's appearance. Scammon says: "The California Gray is unlike other species of baleen whales in color, being of a mottled gray, very light in some individuals, while others, both male and female, are nearly black" (*l. c.*, p. 20). Scammon's figure (*l. c.*, plate ii, fig. 1) shows a rather slender whale, gray, and irregularly marked with white on the entire upper half of the body from the head to the flukes; the lower half is represented as almost plain.

This type of coloration is just the reverse of what was observed in Korea specimens. It is true that several examples were seen which had the back more or less heavily marked, but in every case where this occurred the lower half of the body was so thickly covered with white and gray patches that there was a great preponderance of the light color. Unless the California specimens are very different from those of Korea, which is highly improbable, Scammon's figure is incorrect. This view is strengthened when the drawing of *Balænoptera sulfurea* (*l. c.*, plate xiii) is examined for it is quite unlike a Pacific Sulphurbottom in coloration. Scammon's first figure of *Rhachianectes*, published in 1869,[2] although very crude, gives in the side view a really better suggestion of the color of the animal than does the plate in his 'Marine Mammalia.' In his first figure the markings are shown evenly distributed over the entire body from the head to the flukes and not confined to the dorsal surface as in the later drawing.

In Cope's article on the Gray Whale (1868), Mr. W. H. Dall's description of two specimens seen by him at Monterey, Cal., is quoted, as follows: "Color above and below, black, with a gray bloom like a plum. This distinguishes this species from the known Balænæ of the Pacific, which are more or less white on the belly and fin" (*l. c.*, p. 226).

Pechuel's figure of *Rhachianectes* is diagrammatic and there is little attempt at coloration.

[1] This does not include fœtus No. 1a.

[2] Proc. Phil. Acad. Nat. Sci. Phil., 1869, fig. 8.

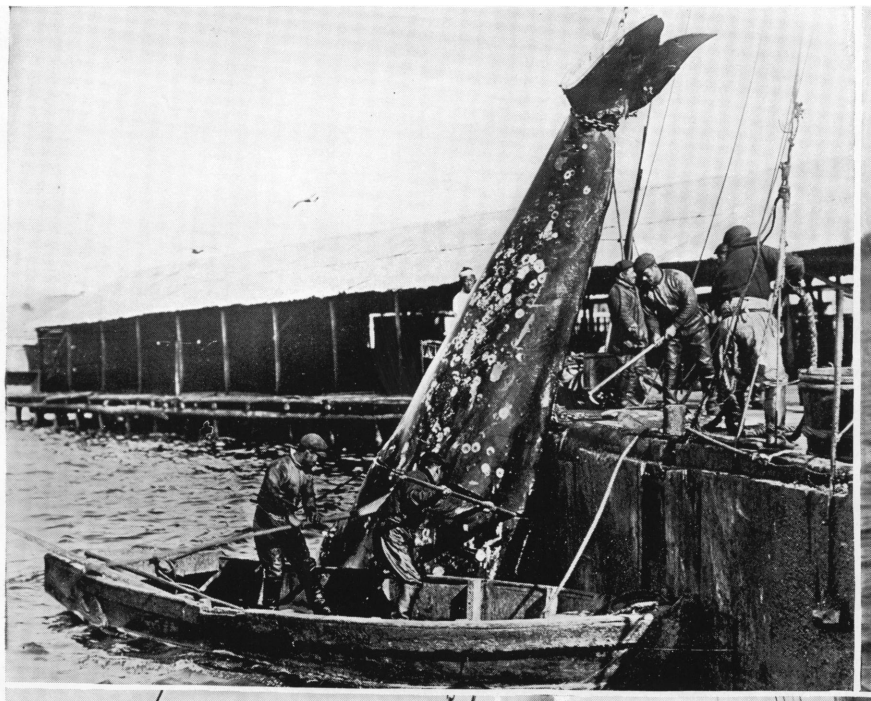
PLATE XIX.

PLATE XIX.

RHACHIANECTES GLAUCUS.

Fig. 1. Lateral view of peduncle showing white markings, mostly cirriped scars.
Fig. 2. Lateral view of peduncle showing normal gray and white markings and total absence of cirriped scars.
Fig. 3. Head, pectoral fin and section of back blubber.
Fig. 4. Direct lateral view of peduncle showing dorsal crenulations.
Fig. 5. Dorsal view of peduncle showing normal gray markings and flukes.
Fig. 6. Peduncle lying upon the wharf.
Fig. 7. Posterior portion of body showing inferior outline.

1



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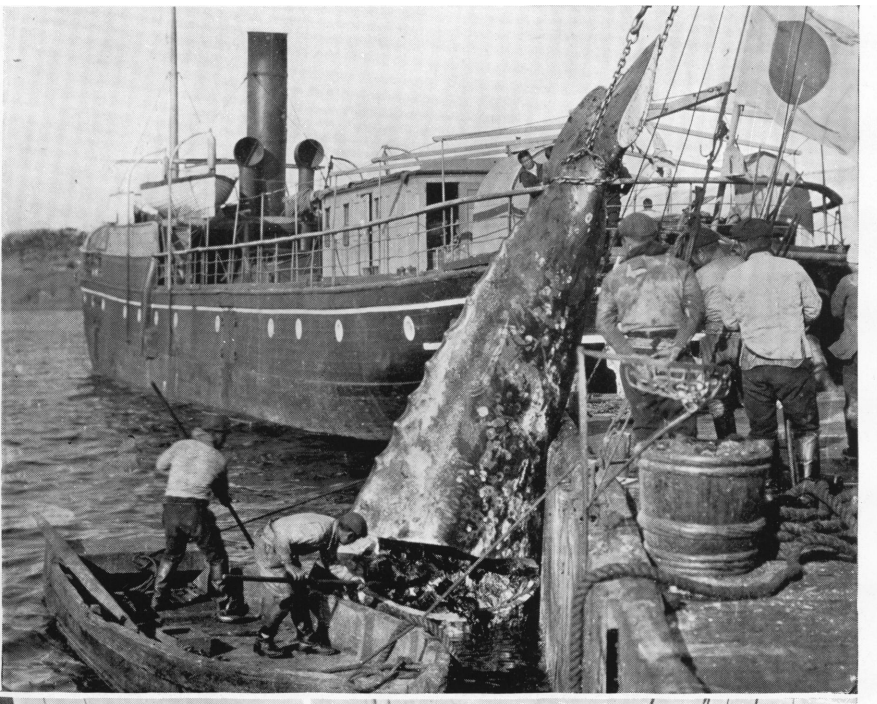

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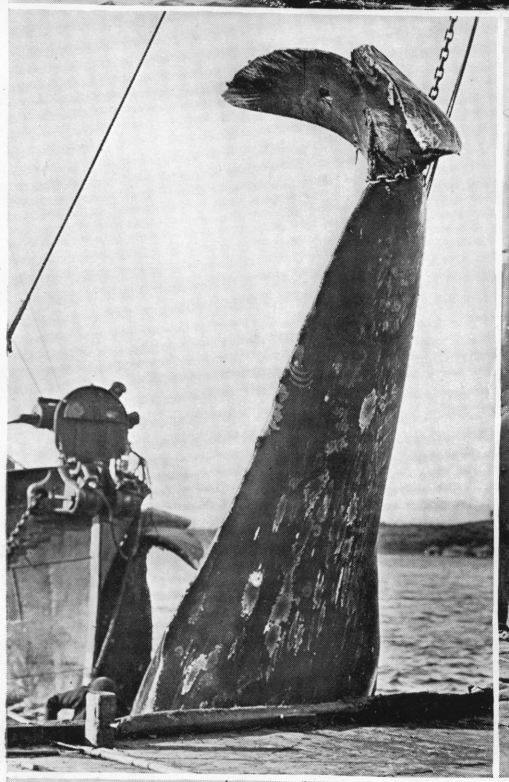



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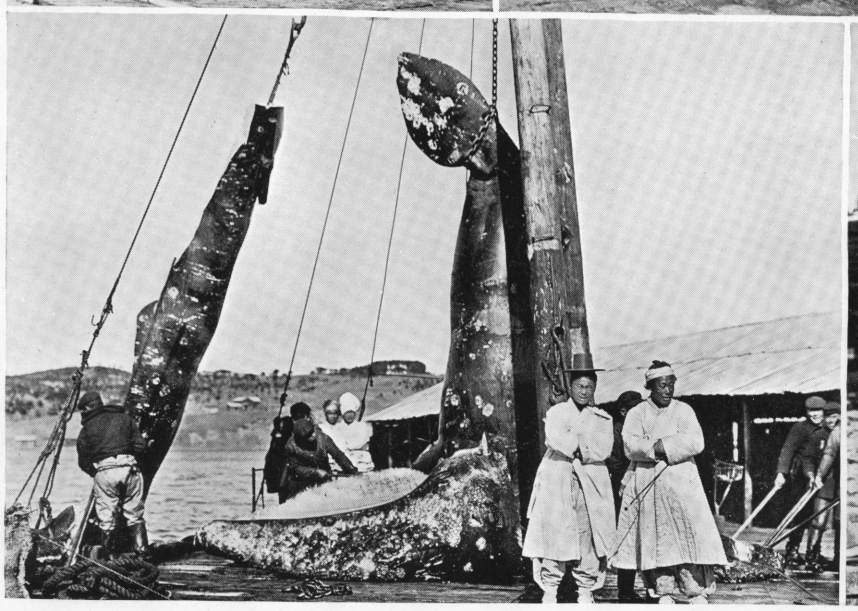

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RHACHIANECTES GLAUCUS.

He says in regard to this: "Abweichend von allen anderen Walen ist seine Farbe ein melirtes grau, Manche sind ganz fleckig, selten sieht man gleichmässig dunkel gefärbte." [1]

The following description of Korea examples is, therefore, the only detailed account of the color of the Gray Whale that has thus far been published.

There seems to be quite as much individual color variation in *R. glaucus* as in other baleen whales, some examples being abnormally dark with but few gray markings while others are very light, the entire body being so thickly covered with blotches of white and gray that there is a preponderance of the light color. It is obvious, therefore, that no description which will apply to all individuals can be given, but between the light and dark extremes there was a certain type of coloration possessed by a majority of the examples which came under my observation. This may be described as follows: The head, throat, back, and the dorsal and ventral ridges of the peduncle are black, or very dark slate, and are usually unmarked. On the dorsal and lateral surfaces of the distal half of the rostrum there is considerable white and light gray in flecks and small spots; this is frequently true of the chin, lower lips, and both mandibular rami. On the under side of the rostrum just exterior to the bases of the baleen rows, there is a band of flesh pink, or white, about three inches wide. The amount of white on the rostrum and lips varies greatly with individuals but it is seldom entirely absent. The throat and sides to the pectorals are usually unmarked. From the fins to a point opposite the anus, on the sides, breast and belly, are many roughly elliptical and circular markings with irregular edges. These markings have gray centers shading to very light gray, or white, on the edges and are broken by small round, or oval, black spots (Plate XX, Fig. 6). They follow the long axis of the body and generally closely approximate each other.

On the sides of the peduncle the gray markings become scattered and are generally smaller and darker. The whole body from the head to the flukes has many white or light gray circular scars of varying sizes, apparently left by parasitic cirripeds; on some individuals these almost obscure all other markings.

The pectoral fins are dark slate like the body. Above, on the posterior half, there are a few scattered white circles and spots. Below, the white circles are more numerous and on the distal half are two more or less broken bands of white, or very light gray, about 8 cm. wide and 45 cm. long between the 2nd and 3rd and 3rd and 4th fingers; the band between the 2nd and 3rd fingers is usually the longer. The posterior edge of the fin is very frequently white.

The flukes are black or dark slate like the body, a few white circles and spots being scattered over both surfaces, generally more on the lower. Frequently the posterior edges and tips are white.

In connection with the preceding description it is interesting to refer to the color of fœtus No. 1*a*, described below. This specimen was almost ready for birth and gives an excellent idea of the disposition of the markings on the Gray Whale before the body has been scarred by parasites and by contact with rocks. The general color must become much darker after birth than it is during fœtal life.

Color Variations.— There are striking variations from the type of coloration described above. Three specimens out of the twenty-one on which color notes were taken were exceptionally light colored. One (No. 8, male) had the entire rostrum, lips and mandibular rami dotted and specked

[1] Pechuel-Loesche, Wale and Walfang. Ausland, Vol. 44, 1871, p. 1186.

with gray and white. The sides of the breast and throat, from the fins forward, were streaked longitudinally with long gray lines, and the center of the throat thickly splashed with white. The back was heavily marked with oblong blotches of white. The only portion of the whale unmarked was the dorsal and ventral ridges of the peduncle.

A second whale (No. 11, male) had almost no white on the lips, rostrum or throat, but the sides of the body and peduncle, from the fins to the flukes, were so thickly washed, circled and blotched with gray and white that there was much more light than dark color.

No. 19, female, had the lower lips and distal portion of the mandible finely dotted and flecked with gray and white. The sides, belly, and the entire peduncle were so thickly covered with small light gray patches, that there was more light than dark color. The ground color of this whale was dark gray and not slate, or black, as usual.

No. 3 was a dark whale and No. 5 exceptionally so. The body was black and had only a few small and rather indistinct gray markings on the sides, back and lower half of the peduncle.

No. 6, female, was black. On the left side of the throat were a few long stripes of white, which seemed to be scars. The remainder of the throat, breast and belly was unmarked save for a single large, irregular, light-gray patch on the belly; the entire peduncle was plain except for a little white along the dorsal ridge. No. 14, male, was much like No. 6; No. 17, male, although a very dark individual, had the rostrum, lips and mandibular rami mixed white and gray, and the sides of the peduncle, body and back streaked with long, narrow gray lines.

There seems to be a tendency among the whalers to believe that all individuals which show a preponderance of light color are of the greatest age. Averages and comparisons of the lengths of the very dark, very light, and normal examples of *R. glaucus* shows but little difference between them and gives no basis for believing that the animals become lighter with increasing years. Only three of the whales which I examined were females, one of these being exceptionally dark and the other somewhat lighter than normal. The males presented both light and dark extremes and every variety of intermediate coloration. I believe, therefore, that the color differences have nothing whatever to do with sex or age, or that they are other than purely individual.

For reference the field descriptions of twenty-one individuals examined at Ulsan, Korea, are given below:

Field color descriptions of 23 Korea specimens.

No. 1. Female. Length, 1300 cm. General color dark slate. Much white on the distal half of the rostrum, snout and upper lips just above the bases of the baleen rows. Many fine, grayish lines on the back, and numbers of irregular white streaks over the entire body; the latter appeared to be scars from old wounds. Inferior half of peduncle from genitalia to flukes thickly marked with irregular elliptical patches of light gray.

Pectoral fins dark slate above, having both margins and tips whitish, the light color extending far up on the superior surface of the fin.

Flukes above dark slate with many white dashes and circles, the latter undoubtedly caused by parasitic cirripeds.

No. 1*a*. Fœtus. Male. Length, 476 cm. General color gray. The entire head and throat to the posterior insertion of the pectoral fins is light gray. A line of small, dark gray spots and dashes extends from the eye to a point a short distance above the pectoral. On the throat are a few small patches of very light gray, almost flesh white, and several large irregular markings of dark gray.

PLATE XX.

PLATE XX.

RHACHIANECTES GLAUCUS.

Fig. 1. Direct lateral view of head showing few parasite scars.
Fig. 2. Three-quarters posterior view of head showing many parasite scars.
Fig. 3. Dorsal view of head and blowholes; note the barnacles *Cryptolepas rhachianecti* embedded in the skin, and the masses of *Cyamus scammoni*.
Fig. 4. Front view of head.
Fig. 5. Direct lateral view of head and mandible of fœtus No. 1*a*.
Fig. 6. Section of peduncle showing normal gray and white markings.

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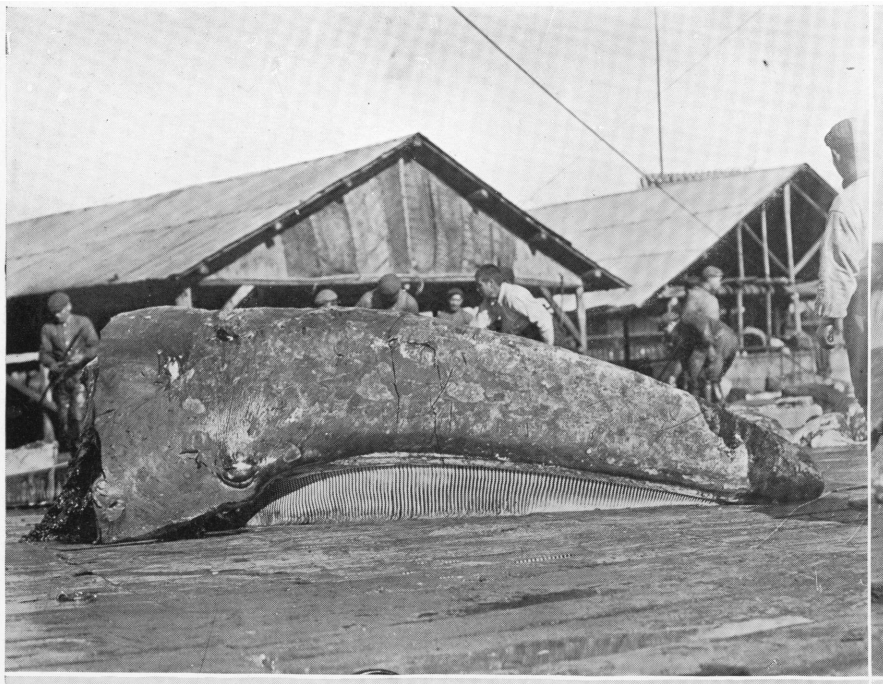

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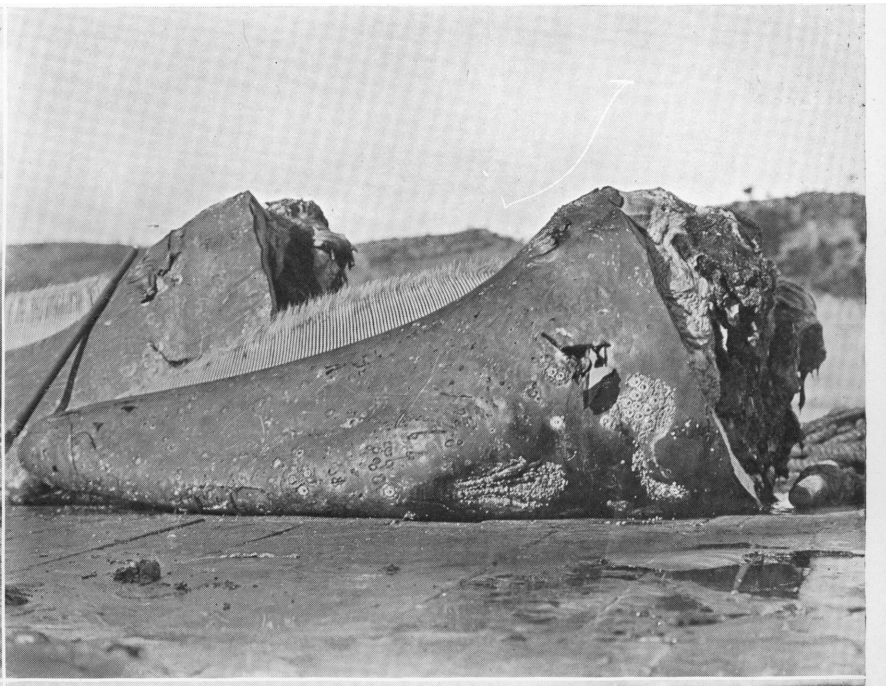

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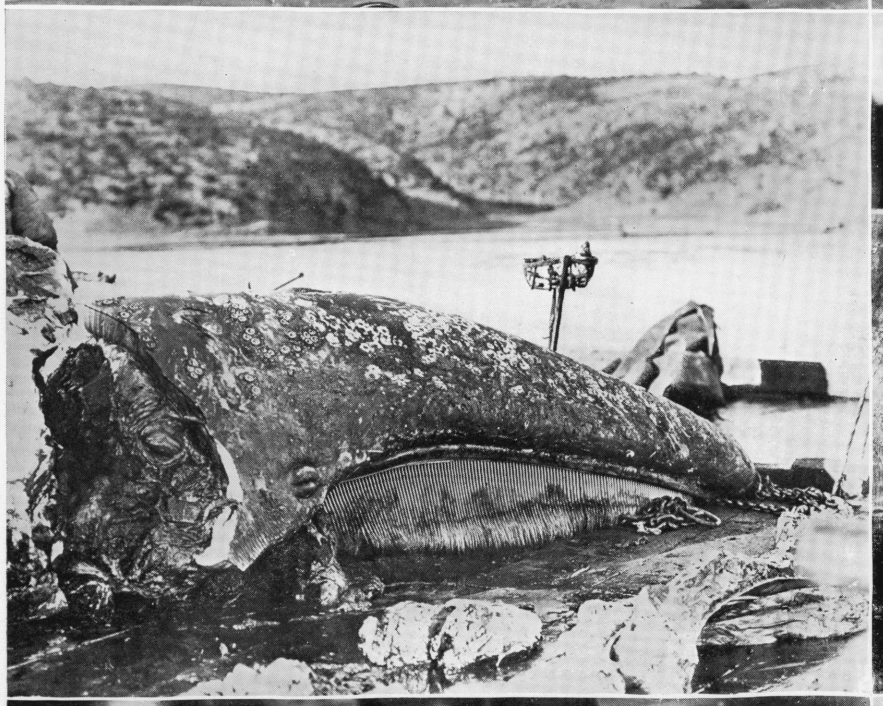

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4



RHACHIANECTES GLAUCUS.

On the sides a slight ridge is formed by the ends of the vertebral transverse processes below which the lateral and ventral surfaces of the body, forward almost to the pectoral fins, bear many irregular oblong and elliptical patches of very light gray; the markings are longitudinal, follow the long axis of the body and are so thick that there is more of the light than of the dark color. The back, above the line of the transverse processes, is light gray thinly marked with irregular, dark gray oval and oblong patches. On the right side, just posterior to the tip of the pectoral laid back, is a circular, pure white spot about 4 centimeters in diameter and a second smaller one above the posterior insertion of the fin.

The pectorals are plain dark gray on both surfaces but have light posterior and anterior edges.

The flukes are plain light gray above with dark anterior and posterior margins. Below, the ground color is light gray but coarse, broken whitish lines run transversely across each fluke from the anterior edge and curve inward toward the notch; this gives more white than dark color to the inferior surface.

No. 2. Male. Length, 1160 cm. Many fine white spots and flecks on snout, symphysis of mandible, and on both rami, but the remainder of the head is plain dark gray. Posterior to the genitalia both sides of the body have many large irregular patches of light gray about thirty cm. long by twelve cm. wide, and numerous blotches, circles and spots of white. There is a large patch of light gray about 150 cm. long by 45 cm. wide on the right side of the back and a large white spot just posterior to the tip of the pectoral fin laid back. The mid-dorsal region has either very few gray markings or none at all. The lower half of the peduncle is covered with rather fine dashes and circles of white.

The pectoral fins are alike on both surfaces. On the distal two-thirds between the second and third and the third and fourth digits there are two broad parallel bands of white. The remainder of the fin is so dotted, barred and circled with white that there is more white than dark.

Both surfaces of the flukes are dark slate thickly covered with irregular bands, spots and dashes of white. The left lobe has the inferior surface of the distal end almost entirely white.

No. 3. Male. Length, 1240 cm. A dark individual. The general color is dark slate, almost black. On the dorsal and lateral surface of the rostrum there is considerable light gray, but except for numerous cirriped scars, especially on the sides of the peduncle, the body has comparatively few light markings.

On both surfaces of the pectoral fins there is a broad longitudinal band of white between the fingers, and a few circles and spots of white on other parts of the flipper. The posterior edges are also white.

No. 4. Male. Length, 1170 cm. General color of body dark slate. The entire rostrum is clear light gray, shading into darker on the head, but does not show much white; neither is there white on the lips or mandibular rami. The dorsal region of the peduncle and body forward to the pectoral fins is unmarked dark slate but the sides have many small spots, dashes, and circular scars of white.

The pectoral fins are dark slate above and have a whitish longitudinal band between the fingers; also a few large cirriped scars. The anterior edge of the fin is dark slate and the posterior edge white.

No. 5. Male. Length, 1143 cm. A very dark individual. Head, back, sides and upper

half of peduncle, black. Lower half of peduncle has a few small, light gray markings and on the back and sides near the pectorals are several rather indistinct, gray patches; scattered over the body are a few large, white circular scars. Mucous membrane in the roof of the mouth light pink as are the lips just above the bases of the baleen rows.

The pectoral fins are black, above, except for two or three large white circles. Below, there is one large oblong patch of white between the fingers.

Both surfaces of the flukes are plain, unmarked black.

No. 6. Female. Length, 1317 cm. A very dark whale. Throat, breast and belly plain black except for a few long white stripes (apparently scars) just above the furrows and a large, irregular, light gray patch on the belly. The back and sides are black, almost unmarked, and on the peduncle *there are no gray patches* and only a few cirriped scars; along the dorsal ridge is a little white.

The superior surface of the pectoral fins is black with a few white circles; inferiorly both flippers are marbled and circled with white.

No. 7. Male. Length, 1202 cm. The entire distal third of the rostrum and the dorsal ridge to the blowholes is greatly roughened, or "cornified," thickly infested with parasitic *Cyamus*. There is no white on the rostrum.

The superior surface of each pectoral fin has but little white. On the inferior surface two broad bands of white run between the fingers to the tip of the fin and there is a large white patch near the base.

No. 8. Male. Length, 1240 cm. The lightest colored specimen which has been brought to the station. The dorsal ridge of the rostrum is almost entirely white having but few gray specks; the left side of the rostrum is like the dorsal surface but the right side is covered with fine gray and white flecks and dots giving a "pepper and salt" effect (apparently many small barnacles had fastened here). From chin to pectorals the sides of the throat and breast are streaked with long, longitudinal gray lines about five mm. wide and the center of the throat is thickly splashed with white. The rami of the mandible and the lower lips are mixed white and gray ("pepper and salt"). The entire back is thickly marked with small white circles and dots and the sides of the body, posterior to the fins, and of the peduncle are covered with blotches of white, fairly regular in size and about 25 cm. long by 10 wide; the edges of the blotches are irregular. The mid-dorsal and mid-ventral regions of the peduncle are plain black except for a circular patch of white about 30 cm. in diameter.

On the inferior surface the pectorals have two broad longitudinal bands between the digits, that nearest the posterior edge being the longest; there are also many smaller patches and scars on the lower surface. Above, the pectorals have much less white, only one band being present.

The flukes are black, above, thinly circled with white but below have much white.

No. 9. Female. Length, 1160 cm. Sides of body and of the peduncle blotched with light gray; the markings are heavier on the body. Ventral region almost plain.

No. 10. Male. Length, 1050 cm. A dark individual. Throat and lips plain dark slate with practically no lighter color. On the sides backward to a point opposite the anus are a good many large, gray, oval and oblong markings having irregular margins; the sides are also thickly studded with barnacles. The dorsal and ventral regions of the peduncle are plain but there are a few white circles and spots on the sides. The dorsal "hump" has patches of light gray, almost white, on either side and a large white spot on the right side; just anterior to the penis is a gray blotch.

Above, the pectoral is black with only one white spot.

The flukes are black on both surfaces save for a few white circles; the distal half of the posterior edge is all white.

No. 11. Male. Length, 1075 cm. A light individual. There is almost no white on the rostrum, lips, or throat. Sides of body and of peduncle so thickly washed, circled and marked with gray and white that there is much more light than dark color present.

No. 13. Male. Length, 1250 cm. Sides of body from the fins to a point opposite the anus, have many large gray and white markings and an extensive area of clear light gray. The peduncle has few gray markings on the sides but many white barnacle scars (many barnacles are still in position).

On the inferior surface, both fins are black but have a number of white spots joining to form a band about 60 cm. long between the second and third fingers. There are a good many other white spots and circles along the posterior edge, the remainder of the fin being unmarked. The superior surface is almost like the inferior but shows somewhat less white.

No. 14. Male. Length, 1160 cm. An exceptionally dark whale. The head is black showing practically no white or gray markings and but few parasites. On the chin and throat and on the breast between the fins there are many white flecks and circles but the remainder of the breast and belly is plain. On the left side from the fin to a point opposite the penis is an area of clear light gray about 60 cm. wide; on the right side its place is taken by a number of rather dark gray, roughly oblong, markings. The peduncle is almost entirely black but has a few gray patches on the inferior half.

No. 15. Male. Length, 1085 cm. The head shows a little white on the dorsal surface of the rostrum and on the sides a good many white barnacle scars. The sides of the body from the pectoral fins to a point opposite the anus have numerous light gray patches with white edges which almost join each other; these also cover the belly but do not extend on to the back. The superior half of the peduncle is plain black and the remainder thinly covered with rather small gray markings.

No. 16. Male. Length, 1180 cm. A light individual. The head, lips, throat and back are black except for a few gray patches just posterior to the blowholes and a white spot on the lips. The sides of the body from the fins to a point opposite the anus are covered with rather small gray patches which become larger and more numerous on the lateral surfaces of the peduncle. (These patches are gray in the center shading to white on the edges and broken by small black spots or dashes). The dorsal and ventral regions of the peduncle are unmarked.

The pectoral fins are black, above, circled with white. The inferior surface has fewer circles but is washed with white in several places. The flukes are black below with a few white circles. (In coloration the tail resembles that of *Megaptera*).

No. 17. Male. Length, 980 cm. A dark whale. The sides of the rostrum, lips and mandibular rami are mixed gray and white ("pepper and salt"). The back, sides of body and peduncle are marked with long gray lines which resemble scratches but seem to be normal.

The flukes are very light colored on the inferior surface and have whitish lines running transversely across each lobe and curving inward toward the notch.

No. 18. Male. Length 1190 cm. The dorsal and lateral surfaces of the rostrum are very light gray; the entire mandible is dark but shades into very light gray about 60 cm. from the symphysis. The sides of the body from the pectoral fins to a point opposite the anus has many,

rather dark gray markings a few of which are present on the proximal half of the peduncle; the remainder of the peduncle is very dark slate. The back is unmarked save for a few small barnacle scars.

No. 19. Male. Length, 1180 cm. A very light whale. The ground color of the body is dark gray and not the usual slate, or black. Distal half of mandible gray and white mixed. The sides of the body, belly and entire peduncle are thickly covered with small gray patches, irregular in shape, but having their longitudinal axes following the axis of the body. The gray markings are about 15 cm. long by 8 cm. wide and coalesce so that there is more of the light gray and white than the darker ground color.

No. 20. Male. Length, 1215 cm. Ground color dark gray. Sides of rostrum and head to the eyes very light gray; just above the bases of the baleen rows is the usual narrow pinkish band. Sides of body to the fins have many gray markings, and the back, belly and, in fact, the entire body is thickly covered with white cirriped scars. The dorsal and ventral regions of the peduncle are unmarked, but the sides have a number of gray patches which become smaller posteriorly and cease about 120 cm. from the flukes.

The pectorals are dark on the superior surfaces with only a few white flecks. There is a considerable quantity of white flecks, spots and circles scattered over the inferior surfaces and the posterior edges are white.

The flukes are dark above and below showing but few white circles and spots.

No. 23. Male. Length, 1235 cm. A light individual. The head, lips and jaws are mostly light gray with flecks of white. There is much light gray on the sides of the body in small patches, bars, dashes and flecks. The sides of the peduncle show some light gray markings and the ventral surface a few irregular white lines resembling scratches.

External Anatomy.

Plates XX–XXIV.

Outline of Body.— The rostrum is strongly convex, the highest point being just anterior to the blowholes. Directly behind the spiracles there is a shallow concavity about sixty cm. long, and from that point to the "hump" the dorsal outline is regularly convex. From the hump the upper ridge of the peduncle slants very gradually downward to the flukes. The throat is rather flat but opposite a point midway between the eye and the anterior insertion of the fin, the breast and belly swell outward in a gradual curve to the anus broken only by a slight bulge at the penis. At the anus there is an abrupt dip and from that point to the flukes the ventral outline of the peduncle is slightly convex; the greatest convexity is just anterior to a point midway between the anus and flukes. The body is deepest opposite the tip of the pectoral fin laid back.

The outline of the body in Scammon's figure of *Rhachianectes* needs some correction. From the blowholes to the end of the peduncle crenulations the back is straight when it should be convex and there is little indication of a hump. The breast and belly are hardly full enough, the prominent dip just posterior to the anus is not shown, and the ventral outline of the peduncle should be slightly convex.

Head.— The head of *Rhachianectes* is distinctly characteristic and differs strongly from that of all other baleen whales. Its shape, in some respects, is intermediate between that of the

PLATE XXI.

PLATE XXI.

RHACHIANECTES GLAUCUS.

Fig. 1. Eye and ear.
Fig. 2. Inner view of baleen.
Fig. 3. Blowholes and *Cyamus scammoni*.
Fig. 4. Three-quarters view of tongue.
Fig. 5. Lateral view of anterior portion of snout showing cornified areas due to the action of parasites.
Fig. 6. Inferior view of anterior portion of snout.
Fig. 7. Fœtus No. 1*a*.

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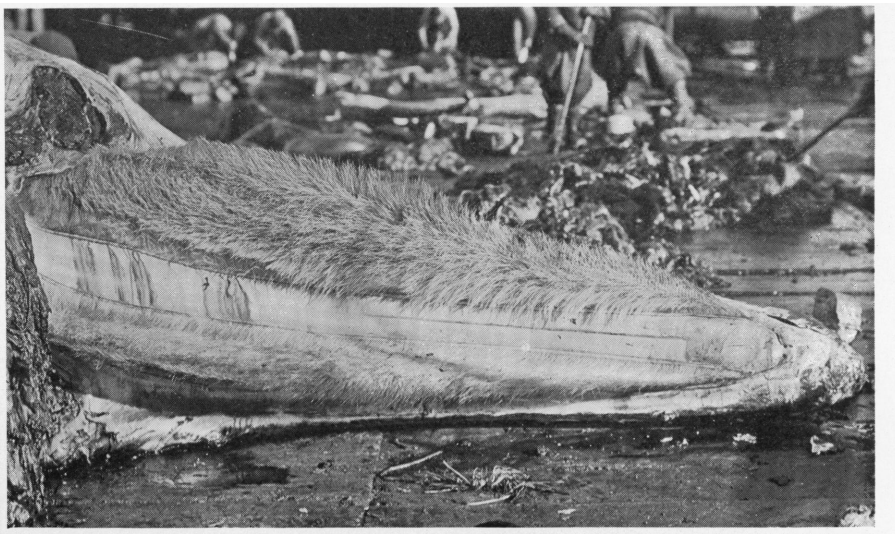

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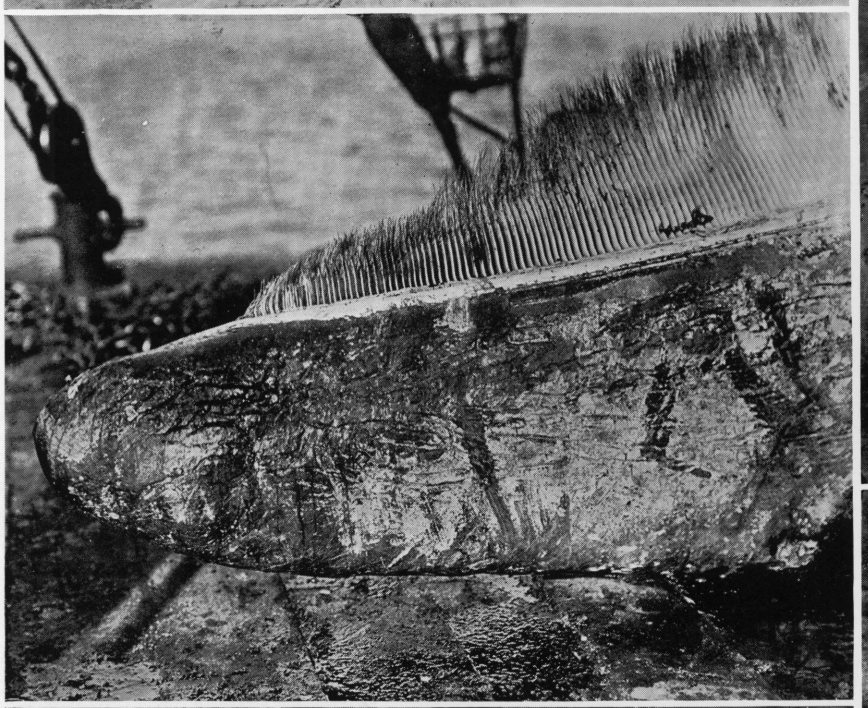

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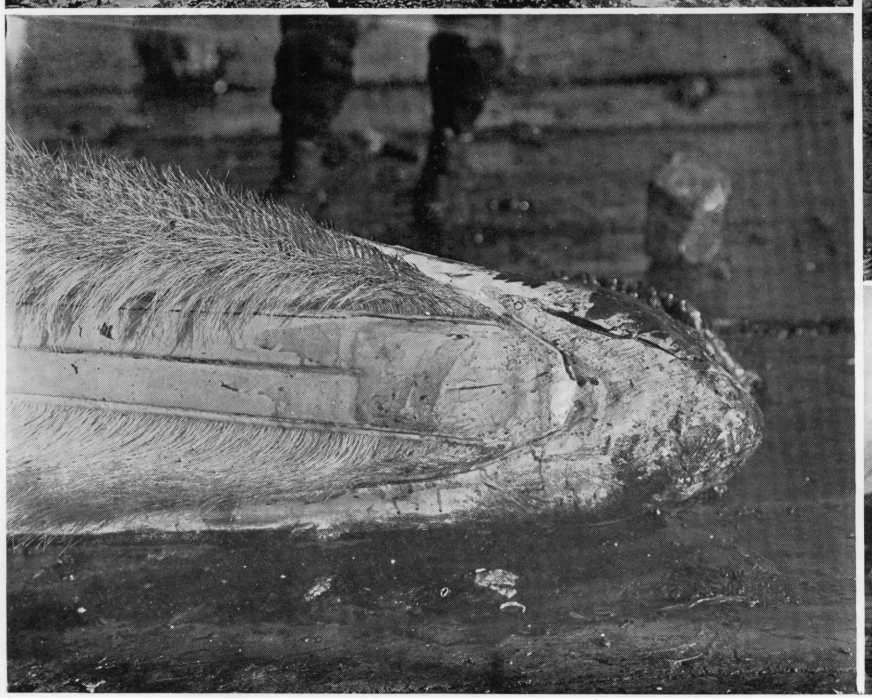

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RHACHIANECTES GLAUCUS.

Balæninæ and the Balænopterinæ. It is not so large proportionately, and the rostrum is neither as narrow nor as curved as in the former, but is much narrower and deeper than in the latter.

The rostrum is convex dorsally, narrow and very deep, especially so just anterior to the blowholes. On either side of the rostrum just anterior to, and below, the spiracles is a prominent swelling about forty-five cm. wide which runs forward, narrows, and gradually becomes lost. Immediately below this swelling is a shallow depression extending for the entire antero-posterior length of the rostrum.

The head is deep vertically and in whale No. 3, male, 1240 cm. in length, the distance from the eye to the summit of the head over the curve of the side was 94 cm.

The blowholes are situated in a slight depression just behind the highest point of the rostrum, the anterior ends being slightly higher than are the posterior. They appear as two slightly curved slits, the convexities inward, having a long and rather shallow furrow between them. In whale No. 1, 1300 cm. in length, the blowholes were 25 cm. long, the anterior ends being 7 cm. apart and the posterior ends 23 cm.

In Cope's description from Dr. W. H. Dall's note there is the following statement: "....the blowholes are entirely concealed by four dermal plicæ, which accounts for the small misty spout peculiar to the species" (*l. c.*, 1868, p. 226). I am at a loss to know what is meant by the "four dermal plicæ," as the blowholes of all the specimens which I examined were open and did not differ greatly from those of other baleen whales.

The region immediately about the spiracles was usually thickly infested with parasitic *Cyamus scammoni*.

Eye.— The eye forms a rather prominent swelling above, and a little behind, the corner of the mouth and is surrounded by two furrows the anterior and posterior ends of which almost meet. In some cases the ends of the furrows actually join thus forming a complete circle about the eye but in the majority of individuals the ends stand a short distance apart. The upper lid is considerably fuller and more prominent than is the lower. On whale No. 21, male, 1225 cm. in length, the furrows about the eye were each 18 cm. long, and the eye opening itself 5 cm. from the anterior to the posterior commissure.

The eyeball from an adult male 1158 cm. in length had a circumference of 205 mm. after it had been trimmed of adhering fat. The iris was 26 mm. long and 17 mm. in vertical diameter. The pupil was 10 mm. long and 6 mm. in diameter, oval, with the superior edge somewhat flattened.

The iris was a clear, dark brown band 6 mm. wide, the outer edge of which shaded into a narrow whitish ring. Encircling the iris was a band of light gray, 4 mm. in width, which shaded off gradually into very dark gray.

Auricular orifice.— The ear opening varies in size, as in all large whales, but is usually about 18 mm. in longitudinal diameter and directed upward at an angle of nearly 30 degrees. The meatus is a little larger than a good sized pencil.

The position of the ear is somewhat variable. In whale No. 1, female, 1300 cm. in length, the ear was 56 cm. behind the eye and 20 cm. *above* it. In fœtus No. 1*a*, male, from the same whale, the ear was 24 cm. behind the eye and 1 cm. above it. In none of the other twenty-three specimens on which notes were taken was the ear above the eye, it usually being from 2 to 5 cm. below it.

Scammon remarks in this connection: "The ear, which appears externally like a mere slit

in the skin two and one half inches in length, is about eighteen inches behind the eye, and a little above it" (*l. c.*, p. 20). In the table of measurements the distance from the eye to the ear of eleven specimens will be found.

Tongue.— The tongue of *Rhachianectes* is narrow, thick and solid, resembling that of a Right Whale much more strongly than it does the soft, shapeless tongue of *Megaptera* or any *Balænoptera*. The dorsal surface is regularly convex except at the distal end where it becomes concave, and the tip is upturned and deeply cleft. There is a narrow flattened strip on the top which runs from the proximal to the distal end. A cross-section of the tongue would be a semicircle with a slight dorsal compression. The color is usually flesh-pink becoming bluish gray at the tip.

Whale No. 17, male, 980 cm. in length, had a tongue 145 cm. long, 78 cm. wide over the curve and 50 cm. thick in the center. The tongue of No. 18, male, 1190 cm. in length, was 170 cm. long and 110 cm. wide over the curve.

Baleen.— The baleen plates of *Rhachianectes* differ from those of all other whales in being very thick and heavy, in the almost complete absence of transverse ridges, in having the outer edges thick and rounded instead of thin and sharp, and in the coarseness of the bristles. The baleen rows are not joined anteriorly by a narrow strip of small bristle-like plates as are those of the Balænopterinæ, in this respect resembling the Balæninæ.

The basal half of each plate is regularly concave, but in the distal half the concavity gradually disappears and the plate becomes flat. The color of the laminæ is yellowish white, or light yellow.

There are decidedly fewer baleen laminæ in each row than in any other large whale, the number varying from 138 to 174 on each side, the distance between the plates at the bases is from 5 to 10 mm. Following is a record of the number of baleen plates, *on one side only*, of different individuals, counting in every case the first and last lamina which was more than 50 mm. long and 5 mm. wide; the plates were all counted while *in situ:* 174, 168, 164, 162, 160, 158, 154, 148, 138.

The anterior ends of the baleen rows of whale No. 21, male, 1225 cm. in length were 35 cm. from the tip of the snout and 15 cm. apart; the posterior ends at the bases were 14 cm. apart and at the widest point the tips of the two rows diverged 65 cm.

The mucous membrane in the roof of the mouth between the bases of the baleen rows is white or flesh-pink.

The bristles of the proximal half of each plate are about 13 cm. in length but gradually elongate reaching a length of 25 cm. near the tips; they are round, very coarse and contrast strongly with the finer bristles of all other baleen whales. When seen *in situ* the bristles give the effect of a mat of thick, coarse fibers.

The baleen bristles are either entirely yellowish white like the plates themselves, or those of the posterior section may be gray, or dark gray, and the anterior portion yellowish white. The color of the bristles of twelve individuals was recorded showing that seven had some portion gray and five entirely yellowish white. Following is a list of the specimens in which the color of the bristles was noted:

PLATE XXII.

PLATE XXII.

RHACHIANECTES GLAUCUS.

Fig. 1. Throat showing two grooves.
Fig. 2. " " " "
Fig. 3. " " three "
Fig. 4. " " " "
Fig. 5. " " " "
Fig. 6. Tongue in position.

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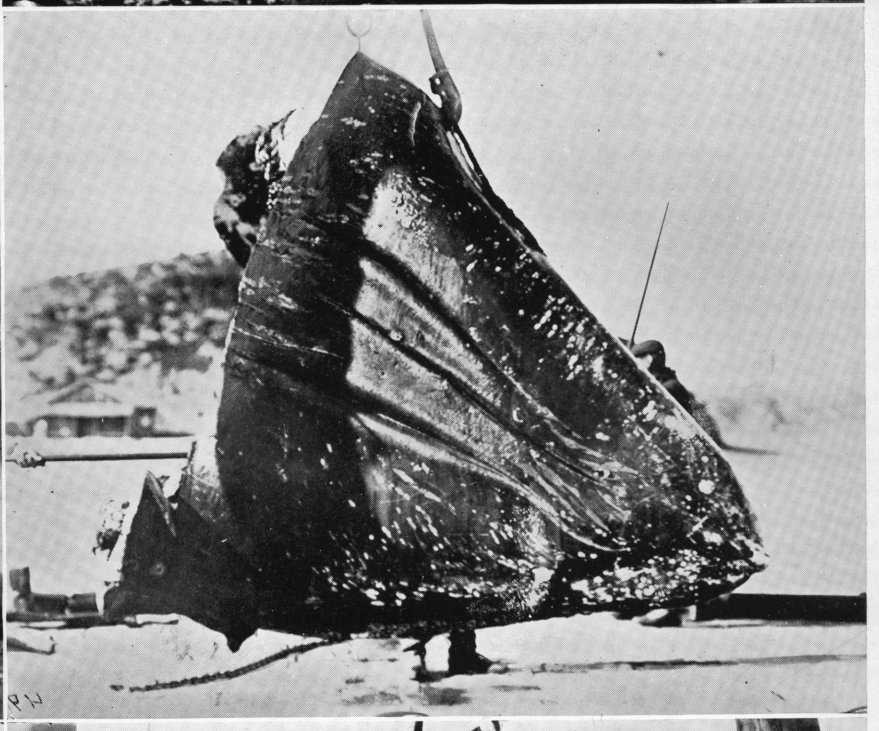

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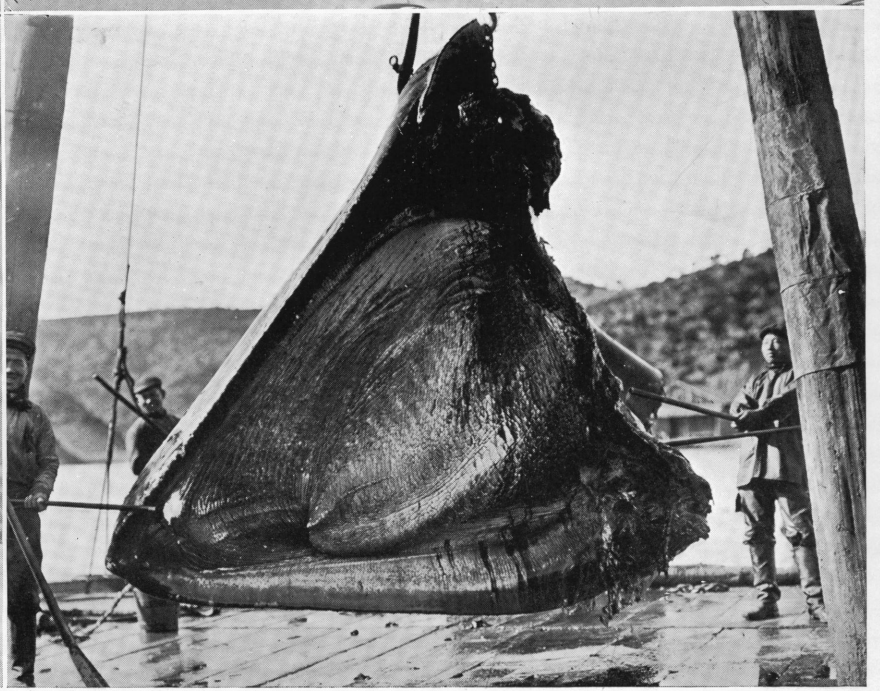

RHACHIANECTES GLAUCUS.

Color of bristles.

Capture Number	Sex	
4	♂	Posterior half gray, anterior half yellowish.
5	♂	" " " " " "
6	♀	All yellowish.
7	♂	Posterior half dark gray, anterior half yellowish.
8	♂	" two-thirds gray, anterior one-third yellowish.
11	♂	All yellowish.
13	♂	Posterior two-thirds gray, anterior one-third yellowish.
14	♂	All yellowish.
18	♂	" "
20	♂	Posterior three-fourths gray, anterior one-fourth yellowish.
21	♂	All yellowish.
23	♂	Posterior half gray, anterior half yellowish.

The descriptions given above of the baleen and bristles were written at the whaling station in Korea with fresh specimens at hand. I find upon examination of the set of baleen which was shipped to the Museum that both the bristles and laminæ are now very much darker than when fresh. This is due both to the drying of the plates and from soiling with dirt and grease. The bristles are now a strong brown and the plates yellowish-brown. I believe that in the great majority of cases any light colored baleen while being shipped from the field to a museum will be more or less soiled in transit and consequently the only reliable descriptions of such material are those that have been taken from fresh specimens.

Dall says that *Rhachianectes* has 145 laminæ of baleen on each side and that it is "light yellow," while Scammon describes it as "light brown or nearly white." Van Beneden speaks of the baleen in the Vienna Museum as being pale like that of *Balœnoptera acuto-rostrata*. The baleen in the U. S. National Museum from San Louis Obispo, Cal., is stated by Dr. True to be yellowish-white except at one end of the series where for a distance of about eight inches the blades and bristles are dull chocolate-brown. He says: "The largest plates measure 18 in. in length without the bristles, and 6 in. at the base. The longest bristles measure $9\frac{1}{2}$ in., and were perhaps originally a little longer" (*l. c.*, p. 290).

Throat furrows.— On either side of the median gular line *Rhachianectes glaucus* has two or more deep furrows. Their anterior ends closely approach each other and stand parallel for a short distance but gradually spread apart posteriorly. The furrows begin about 165 cm. from the tip of the mandible and end opposite a point half way between the eye and ear; the posterior ends are generally almost three times as far apart as are the anterior. Whale No. 24, male, 1225 cm. in length, had furrows 170 cm. long, the anterior ends being 20 cm. apart and the posterior ends 50 cm.; the anterior ends were 75 cm. from the tip of the lower jaw.

Although two furrows seem to be the usual number for *R. glaucus*, three are not infrequently present, and one individual which I examined possessed *four*. Whale No. 3, male, had three grooves, the left being 150 cm. long and the right 116 cm.; between their anterior ends was a shorter furrow 100 cm. in length. No. 4, male, also had three furrows, the two outer being 165 cm. long and the median 130 cm. The two outer furrows of No. 14, male, were 120 cm. in length and the one between them 154 cm. long; this was the only individual in which the median furrow was the longest of the three. In No. 16, male, the median furrow was 62 cm. in length while the two outer measured 150 cm.

No. 20, male, had *four* distinct furrows; the median and two outer ones were of about the

same length and between the middle and left near the *posterior* end was a fourth short groove. Out of the twenty-one specimens in which the number of gular furrows were recorded fifteen had two, and six three, or more. Several whales were brought in which were not measured or described and among them were four or five individuals showing three throat furrows. The grooves are almost 5 cm. in depth and have rounded edges.

The gular furrows of *Rhachianectes* seem to be a specialization in the direction of the throat and breast grooves of the Balænopterinæ. Since in *Rhachianectes* they are presumably present to increase the throat capacity they throw light upon the origin of the folds in the Balænopterinæ and tend to substantiate Prof. Kükenthal's theory that their purpose is to allow the short-headed members of this subfamily to take into the mouth a greater quantity of water containing their food.

The grooves of the Balænopterinæ in their early development were probably few in number and confined to the gular region, as in the case of *Rhachianectes*. As specialization of the entire body continued the furrows increased in number and in length extending backward upon the abdomen to give the greater thoracic expansion made necessary by the extraordinary development of the lungs.

It is well known that the sternum in all baleen whales is reduced to a vestige, and that the proximal ends of the ribs articulate loosely with the vertebral column, the distal ends of all but the first pair being free. Thus the frame-work of the thoracic cavity is capable of great lateral movement. In conjunction with the skeletal changes the lungs become greatly enlarged and adapted to retain the air during a considerable period of submergence. The increased power of lung expansion called for external as well as internal modification of the breast and the furrows which had already developed upon the throat became more numerous and prolonged posteriorly. The greatest number of furrows and their most frequent branching is between the pectoral fins, as might be expected.

In the existing Balænopterinæ, when the lungs are filled with air the whole thorax expands laterally and with it the flexible skin between the folds. Thus the furrows, besides their original function of increasing the throat capacity during the feeding operation, are also of use during respiration. *Rhachianectes* being a shallow water whale and a relatively primitive form, has not as yet developed the furrows upon the breast and abdomen.

In the case of the Balæninæ extensive specialization of the entire head has taken place and it has become of such a proportionately great size that there has been no necessity for increasing the throat capacity by the development of furrows; like the head, the entire thorax has become enormously enlarged by the great thickening of the body and has thus accommodated itself to the processes of respiration.

The Odontoceti, because of the nature of their food and the manner of securing it, are not under the necessity of increasing their throat capacity by the development of furrows.[1] In this group, moreover, which are not as extensively specialized as are the baleen whales, the sternum is long and the "thoracic box" is relatively immobile.

Pectoral limb.— The pectoral fins of *Rhachianectes* are distinctly individual being intermediate in shape between those of the Balæninæ and the Balænopterinæ. They are much broader and thicker proportionately and not so pointed as the fins of the latter subfamily, but are more lanceolate, and not as heavy, as thick or as broad as the pectorals of the Balæninæ.

[1] This is not literally true since the Ziphioides have two throat furrows.

PLATE XXIII.

PLATE XXIII.

RHACHIANECTES GLAUCUS.

Fig. 1. Superior surface of uninjured pectoral fin.
Fig. 2. Pectoral fin injured and infested with parasitic *Cyamus scammoni*.
Fig. 3. Superior surface of slightly injured pectoral fin.
Fig. 4. Inferior surface of pectoral fin showing usual type of coloration (slightly injured).
Fig. 5. Inferior surface of pectoral fin.
Fig. 6. " " " " "
Fig. 7. " " " " " (injured).
Fig. 8. " " " " " "

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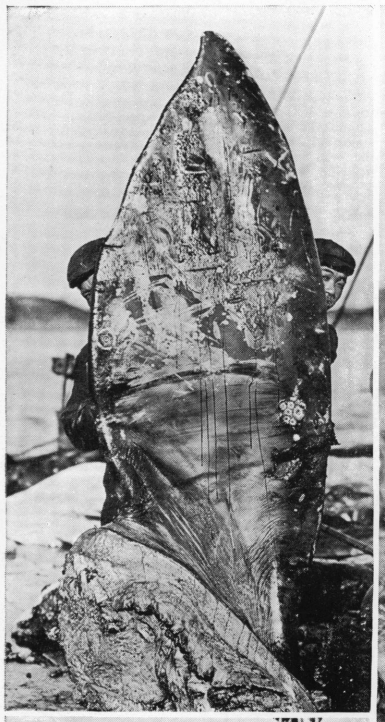



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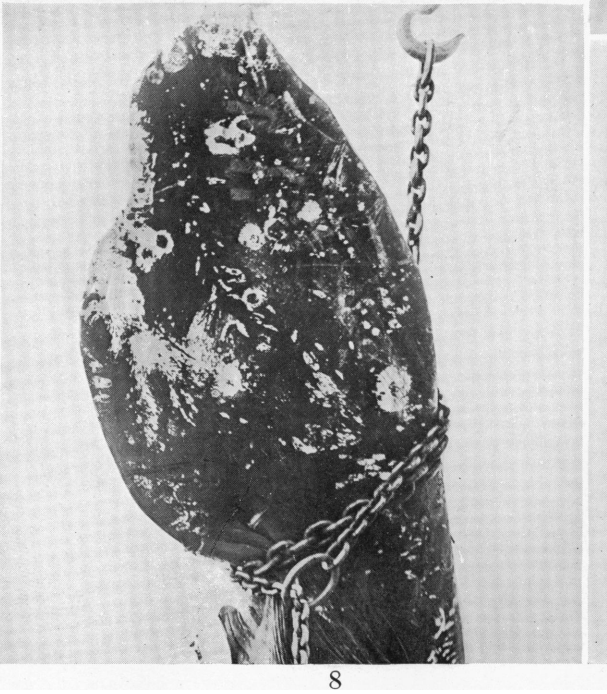

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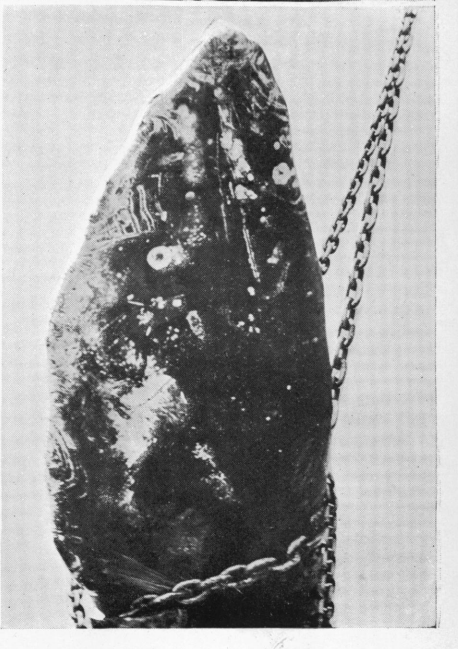

8

RHACHIANECTES GLAUCUS.

If photos of the pectoral of *Rhachianectes* are compared with those of a Right Whale or of any *Balænoptera* it will be seen at a glance that its shape is intermediate between the two types.

The flipper of *Rhachianectes* is broadly lanceolate. The posterior edge is about 3 cm. thick and strongly convex except just behind the rather blunt tip where a shallow concavity is formed; the anterior edge is regularly convex. The greatest breadth of the fin is at a point almost midway between the tip and the axilla, and the four digits are so prominently outlined that each may be traced for almost its full length before the fin has been stripped of blubber. There is considerable variation in the breadth of the pectoral among different individuals due to a greater or less convexity of the posterior border. Out of the twenty-three specimens on which notes were taken all but two had at least one of the flippers more or less injured on the posterior edges or tips. This, I believe, was mainly the work of Killers (*Orca orca*) which apparently keep the Gray Whales in a continual state of terror when upon their annual migrations. It may also be due, in some degree, to contact with rocks, as this species is generally to be found close in shore and frequently rolls about in the surf in very shallow water. Wherever the edges or tips of the fins were injured they were invariably thickly covered with parasitic crustaceans, *Cyamus scammoni*, and frequently the hard barnacle *Cryptolepas rhachianecti* was embedded on both surfaces.

Scammon's figure is hardly an accurate representation of the flipper of *Rhachianectes glaucus*. The outer edge is too straight, the tip is too blunt, and the fin is not broad enough.

In color, the pectorals are dark slate like the body. Above, on the posterior half, are a few scattered white circles, spots and flecks; below, the white circles and spots are more numerous and there are two, more or less broken, bands of white, or very light gray, about 8 cm. wide and 45 cm. long between the 2nd and 3rd, and 3rd and 4th fingers; the band between the 2nd and 3rd digits is usually the longer. The posterior edge of the fin is generally white.

There is much variation in the amount of white on the pectorals. Some individuals had the two bands between the fingers present on both surfaces and the entire fin thickly covered with spots, circles, dashes and flecks of white. Others had the distal third of the flipper washed with light gray, or white, while in still other cases white was practically absent on both surfaces. In almost all cases, however, there was more of the light markings on the lower surface than on the upper. A large proportion of the white circles and spots seemed to be scars left by parasitic cirripeds and were exactly similar to those on the flippers of *Megaptera*.

Flukes.— The flukes of *Rhachianectes glaucus* are quite unlike those of any other large whale. In shape they resemble most closely those of *Physeter macrocephalus* but both the anterior and posterior edges are more convex than in the latter species and the notch is more open and shallower. They are strikingly different from the slender, graceful flukes of *Balænoptera* and equally so from *Balæna* and *Eubalæna*. The resemblances to *Megaptera* are only superficial.

When either lobe of the flukes of *Rhachianectes glaucus* is viewed singly it is strongly suggestive of the pectoral fin in shape. The anterior margin is slightly convex becoming more so near the distal end. The posterior edge for the proximal two-thirds is strongly convex, but the distal third just behind the tip is slightly concave. Since the tips of the flukes in all adult specimens are more or less injured the concavity generally does not show and the posterior edge is evenly convex from the notch to the tip. The posterior edge, instead of being extremely thin as in *Balænoptera*, is almost three cm. in thickness and is broken by shallow, rounded emarginations. These crenulations must be normal as they were present in a fœtus (No. 1*a*) which was almost ready for birth, and in nearly all the adult specimens. They are analogous to the emarginations on the

flukes of the *Megaptera* but are neither so numerous nor so deep and give a wavy effect rather than the scalloped appearance seen in the Humpback.

The entire posterior edge is frequently infested with *Cyamus*, which fasten themselves upon the slightest abrasion, and the posterior outline is often entirely changed by the attacks of these parasites or by other injuries. The notch is deep and usually open but varies considerably in this respect.

The flukes are black above and below like the body. A few circles, flecks and dashes of white are scattered over both surfaces, the lower usually being most heavily marked. As with the pectorals, the amount of white is extremely variable. The white circles and spots in many cases are the scars left by barnacles; two or three individuals had flukes exactly resembling those of a Humpback in color.

The flukes of a fœtus (No. 1*a*) on the inferior surface had wide, dark gray anterior and posterior borders and very light gray central portions. Many broken whitish lines curving inward toward the notch ran transversely across each lobe starting on the anterior edge. In a general way this was suggestive of the inferior surface of the flukes of *Balænoptera musculus*. One adult individual (No. 17) had flukes marked in exactly the same manner but as it was quite unlike all other specimens examined this must be considered to be an unusual type of coloration.

Dorsal crenulations of peduncle.— On the dorsal ridge of the peduncle, beginning about 100 cm. from the insertion of the flukes, is a series of low, rounded crenulations which end a short distance beyond a point opposite the anus in an evenly rounded bunch, or "hump," about 50 cm. long and 7 or 8 cm. high. The crenulations are about 30 cm. apart, those nearest the flukes being the least developed and those just posterior to the "hump" the most prominent. Their number and size are open to considerable variation, one individual having only 6 rather indistinct tubercles while another had 14, even the most posterior of the row being well developed; 9 or 10 is the usual number as shown by the following table:

Number of crenulations.

Capture Number	Sex	
5	♂	9
6	♀	6
8	♂	10
10	♂	10
11	♂	8
13	♂	10
14	♂	10
15	♂	7
20	♂	14
22	♂	9
23	♂	9

These crenulations are very similar to those on the dorsal ridge of the peduncle of the Humpback but are somewhat more prominent. They were noted by Dall, Scammon and Townsend. Dall says: "On the vertebral line, for fourteen feet from the caudal flukes, is a series of 18 ridges, like the teeth of a saw, which are altogether dermal in their character" (*l. c.*, 1868, p. 226). Out of some 30 individuals which I examined only one possessed as many as 14, the next highest being 10; it would appear, therefore, that 18 is rather an unusual number.

Scammon's statement that it "has a succession of ridges, crosswise along the back, from

PLATE XXIV.

PLATE XXIV.

RHACHIANECTES GLAUCUS.

Fig. 1. Flukes showing barnacle scars; posterior edges slightly injured.
Fig. 2. Flukes; posterior edges very slightly injured.
Fig. 3. Posterior edge of flukes.
Fig. 4. Peduncle of fœtus No. 1*a*.
Fig. 5. Section of blubber at end of peduncle crenulations ("hump").
Fig. 6. Gray Whale spouting blood.
Fig. 7. Normal spout of a Gray Whale.

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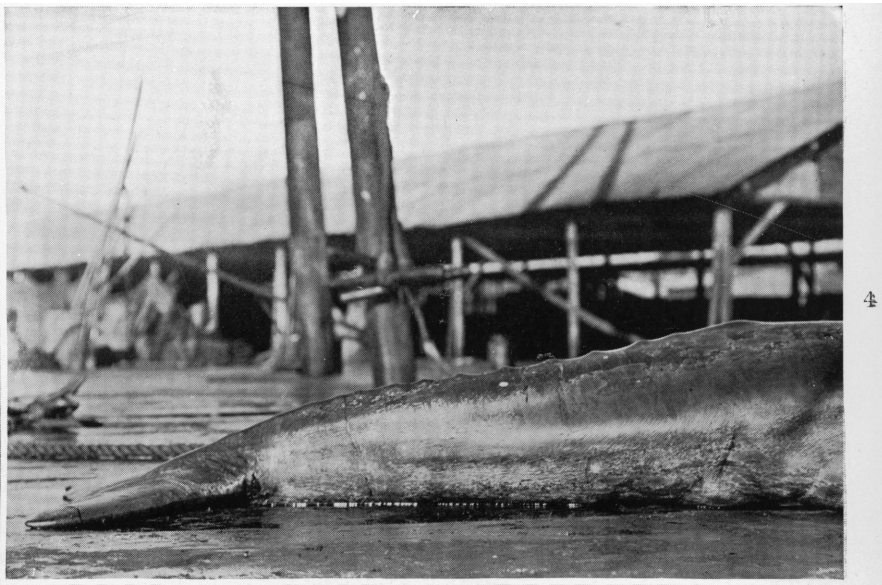

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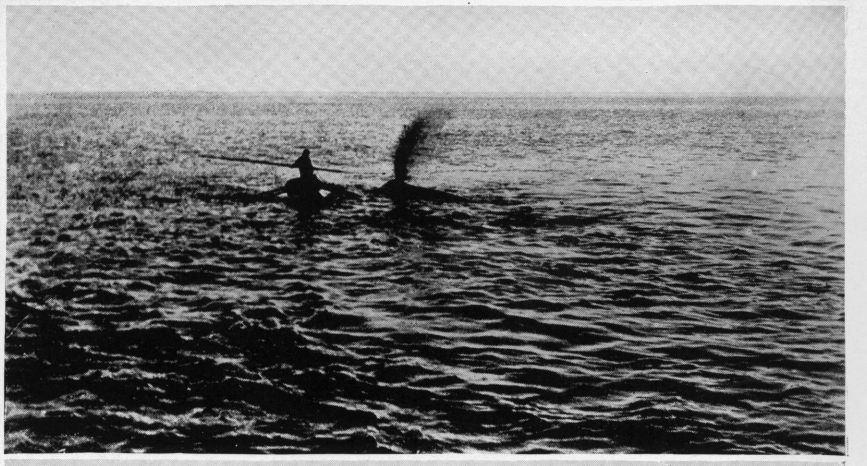

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RHACHIANECTES GLAUCUS.

opposite the vent to the flukes" is misleading for the ridges are certainly never transverse; although he figures them in their proper position he does not show the hump at the anterior end of the series.

Townsend speaks of the crenate ridge as being present in a fœtus but says he did not observe it in the adult. He may have seen a specimen in which it was so slightly developed as to have escaped his notice for it is probably never entirely absent.

In a fœtus 476 cm. long which I examined it was fully developed and 12 crenulations could be distinguished. Townsend's figure shows the crenate ridge as an elevated phlange which gives a somewhat erroneous idea of its true character for the dorsal ridge of the peduncle is not itself extended.

It seems somewhat remarkable that the presence of the hump or bunch, which ends the series of crenulations anteriorly, has not been previously mentioned, for in nearly all the individuals examined it was prominent and attracted my attention at once. By referring to the table of proportional measurements it will be seen that the relative position of the hump is decidedly variable, there being a difference of 11% between the highest and lowest ratios to the total distance from the notch of the flukes to the hump. Its average position relative to the length of the animal is the same as in the *Megaptera*, and by but little modification a dorsal fin similar to that of a Humpback could be derived from it. The fact that Humpbacks have the dorsal ridge of the peduncle distinctly crenulated from the flukes to the hump, in a way similar to that of the Gray Whales, is exceedingly interesting. There is a greater individual variation in the relative position of the dorsal fin in the *Megaptera* than in the *Balænoptera;* it is situated much further forward in the former genus than in the latter, and it has almost every possible shape between a prominent, falcate fin and a low rounded bunch.

Before the pectoral and caudal fins of the Humpback had reached their present high state of specialization it is very probable that the dorsal may have been much less prominent and that, as in the Gray Whales, it formed the terminal bunch at the anterior edge of the peduncle crenulations. As the specialization of the animal continued the dorsal hump increased in size, its shape became modified, and the crenulations in the remainder of the series grew less prominent.

It is possible, therefore, that we may see *Rhachianectes* developing a dorsal fin in a parallel way to the *Megaptera* and that, if specialization is continued, it may become as prominent as in the case of the Humpback and its relative position be more constant.

Hairs.— Both the fœtal and adult *Rhachianectes* possess longer hairs, and they are more widely and more uniformly spread over the entire head, than in any other baleen whale. The hairs were scattered in six irregular rows over the whole rostrum of fœtus No. 1*a*, and a line of 16 on the dorsal ridge extended from the blowholes to the snout. The most posterior hair was on the left side of the head opposite the posterior end of the blowholes.

On each rami of the mandible there were 21 hairs in three irregular rows, the most posterior being a little anterior to a point opposite the corner of the mouth. At the mandibular symphysis three irregular vertical rows, which closely approximated each other, contained 40 hairs. The areas most thickly covered with hirsute remains were the tips of the snout and mandible. Each hair was white, about 20 mm. long, and situated in a small pit surrounded by a dark ring.

On the head and lower jaw of the adult *Rhachianectes* the number and arrangement of the hairs is essentially the same as on the fœtus described above. The hairs are generally longer in the adult than in the fœtus, sometimes reaching a length of 40 mm.; on whale No. 18, male, in several places on the mandibular rami two hairs were found in a single follicle.

A careful examination was made of all parts of the body, both in the fœtus and adult, but in no place other than the head and jaws were there evidences of hair.

Blubber.— The blubber is very thick and fat, and varies in color from red to flesh-pink. Because of this, as noted by Dr. True, the Japanese recognize two kinds of Gray Whale, the "aosaki" (red blubber) and the "shirosaki" (white blubber). Although specimens with blubber strongly red, almost white, and of every intermediate shade, were taken during my stay at Ulsan, I could detect no differences, other than those purely individual, between them.

The blubber varies in thickness with individuals, and on different parts of the body, usually being from 20 cm. at the thinnest to 35 or 40 cm. at the thickest part.

The Japanese consider the meat and blubber to be of poorer quality for eating than those of any other baleen whale. In the winter, during the months of December and January when the price is at its highest, the blubber sells for about 4 sen (2 cents) per pound and the red meat 10 sen (5 cents).

In regard to the blubber Scammon says: "The coating of fat, or blubber, which possesses great solidity and is exceedingly sinewy and tough, varies from six to ten inches in thickness, and is of a reddish cast" (*l. c.*, p. 21).

Parasites.— The entire body of *Rhachianectes* is more or less thickly infested with the parasitic amphipod crustacean *Cyamus scammoni* Dall, and the hard barnacle *Cryptolepas rhachianecti* Dall. The barnacles embed themselves deeply on all parts of the body as well as on the flukes and pectoral fins.

The *Cyamus* are almost invariably to be found about the blowholes, the genital and anal openings, and on the tips and posterior edges of the flukes and flippers. Wherever a cluster of *Cryptolepas* have become embedded, *Cyamus scammoni* will also fasten and frequently cover a wide area having the barnacles as a nucleus; an injury or abrasion of the skin at once becomes the resting place of numbers of parasites. The snout of *Rhachianectes* for a distance of sixty or seventy cm. from the tip is usually cornified in a way similar to the "bonnet" of the Right Whale, and is produced, as in that species, by the action of the parasitic *Cyamus*. In some individuals the entire dorsal ridge of the rostrum from the snout nearly to the blowholes becomes cornified.

When a *Cryptolepas* detaches itself a circular grayish pit remains, which in time becomes white as the wound heals; these scars are exactly like those left by the barnacle *Coronula diadema* upon the *Megaptera*. No barnacles other than *Cryptolepas rhachianecti* were observed upon the Gray Whales, and it seems probable that none other infest this species.

A careful examination of the *Cyamus* taken from Korea specimens demonstrates that they are certainly identifiable with Dall's *Cyamus scammoni* described from the California examples of *Rhachianectes glaucus*. In any case it is doubtful if such highly specialized parasitic forms would show strong changes even if isolated for a long period and thus they furnish little information on the question as to whether or not the Gray Whales of the east and west sides of the Pacific actually mingle in the north.

Osteology.

The skeleton of *Rhachianectes*, other than the skull, has never been completely described, consequently a rather detailed account of its principal characters will be given in the following pages; also comparisons with other genera will be instituted whenever individual peculiarities can be emphasized thereby.

The length of the skeleton of the American Museum specimen, measured in a straight line, is 1107 cm. (36′ 4″). It was taken from a very old male (No. 20), 1250 cm. (41′ ½″) long, on January 19, 1912, at Ulsan, Korea.

The vertebral epiphyses are all firmly ankylosed, in most cases the lines of union being lost, and there are other evidences of extreme age.

Skull.

Plates XXV–XXVII.

In general form the skull of *Rhachianectes* is directly intermediate between the skulls of *Eubalæna* and *Balænoptera*, and somewhat resembles *Neobalæna*. The dorsal outline is much curved and especially high from the nares posteriorly, thereby giving to the occipital plane a comparatively slight obliquity, scarcely greater than in *Eubalæna*. The skull, as seen in profile, is thus quite unlike that of a Fin Whale, not only the whole dorsal outline being more convex but the rostral portion more arched. The interorbital region is thus deep and quite constricted.

The rostrum is narrow and elongate and the lateral outline tapers regularly toward the tip. The premaxillæ in the distal portion are very deep and have almost vertical sides, as in *Eubalæna*, but become somewhat flattened where they spread apart for the narial opening. Proximally they end a considerable distance from the vertex of the skull *leaving a wide area of the frontals exposed*, a primitive condition. The proximal portions of the premaxillæ enclosing the nasals appear as broad strips, superiorly placed, and articulate with the frontals by a deep interdigitating suture.

The maxillæ instead of being almost horizontal as in the Balænopterinæ are sharply oblique. Their inner (superior) edges slope abruptly downward in the distal half of the rostrum but in the proximal half are almost parallel with the skull axis. Each maxilla sends a narrow projection backward toward the vertex of the cranium, ending beside the premaxillæ. The lateral extentions of the maxillæ are remarkable in the fact that each one *overlaps the anterior edge of the orbital process of the frontal*, and bears posteriorly a strong tubercle which, with the anterior end of the orbit, partially encloses a large oblique foramen.

The nasals are very broad and long, joining in the median line to form a prominent crest; they occupy half the space between the nares and the summit of the occipital bone.

Compared with *Balænoptera* and *Megaptera* the orbital processes of the frontals are narrower, shorter and consequently less massive, but are much wider and less elongate than in *Eubalæna*. Viewed from below they have the trumpet-shaped form so characteristic of the fossil genus *Plesiocetus*. The posterior edges of the orbital processes of the frontals from the skull-vertex to the orbits present irregular margins; a primitive character.

The squamosal is comparatively small and has a straight outer edge quite unlike the concave squamosals of either *Balænoptera*, *Megaptera* or *Eubalæna;* in this respect the squamosal of *Rhachianectes* resembles that of fossil genera. The "temporal ridge," formed by the anterior margins of the temporal fossa, is well marked, thus showing an interesting primitive condition.

The supraoccipital presents three deep concavities, and on the superior portion two prominent and peculiar rugosities. These are undoubtedly homologous with the similar processes just under the lambdoid crest on the supraoccipital of dogs and other mammals, where the *rectus capitis posterior major* and *minor* muscles, which assist in raising the snout, are attached.

Their development, and the presence of similar rugosities below upon the basi-sphenoid and basi-occipital bones, are probably correlated with the fact that the cervical vertebræ are all free, and the neck is somewhat less abbreviated than in other large cetaceans thus allowing greater movement of the head.

The most interesting characters of the inferior surface of the skull are the comparatively short posterior extension of the vomer and pterygoid bones, the heavy pterygoids and, as mentioned above, the strongly down-turned edges of the basioccipital and basi-sphenoid which are exceedingly thick and massive.



Fig. 1. Inner view of tympanic bulla of *Rhachianectes glaucus*.

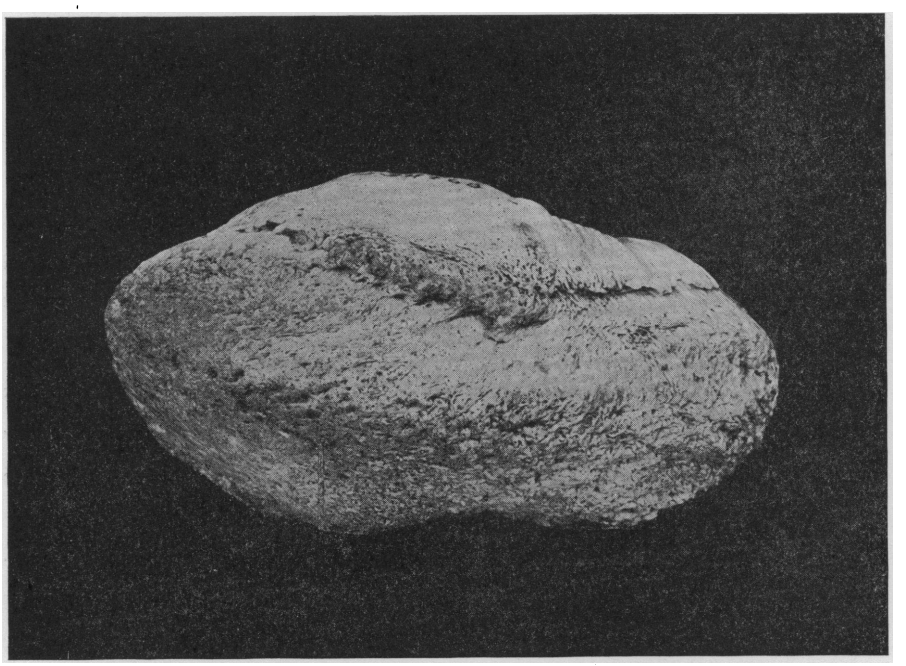

Fig. 2. Inferior view of tympanic bulla of *Rhachianectes glaucus*.

True remarks in regard to the peculiarities of the skull of *Rhachianectes:* "Most striking are the rugosities of the occipital, the large size of the nasals, the shortness of the nasal portion of the intermaxillæ, and their great depth anteriorly, the overlapping of the orbital processes of the frontal by the proximal portion of the maxilla, and the strong tubercle on the posterior margin of the former. All these characters are seen equally as well developed in the skulls figured by Malm as in the Monterey specimen.

"These and many other characters stamp it as a very distinct form, approaching closely neither *Balæna* nor *Balænoptera*" (*l. c.*, p. 291). Dall, Van Beneden, Malm and Beddard have also more or less completely described the skull of *Rhachianectes*.

The mandibular rami are without coronoid processes these being represented only by flattened tubercles. Each

PLATE XXV.

PLATE XXV.

RHACHIANECTES GLAUCUS.

Fig. 1. Dorsal view of the skull from California in the U. S. National Museum.
Fig. 2. Dorsal view of the skull from Korea in the American Museum.



1 2

RHACHIANECTES GLAUCUS.

PLATE XXVI.

PLATE XXVI.

RHACHIANECTES GLAUCUS.

Fig. 1. Ventral view of the skull from California in the U. S. National Museum.
Fig. 2. Ventral view of the skull from Korea in the American Museum.



1 2

RHACHIANECTES GLAUCUS.

ramus is moderately bowed and the superior outline from the coronoid rudiment to the distal end is regularly convex; the inferior outline is a succession of slight convexities and concavities as shown by the figures. On the inner side of the superior edge for the distal three fourths of the ramus is a well-marked alveolar sinus which becomes very deep near the tip. Both rami show the effects of a former injury.

The mandible of *Rhachianectes* strongly resembles that of the Balæninæ, and shows little concavity on the inner side proximally; it is surprising to find a specialized mandible of this type when the many other primitive characters of the skull are considered.

The tympanic bullæ of *Rhachianectes* are small and remarkable because of their strong lateral compression and slightly grooved internal border (that is, the border nearest the median line of the skull). They are totally unlike those of *Eubalæna* in size and general shape and differ from *Balænoptera* in being much less elongate, wider, and more compressed as well as in other points. In size and general outline they somewhat resemble *Megaptera* but instead of being almost globular, as in the latter genus, are greatly flattened. By their compressed form and concave internal border they strongly suggest the tympanic bones of certain fossil genera.

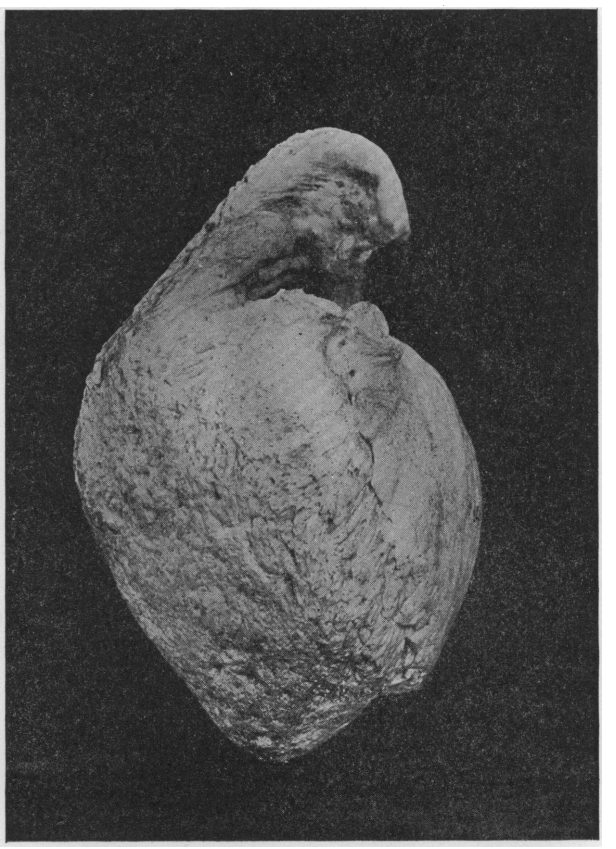

Fig. 3. Posterior view of tympanic bulla of *Rhachianectes glaucus*.

Table VI.— Measurements of skull of Rhachianectes glaucus.

	No. 34260 A. M. N. H. Andrews	No. 13803 U. S. N. M. Dall
	mm.	mm.
Total length from the tip of premx. to occipital condyle (straight)	2570	2464
Greatest breadth	1110	1041
Length of rostrum	2122	1740
Breadth " " at base	605	584
" " " " middle	429[1]	337[1]
" across pmx. at same point	202	184
Length of mx. from frontal border	1761	1651
Greatest breadth across mx. proximally	908	851
Length of premx.	2115	2007
" " nasals in median line	320	305
Breadth " " at anterior end	196	171
Distance from anterior end of nasals to anterior end of supraoccipital	383	375
Length of orbit (least)	172	165
" " palatine bones	424[2]	394[2]
Breadth across anterior ends of zygomatic processes of squamosals	1130	940
Breadth across anterior angles of orbital processes of frontals	950	889
Breadth across posterior angles of orbital processes of frontals	1035	991
Depth of skull from crest of supraoccipital to lowest point of pterygoids	731	

[1] Straight.

[2] The exposed position.

Table VI.— Continued.

	No. 34260 A. M. N. H. Andrews
	mm.
Length of mandible (straight)	2425
" " " (curved)	2500
Depth " " at middle	375
Greatest length tympanic bulla	102
" width " " posteriorly	79

Hyoid Bones.— The hyoid bones differ from those of all other baleen whales with which I am familiar.

The basihyal and two thyrohyals are ankylosed into a long, extremely massive and rugose bone. The central portion (basihyal) is dorso-ventrally compressed and has two short, anterior, conical projections (ceratohyals), but each thyrohyal rapidly thickens, becoming cylindrical

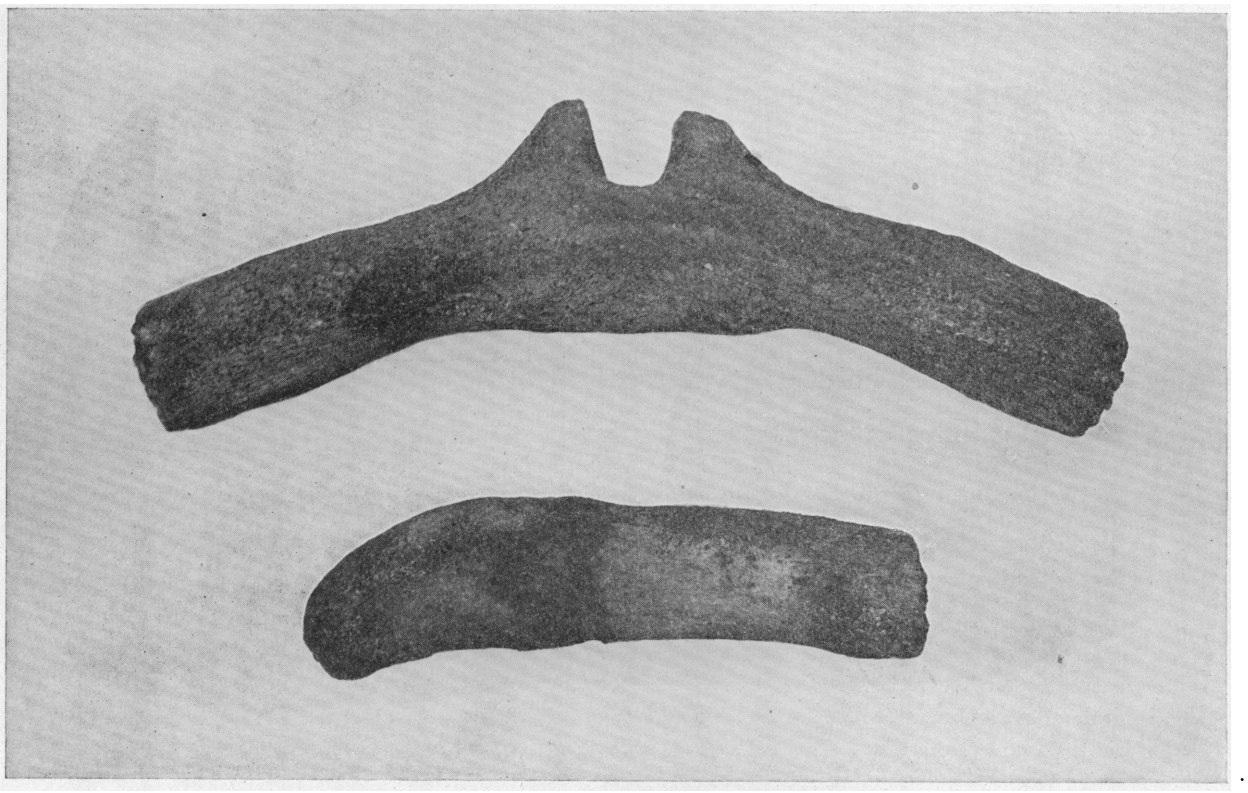

Fig. 4. Hyoid bones of *Rhachianectes glaucus*.

in the distal two-thirds and curved slightly backward. The shape of this portion of the hyoidean apparatus is distinctly individual but resembles that of *Eubalæna* much more than any *Balænoptera*.

The stylohyals, on the other hand, are decidedly more like those of the latter genus than the former. Each is a massive, rugose bone, slightly curved upward and forward. The anterior edge for its greater part is sharp and the posterior margin rounded so that a cross section of the stylohyal would be an ovoid ellipse. These bones are nearly half again as long and twice wider than are the roughly cylindrical stylohyals of an adult 54 ft. female *Eubalæna glacialis* in this Museum.

PLATE XXVII.

PLATE XXVII.

RHACHIANECTES GLAUCUS.

Fig. 1. Lateral view of the skull from California in the U. S. National Museum.
Fig. 2. Lateral view of the skull from Korea in the American Museum.
Fig. 3. External side of the left ramus of the mandible; Korea specimen in the American Museum.
Fig. 4. Internal side of the left ramus of the mandible; Korea specimen in the American Museum.



RHACHIANECTES GLAUCUS.

Measurements of the hyoid bones.

Extreme length of base (thyrohyals and basihyal)	631 cm.
Antero-posterior width across ceratohyal	149 "
Greatest thickness of thyrohyal distal end	105 "
" length of stylohyal	392 "
" width " "	106 "

VERTEBRÆ.

The vertebræ of *Rhachianectes*, through the combination of characters, differ widely from those of the other known genera of baleen whales, the general resemblance being rather more toward *Megaptera* than *Balænoptera* or *Eubalæna*.

The extremely rugose surfaces of practically all of the bones of the skeleton is interesting. I know of no other large Cetacean, except *Physeter macrocephalus*, in which this condition is so pronounced. Fifty-six vertebræ seems to be the normal number for *Rhachianectes glaucus*, the formulæ of three skeletons being as follows:

C	D	L	Ca.	Total		
7	14	12	23	= 56	Am. Mus. Nat. Hist.	(R. C. A.)
7	14[1]	12	23	= 56	U. S. Nat. Mus.	(R. C. A.)
7	14	14	21	= 56	British Mus.	(Beddard)

The differences in these formulæ will be discussed later.

Cervical vertebræ.— The cervical vertebræ are all free and show no tendency toward ankylosis. The atlas differs strongly from that of both *Eubalæna* and *Balænoptera* but bears a considerable resemblance to *Megaptera*. Its most distinctive characters are the massive neural arch, the short transverse processes, and the small size of the condylar facets relative to the height of the vertebræ.

The neural arch is high and exceedingly thick and massive, having an irregular rugose superior surface and an indistinct spine; it is perforated by a transverse arterial foramen. The short bunch-like transverse processes are set obliquely to the vertical plane of the axis, have irregular rounded ends, and are directed slightly upward. They resemble the transverse processes of the *Megaptera* but are shorter and not so wide.

The centrum of the atlas at the bottom slopes strongly upward, and at the sides inward, so that the posterior face is considerably smaller than the anterior. The opening between the condylar facets in conjunction with the neural canal is much shallower than is usual with the atlas of other baleen whales; this character is not so pronounced in the National Museum specimen, the opening being roughly V-shaped, the point directed downward.

On the posterior surface, the internal-superior corners of the facets for articulation with the axis are produced inward appearing as two irregular tubercles when seen from the anterior face of the axis through the space between the condylar facets.

The axis resembles, in general, that of a *Balænoptera*. The neural arch is very thick and massive, has a rugose, truncated summit and an indistinct spine. Each of the posteriorly directed, wing-like transverse processes is perforated somewhat above the center by a rather small oval foramen; the processes are thick and have irregular, rugose surfaces. The articular facets for the atlas are small and between them is a rather prominent odontoid process.

[1] Although but thirteen pairs of ribs are present in the U. S. National Museum specimen, the distal ends of the transverse processes of the twenty-first vertebra show distinct articular facets and indicate that the last pair of ribs has been lost.

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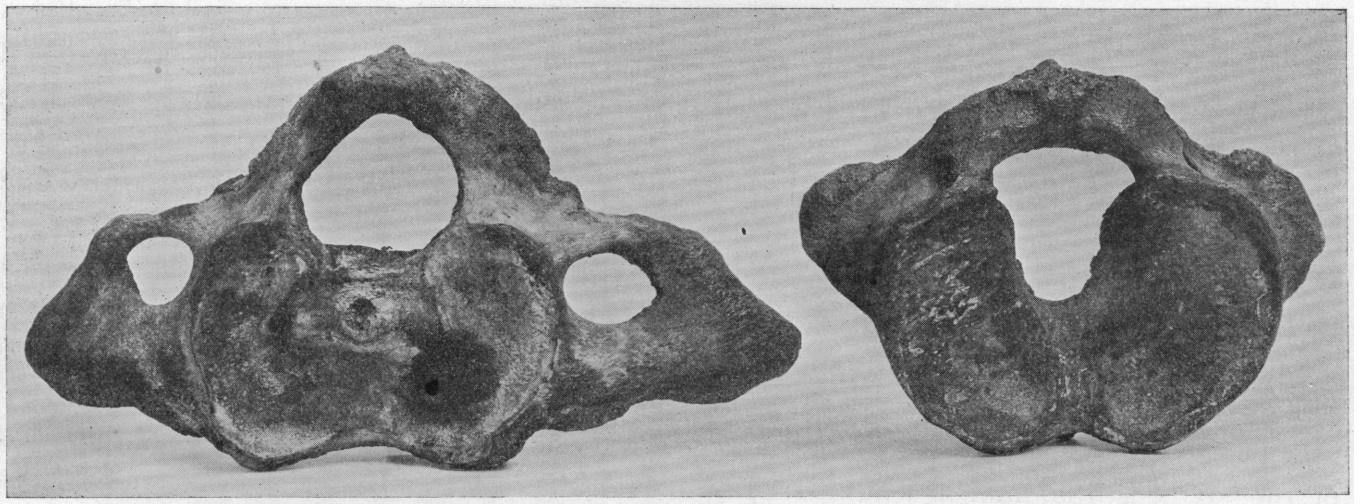

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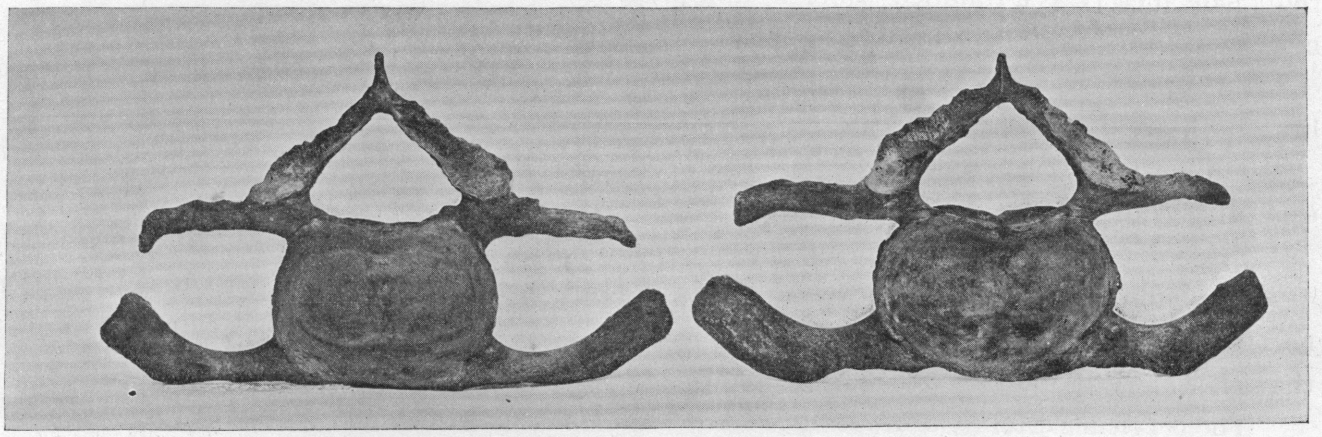

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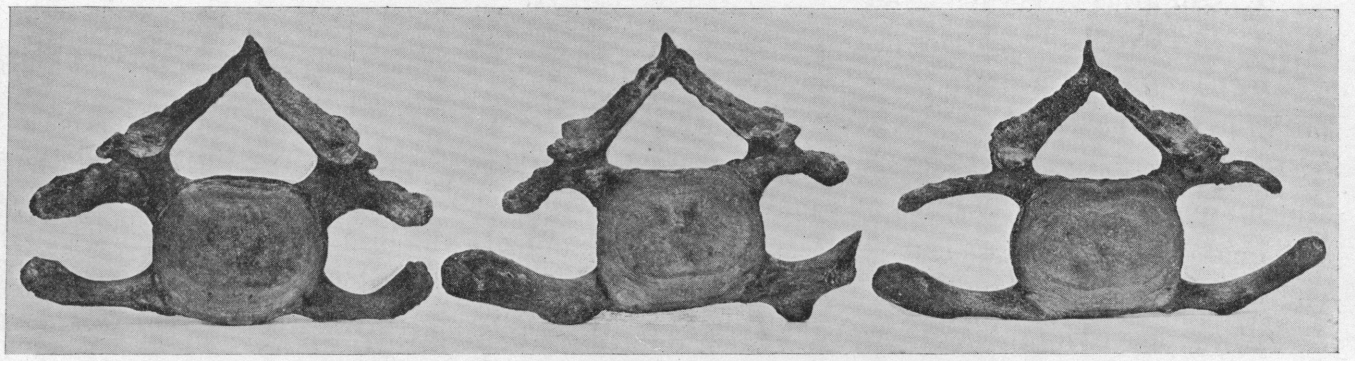

Fig. 5. Atlas and axis of *Rhachianectes glaucus*.
Fig. 6. Third and fourth cervical vertebræ of *Rhachianectes glaucus* (right to left).
Fig. 7. Fifth, sixth and seventh cervical vertebræ of *Rhachianectes glaucus* (right to left).

The third cervical vertebra has a circular body, somewhat compressed dorsally, and on either side two well developed transverse processes. The lower process is thick and roughly cylindrical for half its length, projecting somewhat downward but bends up and back in the distal half where it becomes compressed and blade-like. The upper process is straight, except at the distal end, and directed backward; the distal ends of the two processes stand widely apart (on the right side 50 mm.).

Both the upper and lower transverse processes of the fourth vertebra are similar to those of the third in length and direction, but the lower process is less massive and expanded distally.

On the fifth cervical the lower process is compressed throughout, especially so at the distal end where it is thin and expanded; instead of being directed slightly backward, as are those immediately preceding, it projects straight out and turns upward in the distal portion. The superior process is shorter than that of the fourth vertebra and curved slightly backward and downward.

The inferior transverse process of the sixth cervical is more massive than that of either the fifth or fourth, projects upward and forward and bears on the posterior side, proximally, a prominent flattened tubercle. The superior process of this vertebra is the shortest in the cervical series and projects strongly downward.

The seventh cervical has a lower transverse process which, although it is shorter than that of the sixth, is 135 mm. in length, roughly cylindrical and slightly expanded distally. The lower transverse processes of the seventh cervical of the U. S. Nat. Mus. specimen appear on the right side merely as a rounded tubercle and upon the left as a short process 64 mm. in length; neither seem to have been broken or otherwise injured.

The upper process is thick, compressed and considerably longer than that of the sixth vertebra; both are directed downward.

The anterior zygapophyses of the third vertebra are well developed, becoming larger on each succeeding cervical and appearing on the seventh as tubercles 43 mm. in length.

The spines of all the cervicals increase in height and thickness from the third to the seventh.

The laminæ of the neural arches of the third, fourth, and fifth vertebræ are wide at the bases, narrowing rapidly and uniting at the apices in erect and prominent spines. The arches of all the cervical vertebræ are high and triangular, considerably resembling those of *Megaptera*.

The cervical vertebræ of *Rhachianectes*, considered as a whole, are unique in the *combination* of the following characters:

1. An atlas of peculiar shape.
2. An axis having wing-like transverse processes.
3. Triangular neural arches and long inferior transverse processes in all cervical vertebræ posterior to the axis.[1]

Dorsal vertebræ.—The most distinctive character of the dorsal vertebræ is the zygapophyses, which are extraordinarily thick and massive with heavily rugose surfaces. They appear on the proximal ends of the transverse processes of the fifth dorsal as well developed tubercles rapidly enlarging on the succeeding vertebræ into prominent projections having massive globular ends.

The transverse processes are heavy throughout the series and have expanded, concave distal ends except in the case of the first and last dorsals; the ends of the transverse processes of the tenth thoracic vertebra are the widest of the series.

The neural spines of the first six dorsals are directed forward, those of the seventh, eighth, and ninth are vertical, and the remainder directed backward.[2] The spines increase steadily in antero-posterior width from the first to the twelfth dorsal, which bears the widest spine in the entire vertebral column.

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[1] As noted above, this was not entirely true of the U. S. Nat. Mus. specimen in which the lower transverse processes of the seventh cervical were small.

[2] The spines of the first four dorsal vertebræ of the U. S. Nat. Mus. specimen are directed backward, the fifth, sixth and seventh upward and the remainder backward.

The centrum of the first thoracic is circular except for a slight dorsal flattening; the dorsal compression of the centra becomes more pronounced in the posterior members of the series.

Lumbar vertebræ.— The lumbar vertebræ present certain individual peculiarities in the spines and zygapophyses, by means of which they may be distinguished from those of other whales. The spines of the entire lumbar series are directed strongly backward, that of the ninth being the most oblique of the vertebral column; the backward direction of the spines in the posterior vertebræ of the series is much greater than in *Megaptera* and somewhat more than in *Balænoptera*. All of the spines are regularly convex distally and that of the seventh lumbar is the longest.

The zygapophyses are prominent and show, in a modified form, the expanded distal ends so characteristic of the dorsal vertebræ. Those of the anterior half of the lumbar series are directed outward so that they overhang the anterior faces of the centra more strongly than is usual. The spines and zygapophyses differ in numerous minor ways from those of other genera.

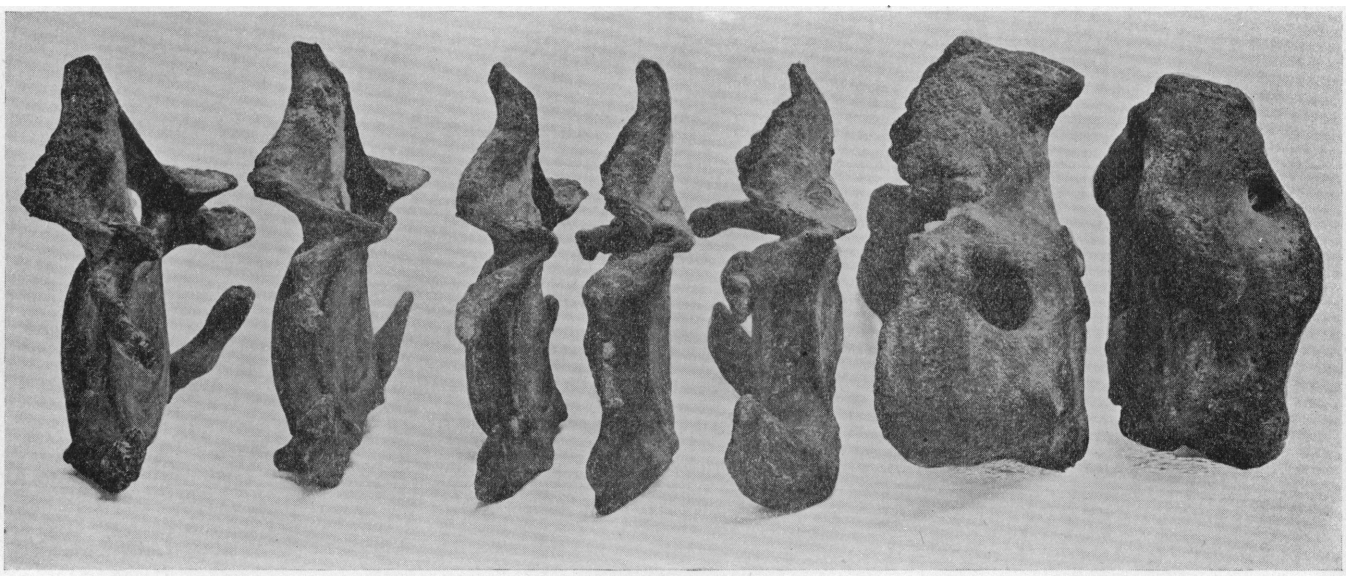


Fig. 8. Cervical vertebræ of *Rhachianectes glaucus*.

The transverse processes of the first four units of the lumbar series are curved somewhat upward, the fifth, sixth and seventh are horizontal, and those of the remaining vertebræ directed more or less downward. The transverse processes of the sixth lumbar are the longest.

Caudal vertebræ.— The caudal vertebræ do not agree closely with those of other baleen whales. In the size, shape, and direction of the transverse processes, spines and zygapophyses, and in the appearance and disappearance of the foramina and processes, many differences are apparent.

The spines decrease gradually in height from the first to the eleventh caudal where they become lost. The zygapophyses of the anterior caudal vertebræ in their expanded, globular distal ends resemble those of the dorsal series, and disappear with the neural spines upon the eleventh vertebra. The spines and zygapophyses show a decidedly greater resemblance to *Megaptera* than to *Balænoptera*.

The transverse process of the first caudal is the widest in the entire vertebral column and is directed strongly downward. The transverse process of the fourth, fifth and sixth caudals arise from the posterior part of the centra and project outward and forward, their inner edges almost meeting the expanded outer margins of the anterior faces of the centra; in this way a partially

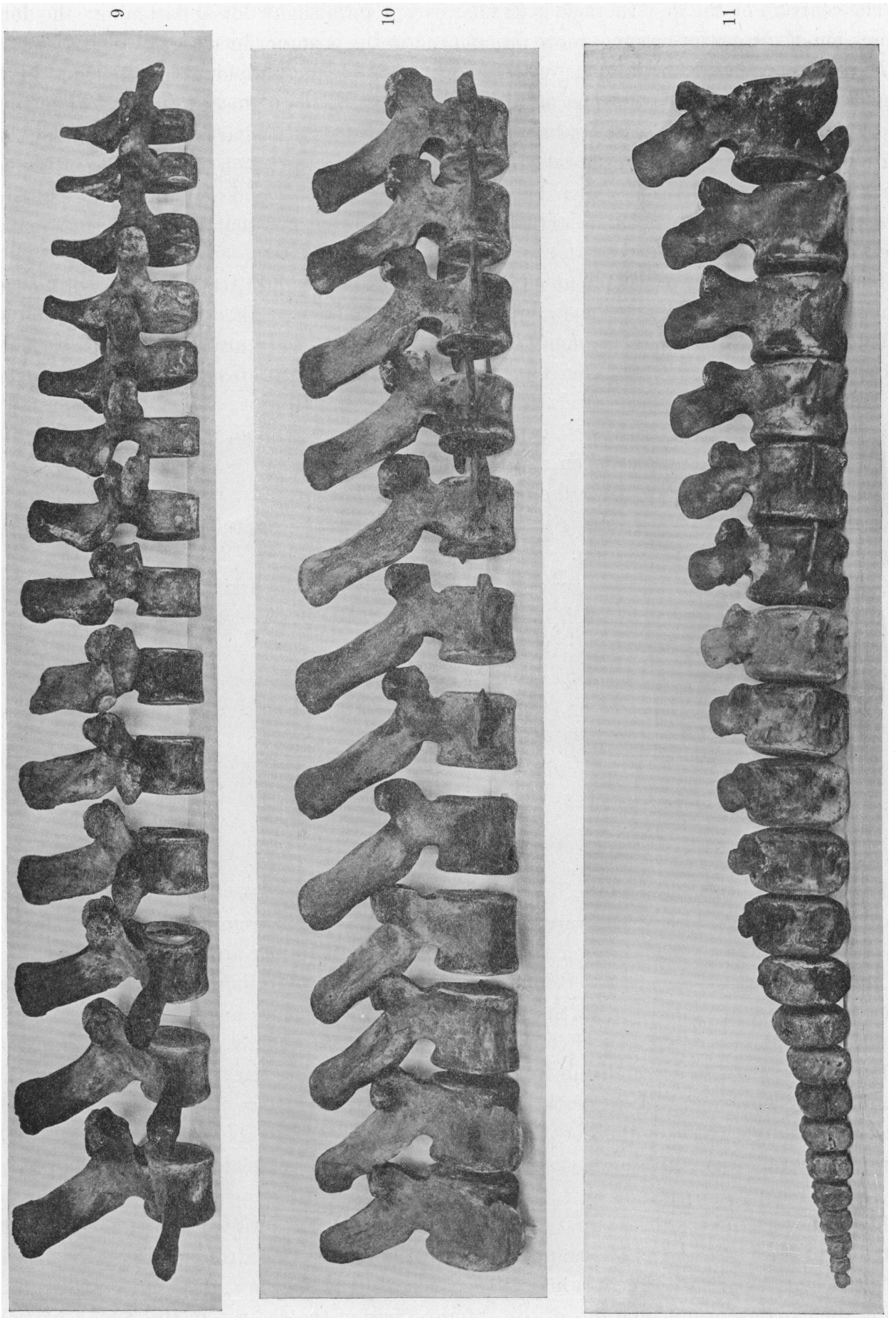


Fig. 9. Dorsal vertebræ of *Rhachianectes glaucus*.
Fig. 10. Lumbar " " " "
Fig. 11. Caudal " " " "

enclosed foramen is formed. On the right side of the sixth caudal this foramen is completely encircled [1] and the transverse process near the center is also perforated by a second vertical canal.

The antero-posterior diameter of the centrum of the first caudal is the greatest of the entire vertebral column and the anterior face is almost a perfect circle. Although the inferior median carina of the thirty-third vertebra is distinctly bifurcated posteriorly, the thirty-fourth is definitely indicated as the first caudal by the presence of the first pair of chevrons which have become firmly ankylosed to its centrum.

Beddard states that he counted in the British Museum specimen 14 lumbar vertebræ and 21 caudals, whereas both the American Museum and U. S. Nat. Mus. skeletons have 12 lumbars and 23 caudals. Since the total number of vertebræ, and also those of the dorsal series, are alike in the three specimens, I believe they will be found to possess a similar number of lumbar and caudal units. Unless the skeletons have been examined with the chevrons *in situ*, or there happens to be an ankylosis as in the case of our specimen, it is difficult to make an absolutely correct determination of the lumbar and caudal units. Although the inferior median carina is usually first distinctly bifurcated upon the first caudal, the division may sometimes occur upon the last lumbar and cannot, therefore, be taken as an infallible guide.

In the following table data as to the appearance and disappearance of the several processes and foramina in *Rhachianectes glaucus* is given. For convenience of reference similar data of other genera are placed in apposition.

	Rhachianectes glaucus		*Eubalæna glacialis*	*Megaptera nodosa*	*Balænoptera physalus*
	Am. Mus. Nat. Hist.	U. S. Nat. Mus.			
Last vertebra to bear a transverse process is No.	41	41	42	39	48
Last vertebra to bear a neural spine is No.	44	44	45	41	50
First vertebra with perforated transverse process is No.	39	38	39	—	43

Table VII.— Measurements of Vertebræ of Rhachianectes glaucus.

	mm.
Atlas, greatest breadth across transverse procesess	417
" " depth	312
" " breadth across condylar facets	317
" " depth of condylar facet	224
" breadth of condylar facet	124
" greatest depth of neural arch	69
" breadth of distal end of tr. proc.	109
Axis, greatest breadth across tr. proc.	662
" " depth	327
" " " of centrum	162
" " breadth " "	289
" " length of right tr. proc.	243
" length of foramen in tr. proc.	89

[1] This foramen does not become enclosed in the U. S. Nat. Mus. specimen.

Table VII.—Continued.

	mm.
5th cervical, breadth across upper tr. proc.	446
" " " " lower " "	528
" " greatest depth (vertical)	318
" " depth of centrum "	157
" " breadth of centrum	195
" " length of upper tr. proc.	130
" " " " lower " "	176
7th cervical, breadth across upper tr. proc.	434
" " " " lower " "	445
" " greatest depth (vertical)	329
" " " " of centrum	164
" " " breadth " "	189
" " " length of upper tr. proc.	135
" " " " " lower " "	135
1st dorsal, breadth across tr. proc.	460
" " greatest depth (vertical)	371
" " " " of centrum	166
" " " breadth of centrum	214
" " length of tr. proc.	155
" " " " spine	94
5th " breadth across tr. proc.	—
" " greatest depth (vertical)	445
" " " " of centrum	175
" " " breadth " "	210
" " " length of tr. proc.	173
" " " height of spine	184
10th " " breadth across tr. proc.	636
" " " depth (vertical)	496
" " " " of centrum	174
" " " breadth " "	227
" " " length of tr. proc.	243
" " " greatest height of spine	259
1st lumbar, breadth across tr. proc.	831
" " greatest depth (vertical)	542
" " " " of centrum	186
" " " breadth " "	229
" " " length of tr. proc.	340
" " " height of spine	323
5th " breadth across tr. proc.	886
" " greatest depth (vertical)	600
" " " " of centrum	206
" " " breadth " "	240
" " " length of tr. proc.	340
" " " height of spine	363
10th " " breadth across tr. proc.	780
" " " depth (vertical	580
" " " " of centrum	225
" " " breadth " "	265
" " " length of tr. proc.	285
" " " height of spine	363
1st caudal, " breadth across tr. proc.	665
" " " depth (vertical)	535
" " " " of centrum	243
" " " breadth " "	274
" " " length tr. proc.	230
" " height of spine	265

Table VII.— Concluded.

			mm.
5th caudal,		breadth across tr. proc.	468
"	"	greatest depth (vertical)	465
"	"	" " of centrum	270
"	"	breadth " "	281
"	"	length tr. proc.	115
"	"	height of spine	210
10th	"	breadth across tr. proc.	275
"	"	depth (vertical)	330
"	"	" of centrum	258
"	"	breadth " "	275
"	"	length of tr. proc.	—
"	"	height of spine	83

Chevrons.

The American Museum skeleton has twelve chevrons and the National Museum ten; apparently two have been lost in the latter case and twelve would seem to be the normal number.

The first chevron in the American Museum series is firmly ankylosed to the centrum of the first caudal vertebra. It is 75 mm. in length, 118 mm. wide and free distally. The second chevron is 180 mm. long and 91 mm. wide, the laminæ uniting distally to form a long hæmal spine. The third chevron is the longest of the series, having a maximum length of 240 mm. and a width of 120 mm.

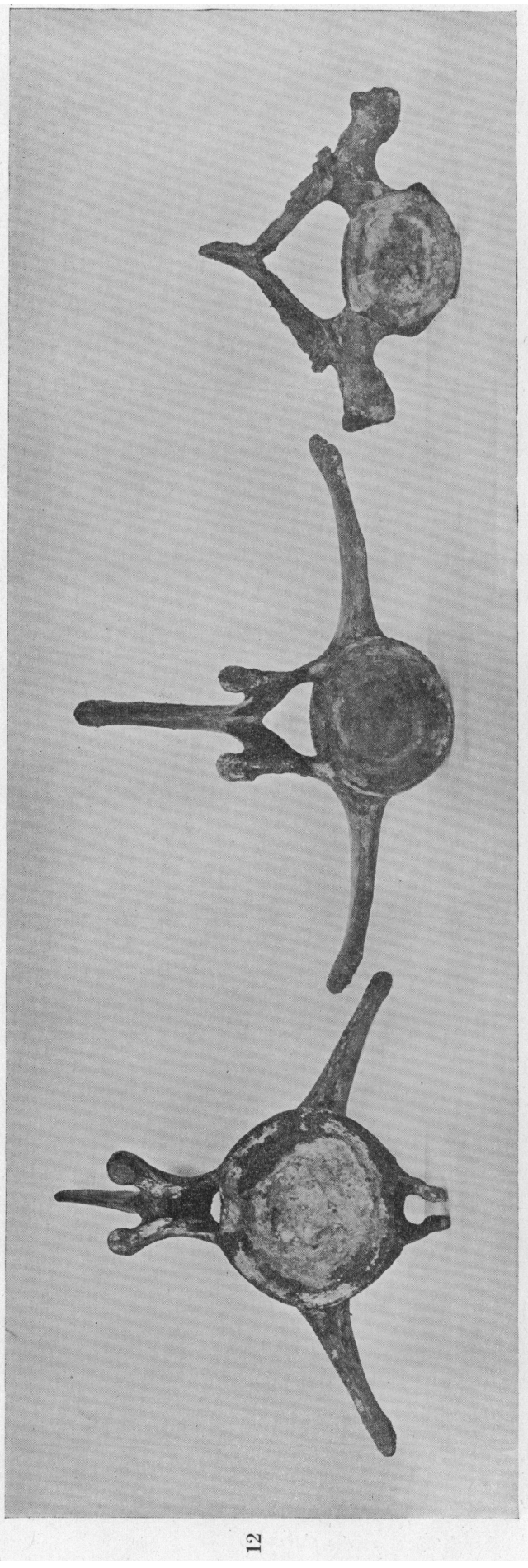
From the third backward, the chevrons increase rapidly in width and gradually decrease in length, the fifth being the widest of the series; its maximum width is 212 mm. The last two members of the series have their distal ends free.

Ribs.

The ribs of *Rhachianectes* are exceedingly interesting. The most important feature of their morphology is to be seen in the proximal ends of the third, fourth, fifth, sixth, and seventh, *on each of which a large tubercle, neck and head are developed.* The prominent tubercle, and the deep concavity between it and the head in all of these ribs gives them a shape very similar to those of the toothed whales and quite unlike any Mystacoceti.

In *Balænoptera* the second and third ribs usually have prominent tubercles and long necks while in the remainder of the series the necks and heads become atrophied, or lost. In *Rhachianectes* the necks and heads do not disappear until the *eighth rib* and up to this point are well developed and prominent. Thus the anterior half of the rib series is articulated to the vertebral column much more firmly than in other baleen whales, and presumably the thorax is capable of less lateral movement.

The proximal end of the first rib is thin and rounded but has a small, outwarding projecting tubercle (the head) near the lower edge. On the second rib this tubercle (the head) is more thoroughly developed, and on the third has become extended into a long neck and an expanded head which project outward at a right angle to the remainder of the rib. The tubercle is very prominent and has a large flattened articular fossa. On the fourth rib the neck is slightly shorter than that of the third and the angle it forms with the shaft is a little wider; its tubercle, however, is considerably larger than that of the third.



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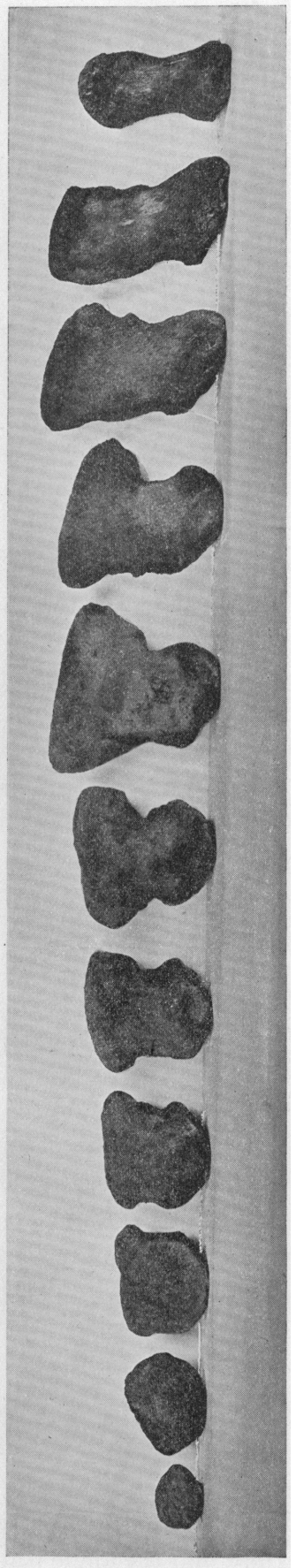

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Fig. 12. First dorsal, first lumbar and first caudal vertebræ of *Rhachianectes glaucus* (right to left).
Fig. 13. Chevrons of *Rhachianectes glaucus*.

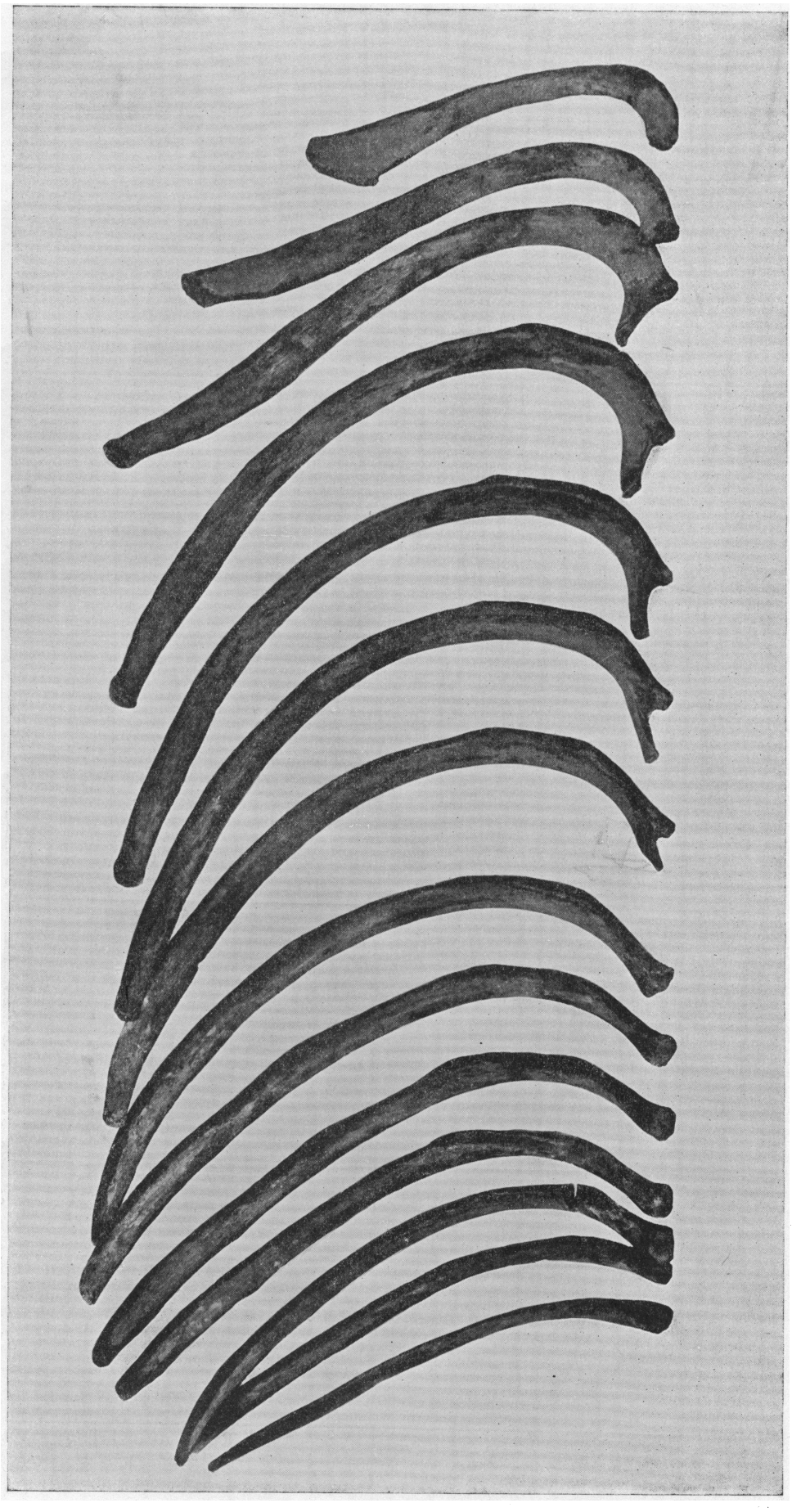

Fig. 14. Ribs of *Rhachianectes glaucus*.

The neck of the fifth rib is shorter and forms a wider angle with the shaft than does the fourth, but its tubercle is larger and more prominent and the concavity of the neck between it and the capitulum is deeper.

The neck of the sixth rib is similar to the fifth in length, size of tubercle and the angle with the shaft. That of the seventh is a little shorter than the sixth, the angle is somewhat wider and the tubercle a little larger.

Upon the eighth rib the neck and head disappear and are represented only by a small projection; the tubercle of the rib is greatly enlarged, however, and is separated from the process representing the neck by a well-marked concavity, which is present to a less extent upon all the succeeding ribs except the last two pairs.

The ribs are all long and massive, considerably exceeding in measurements those of the 40-foot *Megaptera* and the 50-foot *Balænoptera physalus* recorded by Struthers.[1]

The first is of uniform width in its proximal half but rapidly expands in the distal portion where it becomes the widest of the series; the fifth is the longest.

The ribs of the U. S. National Museum specimen differ in the important particulars that upon the first the portion representing the neck and head is considerably more produced than in the American Museum skeleton and that *the second rib bears a fully developed neck and head;* the distance from the tubercle to the end of the head of this rib is 225 mm.

Measurements of the ribs and of the capitular processes of the first eight pairs are given in the appended table:

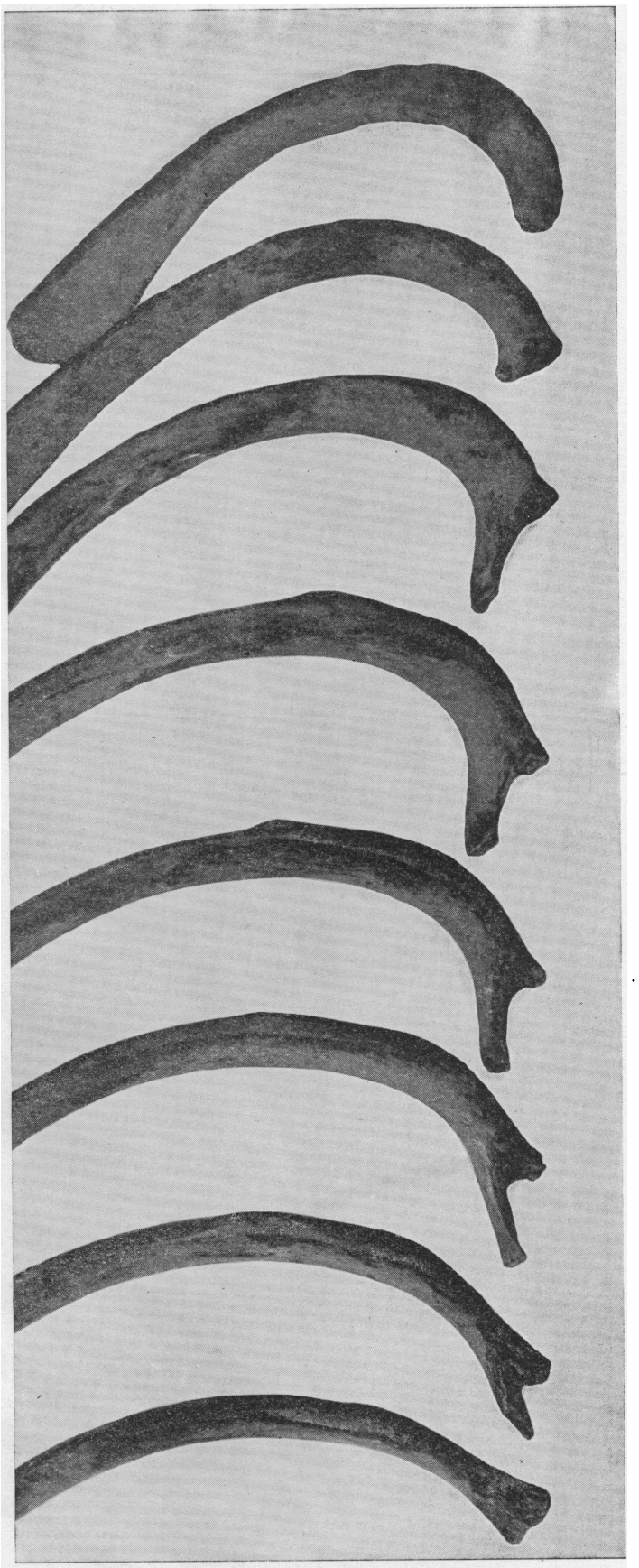

Fig. 15. Proximal portions of first eight ribs of *Rhachianectes glaucus*.

[1] Journal of Anatomy and Physiology, Vol. XXIII (new ser. Vol. III), 1889, p. 143.

Table VIII.—Measurements of the ribs of Rhachianectes glaucus.

	1st	2nd	3rd	4th	5th	6th	7th	8th	14th
Length on outside curve from tip of head to distal end	mm. 1400	mm. 1855	mm. 2255	mm. 2455	mm. 2515	mm. 2490	mm. —[1]	mm. 2335	mm. 1430
Length, straight, from tubercle to distal end	1020	1335	1590	1700	1785	1750	1765	1725	1370
Distance from back of tubercle to end of head	—	125	251	233	213	213	—[1]	110	—

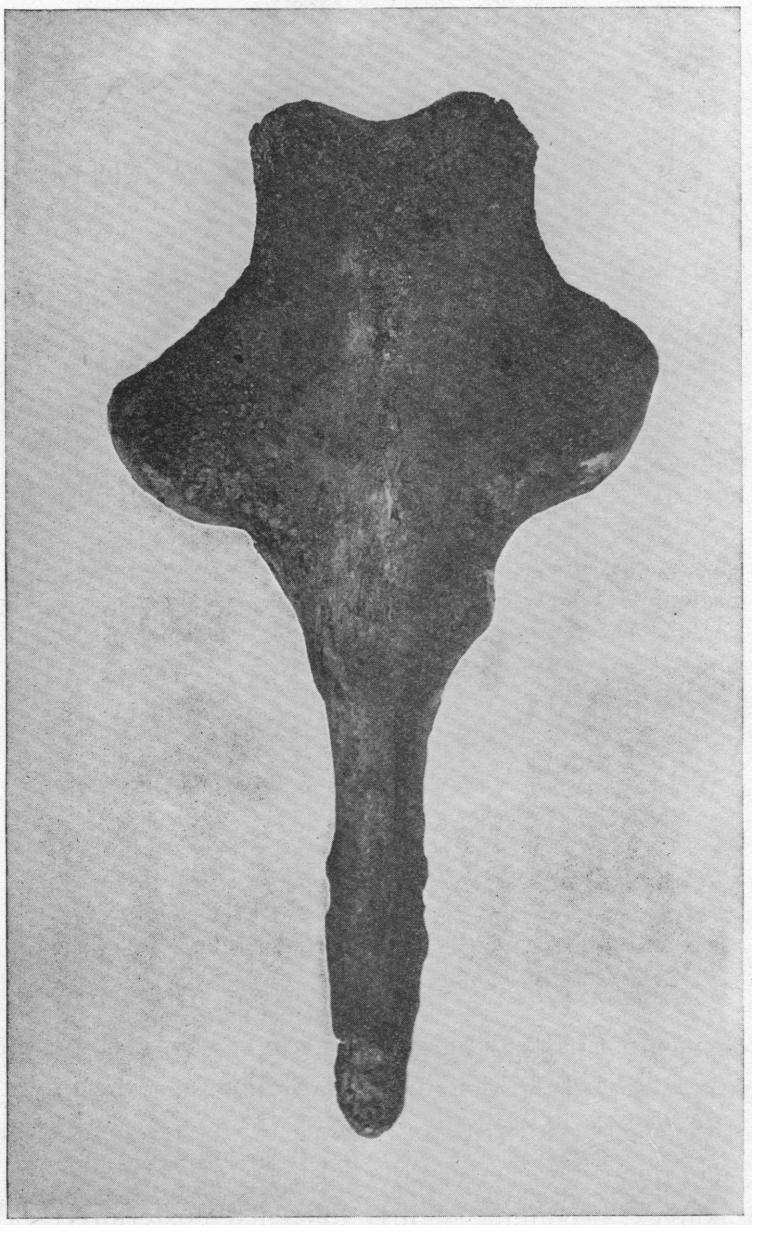

Fig. 16. Sternum of *Rhachianectes glaucus;* Am. Mus. skeleton.

Sternum.

The sternum belonging to the skeleton of *Rhachianectes* in the American Museum has the form of a Latin cross and closely resembles the corresponding bone of *Balænoptera acuto-rostrata*. The lateral arms of the cross are short and irregularly rounded and the summit of the superior portion is abruptly truncated and has a shallow concavity. The inferior prolongation of the sternum is irregularly cylindrical terminating in a blunt point, and is remarkable for its length. The entire sternum, but especially the anterior surface, is rugose and covered with small osseous tubercles which apparently are not due to exostosis but have been developed for tendon attachments.

The sternum of the United States National Museum specimen shows an extraordinary difference in shape from that described above and demonstrates the enormous individual variation to which such almost rudimentary bones are subject. The sternum is concave on the superior surface, has two rounded, wing-like lateral processes and terminates inferiorly in a short irregular spine.

[1] End of neck injured.

Measurements of sternum.

	American Museum	U. S. Nat. Museum
	mm.	mm.
Greatest height (vertical)	460	223
" breadth (across arms)	260	242
Length of lower process	276	165

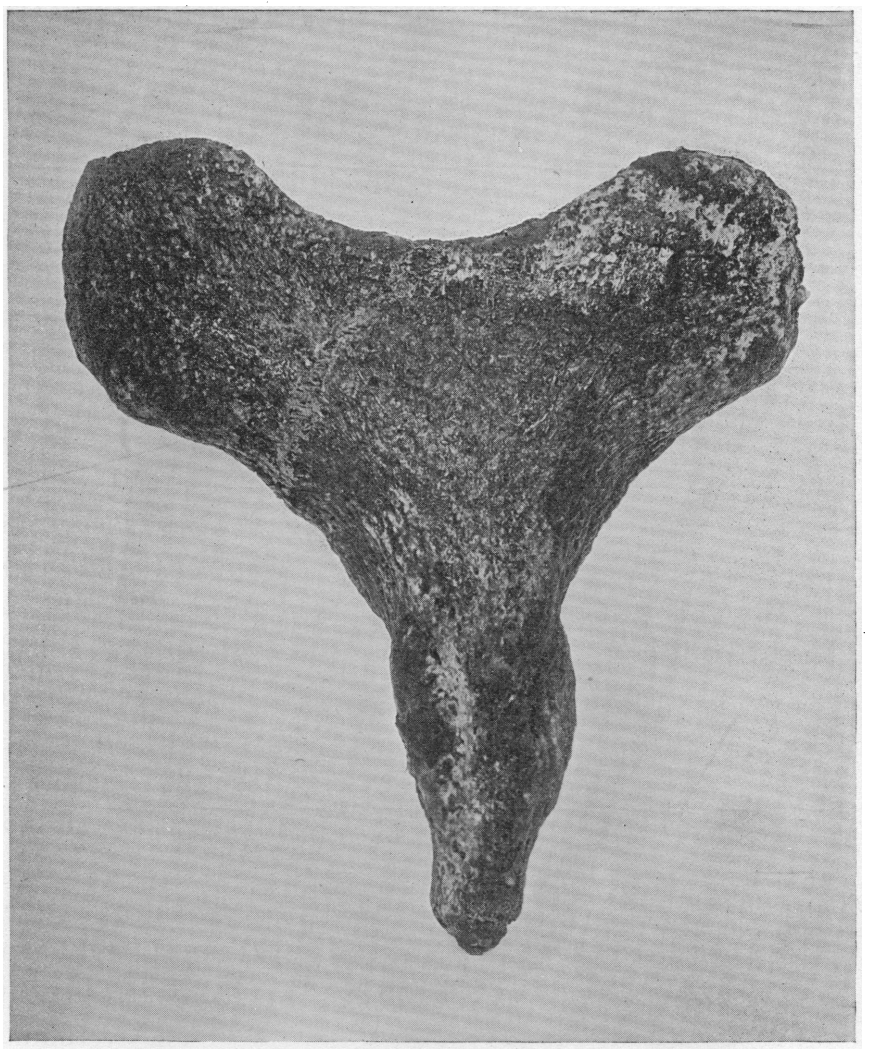

Fig. 17. Sternum of *Rhachianectes glaucus;* U. S. Nat. Mus. skeleton.

Pectoral Limb.

Scapula.— The scapula of *Rhachianectes* is distinctive being intermediate between the wide, low blade of *Balænoptera* and the high, narrower and more symmetrically fan-shaped scapula of *Eubalæna.* In the great height proportional to its width it approaches the latter genus while in the well developed coracoid and large acromion it resembles the former.

The superior margin is quite evenly convex, becoming slightly flattened posteriorly. The glenoid border is almost straight except for a short concavity where it rises from the glenoid fossa and neither it nor the coracoid border overhangs as strongly as in the scapulæ of *Balænoptera.*

The acromion is exceedingly wide throughout, expanded and irregularly rounded distally, and slightly curved.

The coracoid is thick and massive, turned sharply inward and directed somewhat upward from the margin of the glenoid fossa.

The external face of the scapula is quite strongly concave as in *Eubalæna*. It is much thicker and more massive than in *Balænoptera* but not as thick as that of a Right Whale.

Measurements of the scapula are given in Table IX.

Humerus. — The humerus is nearly straight, the superior edge is but slightly concave and the external tuberosity is prominent. In all of these characters the humerus differs from that of *Balæna*, *Eubalæna* and *Megaptera* and strongly resembles the fossil genus *Plesiocetus*; while in *Balænoptera* the head is almost directly upon the summit of the bone, the concavity of the sides gives the humerus quite a different appearance from that of *Rhachianectes*.

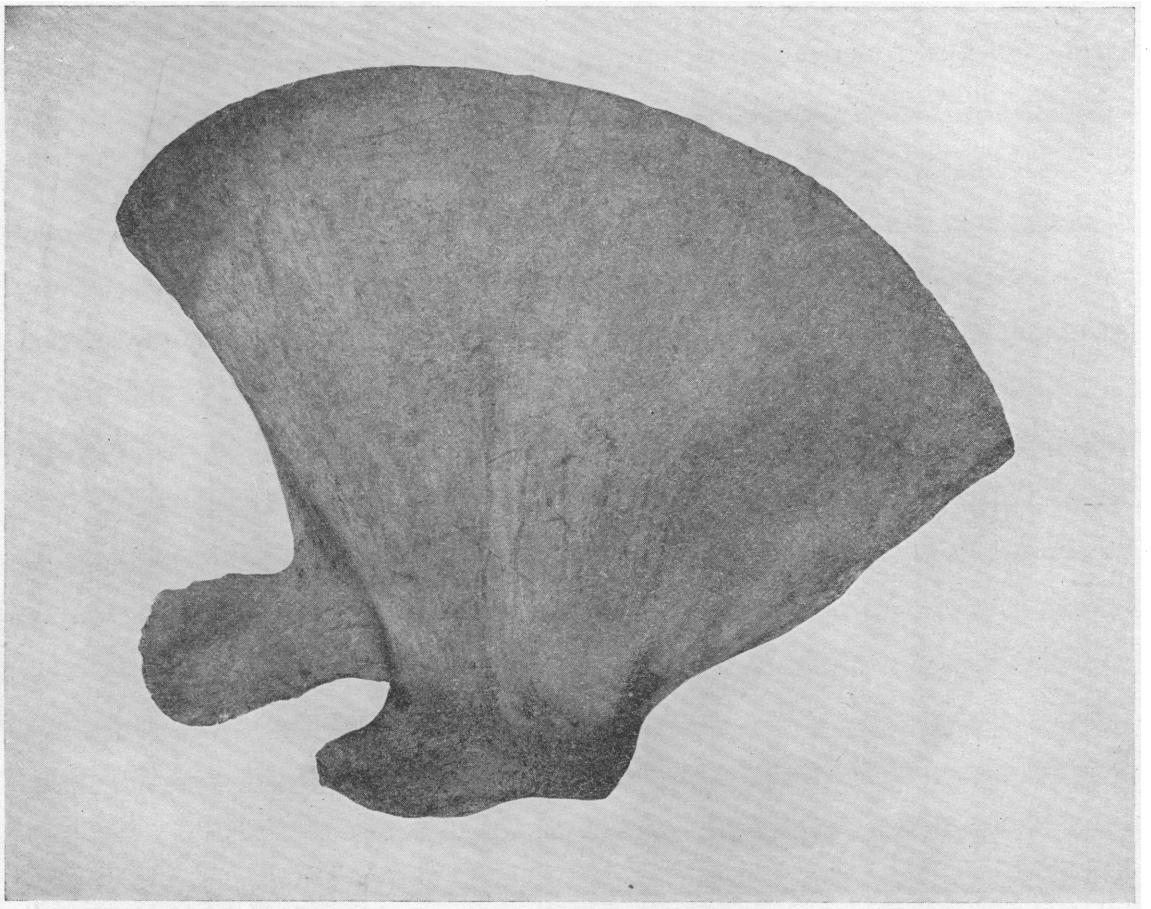

Fig. 18. Inner view of right scapula of *Rhachianectes glaucus;* Am. Mus. skeleton.

Radius.— The radius is remarkable for its width. The exterior edge for its proximal half is slightly convex and in the distal portion a little concave. The interior edge presents a shallow concavity due to the broadening of the bone at the carpal end. For the proximal half the radius is of almost uniform width but in the distal half rapidly expands.

Ulna.— The ulna has a nearly straight inner edge but a strongly concave outer margin due to the rapid broadening of the bone in the distal half. The olecranon process is prominent and projects upward.

The radius and ulna differ markedly from those of *Balæna*, *Eubalæna* and *Megaptera* but in general resemble *Balænoptera*. The broad radius is somewhat similar to that of *B. musculus* but the straight ulna is quite unlike the bone in that species. The radius and ulna of *B. physalus* and *B. borealis* are more slender, more curved and less expanded distally than in *Rhachianectes glaucus*.

Manus.— *Rhachianectes* has four digits in the manus. The phalangeal formulæ of the flippers of the U. S. National Museum specimen (which are more nearly perfect than are those of the American Museum skeleton) are as follows:

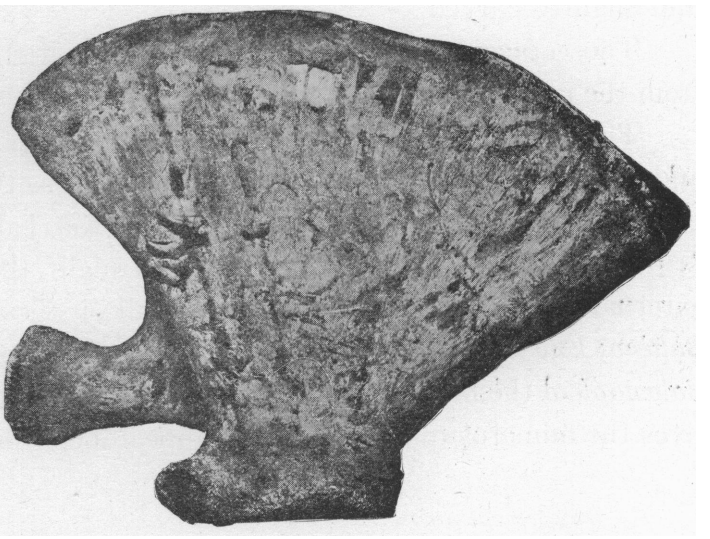

Fig. 19. Inner view of right scapula of *Rhachianectes glaucus*, photographed at Ulsan, Korea.

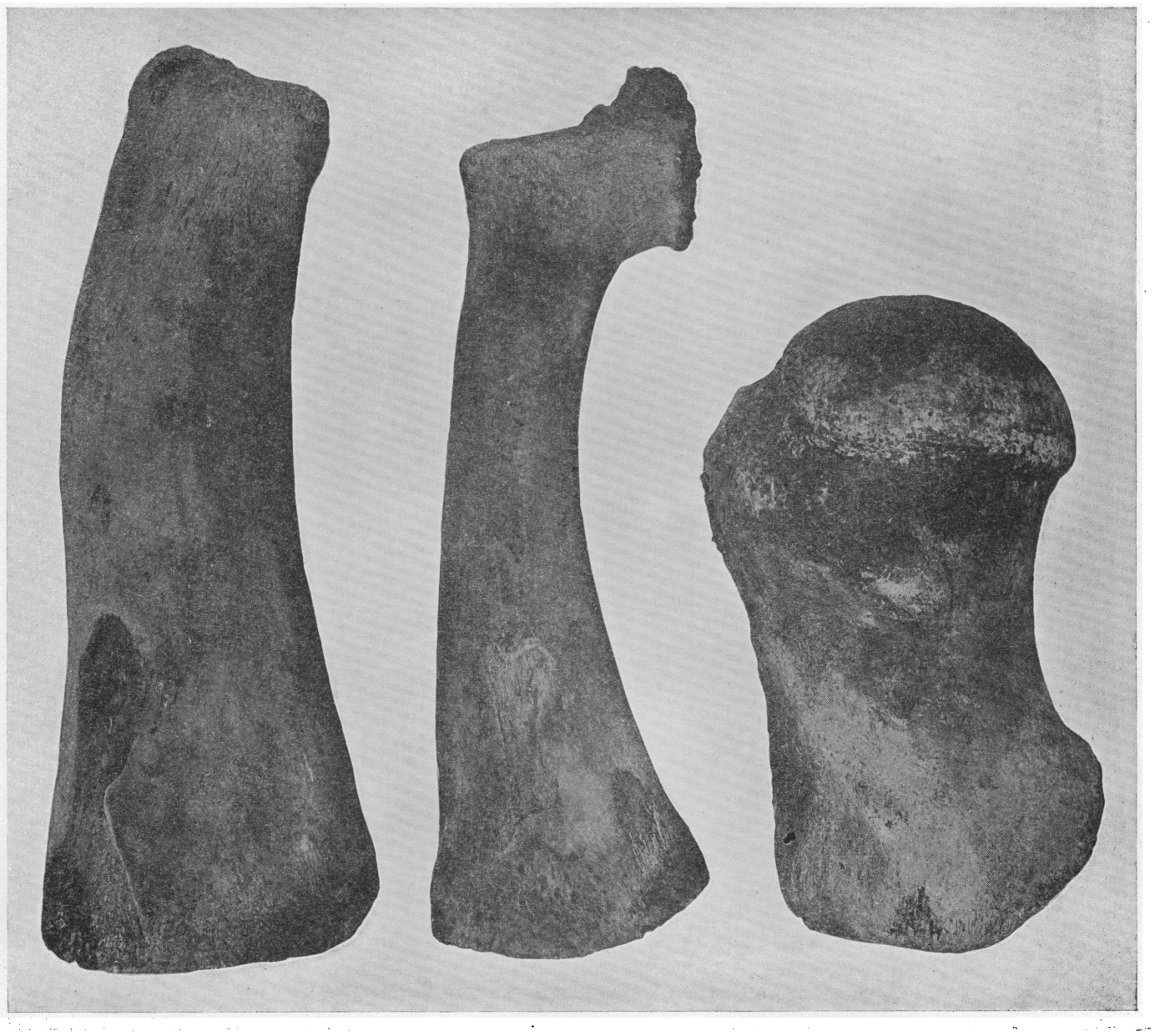

Fig. 20. Humerus, radius and ulna of *Rhachianectes glaucus;* Am. Mus. skeleton.

	II	III	IV	V
Right:	3	3	4	1
Left:	3	4	4	1

The terminal phalanx of the third digit of the left pectoral is a shell of bone and seems to be a normal phalanx which has been injured. This has all the appearance of bony tissue and not of hardened cartilage but it is not present in the right manus. Presumably the tips of both flippers were injured and the correct formulæ for the phalanges is that of the left. The terminal phalanx of the fourth digit of the right manus is also a bony shell but in the corresponding finger of the left hand it has a normal shape and size.

Table IX.—Measurements of Pectoral Limb of Rhachianectes glaucus.

	Am. Mus., No. 34260 mm.
Scapula, greatest height (vertical)	856
" " breadth	1125
" length acromion (inferior edge)	335
" breadth " distally	180
" length coracoid (inferior edge)	146
" breadth glenoid fossa	268
Radius, greatest length	750
" " breadth proximally	183
" " " distally	265
Ulna, greatest length	758
" " breadth proximally	222
" " " distally	226
Humerus, greatest length	520
" " breadth proximally	316
" " " distally	282

Pelvic Rudiments.

The pelvic elements of *Rhachianectes* are exceedingly interesting, the most remarkable features in comparison with other whales being their great size, the less reduction of the pubis and ischium, and the presence of a large foramen.

Those of the American Museum skeleton are two long, slightly curved bones of exactly the same length. The ilium is exceedingly massive, laterally compressed, and has a long dorsal and ventral ridge; a cross-section would be a wide ellipse. The ischium has the same length as the ilium but it is not as massive, is more compressed, and is deeply excavated at the distal end.

The pubis appears as a prominent, roughly cone-shaped tubercle, turned sharply downward and standing at right angles to the remainder of the bone instead of projecting directly outward as in other baleen whales.

Along the inner base of the pubis is a deep longitudinal concavity in the bottom of which, and slightly posterior to the pubis, is a large curved foramen which perforates the bone transversely, emerging on the dorsal surface almost opposite the point of entrance.

Although both the American and U. S. National Museum specimens from which the pelvic elements were secured were males, there is considerable variation in the size and shape of the bones in the two individuals. Those of the U. S. National Museum skeleton are shorter, due to a reduction of the iliac portion, wider through the pubis, slenderer throughout and more

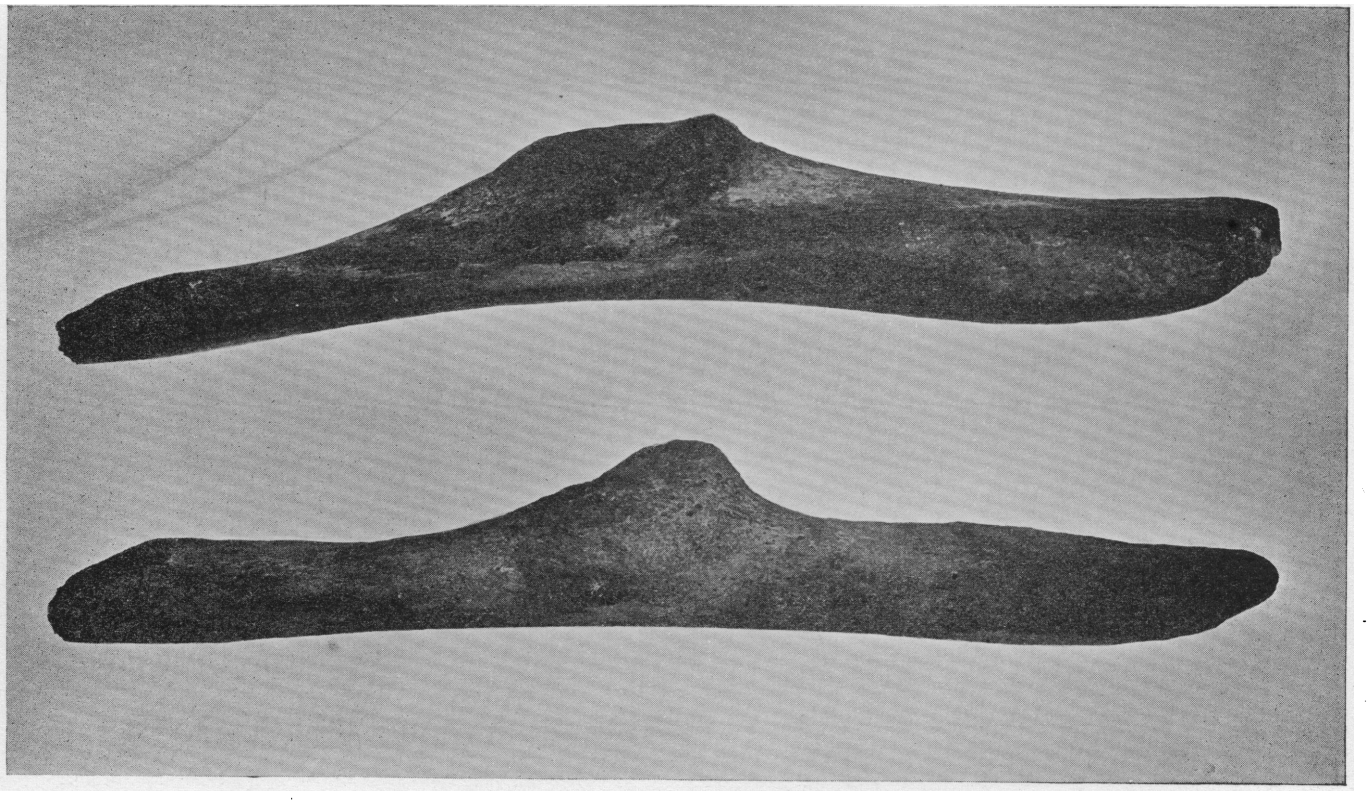

Fig. 21. Pelvic elements of *Rhachianectes glaucus;* Am. Mus. skeleton.

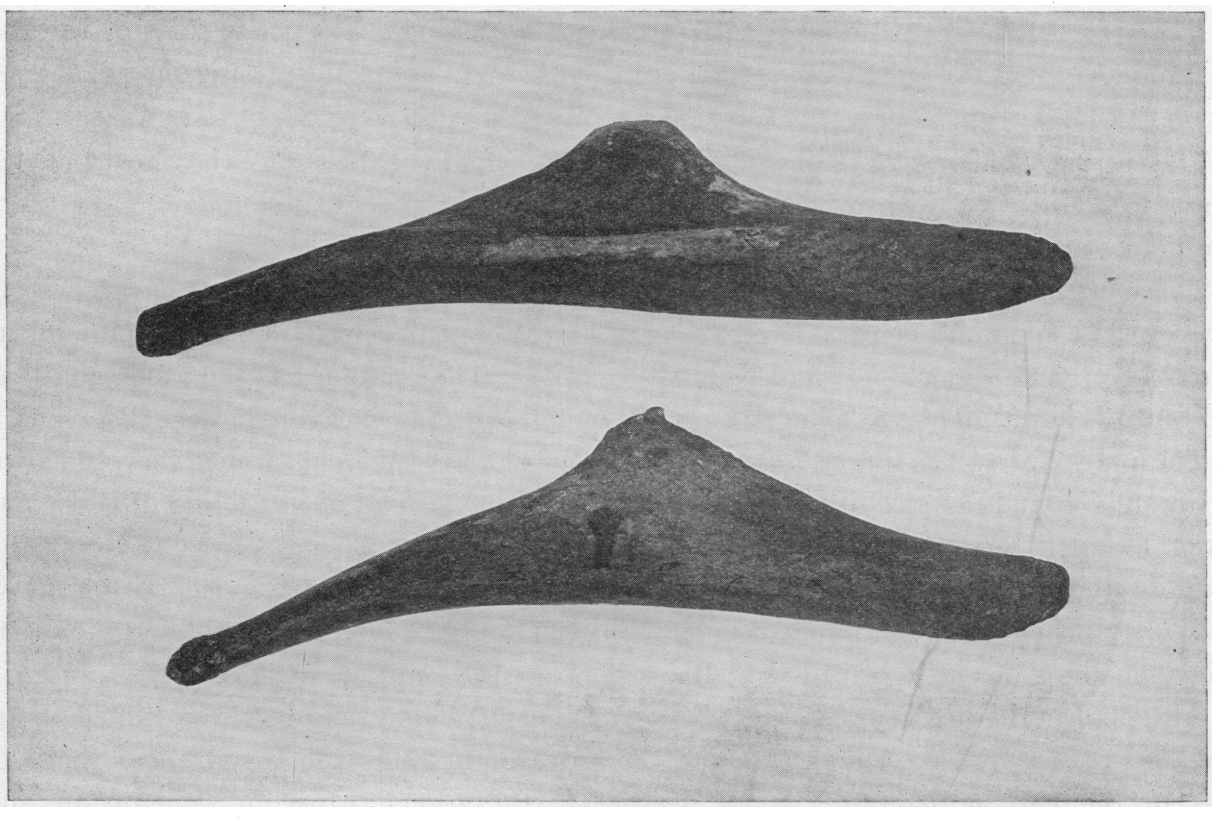

Fig. 22. Pelvic elements of *Rhachianectes glaucus;* U. S. Nat. Mus. skeleton.

curved. In both the ilium is considerably shorter than the ischium, the pubis is not turned as sharply downward as in the American Museum specimen, and the transverse foramen is larger; also there is no excavation of the distal end of the ischium.

The presence of a foramen perforating the pelvic rudiment has been recorded by Struthers in the case of *Balæna mysticetus* but it is rare in other Cetaceans.

It is to be regretted that it was not possible to make a careful examination of the flesh containing the pelvic elements to determine the condition of the femoral rudiments. I believe that *Rhachianectes* will be found to possess a femur larger than that of any other baleen whale when this subject has been more carefully investigated.

Measurements of the pelvic elements.

	American Museum mm.	U. S. Nat. Museum mm.
Length of entire pelvis	501	439
" " ilium	258	210
" " ischium	258	259
Breadth of ilium	74	62
" " ischium	53	49
" across pubis	75	100

CONCLUSIONS.

Specific relationship of California and Korea specimens of Rhachianectes.

Descriptions and measurements of the external anatomy and post-cranial skeleton of California examples of *Rhachianectes* are so general and inaccurate that they furnish few reliable data for use in deciding the specific relationship of the specimens from opposite sides of the Pacific. A discussion of this question, therefore, must rest almost entirely upon the basis of skull characters.

A careful comparison with our Korea specimen of the figures, descriptions and measurements of the American skulls presented by True and Malm shows a remarkably close agreement in all essential points. Examination of the table of measurements shows the only difference worthy of note to be in the proportionately shorter rostrum of the California skull and its less squamosal breadth. Judging from the figures the former difference seems to be due to the fact that the slender prolongations which the maxillæ send backward toward the vertex of the skull are somewhat broken, thus reducing the rostral length. The proportional squamosal breadth of the California skull is somewhat less than in the one from Korea, but since the orbital widths are almost exactly the same, this cannot be considered as of great importance.

There is, so far as I can discover, not the slightest ground for believing the Gray Whales of the east and west Pacific to represent other than a single species. Whether or not the animals mingle in the north during their summer migration has been discussed in the section of this paper relating to habits and need not be again taken up here.

Systematic Position.

Review of former classifications.

1871.— J. E. Gray places *Rhachianectes* in the family Agaphelidæ.

1874.— Gill makes Agaphelidæ of Gray a subfamily under Balænopteridæ and divides that family into the three subfamilies Agaphelinæ, Balænopterinæ and Megapterinæ.

1891.— Flower and Lydekker combine all genera under the family Balænidæ without subfamily divisions.

1897–1904.— Trouessart gives two subfamilies, Balænopterinæ and Balæninæ, under the family Balænidæ and includes *Rhachianectes* in the former.

1900–1902.— Beddard considers *Rhachianectes* as an aberrant genus of the family Balænopteridæ.

1901–04–05.— Elliot recognizes two subfamilies of the Balænidæ and in the Balæninæ includes *Balæna*, *Rhachianectes* and *Megaptera*.

1904.— Max Weber recognizes three families, Rhachianectidæ, Balænidæ and Balænopteridæ.

1910.— Osborn, under the family Balænidæ, recognizes the three subfamilies Rhachianectinæ, Balæninæ and Balænopterinæ.

It will be seen from this brief review of the various classifications of the genus *Rhachianectes* that there has been little agreement as to its systematic position. This is partly due to the fact that up to the present time only the skull has been studied, the post-cranial skeleton never having been described. The results of my work upon this remarkable animal, presented in the preceding pages, lead me to believe that it cannot be included in either of the subfamilies of the Balænidæ and must take rank as a separate family. For this designation Weber's Rhachianectidæ is available and a definition of the family and genus may be formulated as follows:

Family *Rhachianectidæ*.— Skull with a broad strip of the frontals exposed upon the vertex. Maxillæ overlapping the anterior edges of the orbital processes of the frontals. Nasals very long and broad. Mandible without a coronoid process. Cervical vertebræ free. Manus consisting of four digits. Ribs of the anterior half of the series provided with tubercles, necks and heads. Furrows few and short.

Genus *Rhachianectes*.— Head less than one-fourth the length of the body. Baleen laminæ few, short, and thick. No dorsal fin. Pectoral limbs of medium width. Furrows only upon the throat. Rostrum of skull narrow and moderately arched. Premaxillæ sending broad, overlapping projections toward vertex of skull. Prominent rugosities upon the supraoccipital and basioccipital bones of the skull. Tympanic bullæ compressed and somewhat concave on internal border. Scapula having both acromion and coracoid processes.

Primitive Characters of Rhachianectes.

The external and internal anatomy of *Rhachianectes glaucus* presents certain characters which seem to demonstrate that this animal is more primitive than any other existing baleen whale. These may be summarized as follows:

1. Long hairs scattered over the entire head and mandible and not confined to certain regions as in other whales.

2. Baleen plates very short, thick, fewer in number and more widely spaced than in other whales.

3. Skull:

a. Exposure of a wide strip of the frontals upon the vertex of the skull.

b. Long nasal bones.

c. Comparatively small squamosals having straight outer edges. This is noticeably different from the concave squamosals of existing baleen whales and is a character of fossil genera.

d. Proximal ends of the premaxillæ very broad, superiorly placed, and articulate with the frontals by a deep, interdigitating suture.

e. Orbital processes of the frontals anteriorly overlapped by the edges of the maxillæ, posteriorly with irregular margins, and trumpet-shaped; all well marked characters of certain fossil baleen whales.

f. A well emphasized temporal ridge.

g. Prominent rugosities upon the supraoccipital, pterygoids, and basioccipital bones of the skull.

h. Compressed tympanic bullæ having concave internal borders.

4. Cervical vertebræ entirely free and showing no evidences of ankylosis between any members of the series.

5. Atlas and axis possessing massive, rugose neural arches; axis with comparatively small foramina through the wing-like transverse processes.

6. Ribs possessing tubercles, necks and heads as far back as the eighth, and in these portions resembling an Odontocete.

7. A long and straight humerus of the *Plesiocetus* type.

8. Very large pelvic elements, the presence of a large foramen in them and the comparatively slight reduction of the pubis and ischium.

Relationship of Rhachianectes.

Rhachianectes glaucus is apparently not closely related to any of the existing baleen whales but in some respects it stands intermediate between the Balæninæ and Balænopterinæ being nearer the latter. In many skull characters it approaches closely the Pliocene whales of the genus *Plesiocetus* which is allied to the existing Balænopterinæ; in fact, were it not for its specialized mandible it must certainly be considered as nearly related to them. The fossil whales of the *Pleisiocetus* group possessed mandibles having the proximal portion of each ramus, internally, widely concave and leading into a large dental canal; in short, much as in the mandibles of the existing toothed whales. *Rhachianectes*, however, although resembling *Plesiocetus* in many important skull characters, possesses a specialized mandible similar to that of the Right Whales; that is the proximal portion, internally, is not concave and the dental canal is small. This type of mandible prevents the phylogenist from taking *Rhachianectes* off from the *Plesiocetus* group, unless he wishes to consider that while persisting until the present day with comparatively little modification of its primitive skull characters, it has undergone considerable specialization of the mandible alone. This is a perfectly possible supposition, which I am inclined to believe is true, since *Rhachianectes* shows such marked affinities to *Plesiocetus* and is so strongly separated from the other known genera of fossil and recent whales. It is, upon the whole, one of the most remarkable of existing Cetaceans and might be called a "living fossil."

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Fig. 3. " " three "
Fig. 4. " " " "
Fig. 5. " " " "
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Fig. 2. Dorsal view of the skull from Korea in the American Museum.

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EVOLUTIONARY BIOLOGY

Whole-genome sequencing of the blue whale and other rorquals finds signatures for introgressive gene flow

Úlfur Árnason,[1]* Fritjof Lammers,[2,3,4]* Vikas Kumar,[2] Maria A. Nilsson,[2] Axel Janke[2,3,4]†

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Reconstructing the evolution of baleen whales (Mysticeti) has been problematic because morphological and genetic analyses have produced different scenarios. This might be caused by genomic admixture that may have taken place among some rorquals. We present the genomes of six whales, including the blue whale (*Balaenoptera musculus*), to reconstruct a species tree of baleen whales and to identify phylogenetic conflicts. Evolutionary multilocus analyses of 34,192 genome fragments reveal a fast radiation of rorquals at 10.5 to 7.5 million years ago coinciding with oceanic circulation shifts. The evolutionarily enigmatic gray whale (*Eschrichtius robustus*) is placed among rorquals, and the blue whale genome shows a high degree of heterozygosity. The nearly equal frequency of conflicting gene trees suggests that speciation of rorqual evolution occurred under gene flow, which is best depicted by evolutionary networks. Especially in marine environments, sympatric speciation might be common; our results raise questions about how genetic divergence can be established.

INTRODUCTION

Baleen whales (Mysticeti) are strikingly derived marine mammals that encompass the largest animals living on Earth (*1*); however, their evolution is only poorly understood. Today, 15 species of extant baleen whales are known, and the fossil record includes many additional extinct species (*2*). The gigantic blue whale (*Balaenoptera musculus*) with a length of 30 m and a weight exceeding 150 metric tons and the fin whale (*Balaenoptera physalus*) are the largest animals on Earth (*1*). Both belong to the rorqual family (Balaenopteridae). Baleen whales have undergone significant adaptations to marine life and are characterized by their lack of teeth, which have been replaced by keratin bristles, the baleen that is used for filter feeding (*3*). It has been estimated that the blue whale takes in up to 3.6 metric tons of krill every day to supply the energy demand of their huge body sizes (*3*). The large body size of whales allowed them to occupy novel ecological niches by enabling deep dives and to endure long periods of starvation to reach feeding grounds (*4*). The evolutionary history of baleen whales is debated, despite extensive analyses of molecular and morphological characteristics (*2*, *5*). Moreover, molecular analyses of baleen whale evolution disagree with each other depending on the applied marker and type of phylogenetic analysis (*5*–*8*). Of particular interest are the humpback whales (*Megaptera novaeangliae*) and gray whales (*Eschrichtius robustus*), which are each placed in a separate genus or even in its own family, mainly based on analyses of their derived anatomy (*1*). However, these classifications are not supported by recent molecular studies, which suggest that they evolved from within rorquals, making the latter paraphyletic. To reflect this discordance, we will use the family name Balaenopteridae sensu lato, that is, including Balaenopteridae and Eschrichtiidae.

It is difficult to envision that the baleen whales evolved by allopatric speciation under vicariance because the marine environment largely lacks physical barriers for mobile species like whales (*1*, *9*). The study of the evolution of whales is further complicated by the fact that whales can hybridize. In the case of the blue whale and the fin whale, genetic analyses have shown that the female hybrid carried a fetus and had mated with a blue whale (*10*). Thus, these two species, as well as other rorquals, may not be entirely reproductively isolated. In addition, rorquals have a conserved karyotype of $2n = 44$ chromosomes and an identical chromosomal C-banding pattern, which facilitate producing fertile offspring (*11*).

Genomic analyses allow detailed insight into evolutionary processes such as speciation or past hybridization events (*12*) and permit examination of long-standing evolutionary questions (*13*). Introgressive hybridization, speciation with gene flow, and incomplete lineage sorting (ILS) may cause different local genealogies across the genome that can be detected by analyzing whole-genome sequences (*14*). Compared to terrestrial species, genomic data are limited for marine mammals, and before this study, genomic data were only available for three baleen whales: the bowhead whale (*Balaena mysticetus*), the minke whale (*Balaenoptera acutorostrata*), and the fin whale (*15*, *16*).

Here, we present genomic data of six mysticete species including the humpback and gray whale and the largest extant animal ever lived, the blue whale. The data are analyzed under the multispecies coalescent (MSC) that incorporates the genome-wide heterogeneity of gene trees to accurately infer speciation history (*14*). In addition, the genomes allow us to study signals of recent and ancestral introgression, to place divergences into a solid temporal context, and to explore genetic diversity and past demographic history of baleen whales.

RESULTS

Genome sequencing and assembly

Genomic DNA from six baleen whales and a hippopotamus (*Hippopotamus amphibius*) were sequenced with Illumina technology. Reference genome mapping of the whale genome data against the bowhead whale genome (*16*) yielded genome coverages of 6.3 to 27.2× (table S1). RepeatMasker (*17*) identified 40.3% repetitive sequences in the bowhead whale genome assembly. Of these, 6 and 18% were short and long interspersed elements (SINE and LINEs), respectively (table S2). Except for the genomic fraction of SINEs, these results are consistent with the original analyses of Keane *et al.* (*16*). We identified, on average, 25 million fixed single-nucleotide differences relative to the bowhead whale genome (table S3). Consensus sequences of all baleen whale genomes were aligned per scaffold, and repetitive sequences, gaps, and ambiguous bases were

[1]Department of Brain Surgery, Faculty of Medicine, University of Lund, Lund, Sweden. [2]Senckenberg Biodiversity and Climate Research Centre, Senckenberg Gesellschaft für Naturforschung, Senckenberganlage 25, 60325 Frankfurt am Main, Germany. [3]Goethe University Frankfurt, Institute for Ecology, Evolution and Diversity, Biologicum, Max-von-Laue-Straße 13, 60439 Frankfurt am Main, Germany. [4]LOEWE Centre for Translational Biodiversity Genomics, Senckenberganlage 25, 60325 Frankfurt, Germany.
*These authors contributed equally to this work.
†Corresponding author. Email: axel.janke@senckenberg.de

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removed. Empirical analyses and simulations using the approximate unbiased (AU) test (*18*) showed that 20–kilo–base pair (kbp) genome sequence alignments contain sufficient information for statistically significant maximum likelihood (ML) gene tree inference (figs. S1 to S3). The aligned scaffolds yielded 34,192 genome fragments (GFs), each 20 kbp long, totaling 643,840 kbp for each whale. This represents 49% of the nonrepetitive genome sequence. Sequencing the hippopotamus genome yielded 1,684,446,285 filtered reads and a sequencing depth of 55× (table S4). The reads were assembled de novo with Minia (*19*) and scaffolded with SSPACE, resulting in a genome assembly of 2.43 Gbp with a scaffold N50 of 120 kbp. AUGUSTUS (*20*) identified 29,998 coding sequences (CDSs); 37.0% of the genome were masked as repetitive (table S5).

The evolution of whales

Model testing identified the generalized time-reversible model with gamma-distributed rate variation with invariable sites (GTR + 4G + I) as the best-fitting nucleotide substitution model for the ML analyses of GFs. An MSC species tree of baleen whales based on 34,192 GF trees was supported with posterior probabilities of 1.0 for all branches (Fig. 1A and fig. S4). The topology conforms to previous nuclear gene and mitochondrial DNA (mtDNA) analyses (*5*, *21*) and a Bayesian phylogeny of the mtDNA sequences reported herein (fig. S5). The primary characteristic of the tree is the clear distinction between the Balaenidae (right whales) and the branch harboring the five rorquals plus the gray whale (Balaenopteridae sensu lato). The humpback whale (genus *Megaptera*) groups within the rorquals, resulting in a paraphyly of the current genus *Balaenoptera*. The gray whale of the monotypic family Eschrichtiidae is placed inside rorquals as a sister lineage to fin and humpback whale. However, quartet scores, that is, the support for any of three possible phylogenetic arrangements around an internal branch, identified conflict in resolving the branch leading to the ancestor of the gray, fin, and humpback whale (Fig. 1A, branch no. 3). The three possible topologies for this branch receive similar quartet scores (Fig. 1B), contrasting to a posterior probability of 1.0. Thus, we find highly similar support for placing the gray whale as a sister group to blue whales and sei whales or as a distinct clade outside the blue/sei/fin/humpback whale cluster. Somewhat inconclusive support also marks the first branch inside rorquals (Fig. 1B, branch no. 2) that places the minke whale as a sister lineage to the remaining Balaenopteridae sensu lato with a quartet score of 0.7. Phylogenetic conflict is also present in a CONSENSE (*22*) analysis of the GF trees. Although a majority-rule consensus tree confirms the coalescent-based species tree (Fig. 1A and fig. S6), two alternative phylogenetic positions of the gray whale are equally strongly represented (table S6).

The position of the gray whale in the species tree is supported by 10,315 (30.2%) GF trees compared to 8918 (26.1%) and 8721 (25.6%) GF trees, which place the gray whale in different positions inside rorquals.

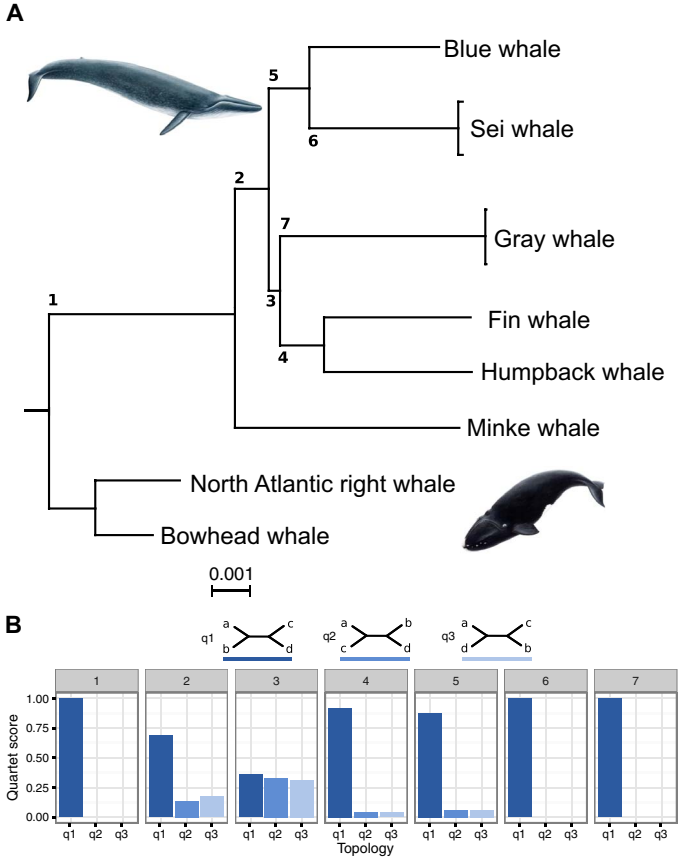

Fig. 1. MSC tree. (**A**) An MSC species tree was constructed from 34,192 individual GFs. Internal branches within Balaenopteridae are numbered 1 to 7. All branches receive maximal support ($P = 1.0$, ASTRAL analysis). Branch lengths were calculated from an ML analysis. Gray whales, family Eschrichtiidae, are placed inside Balaenopteridae as a sister group to fin and humpback whales. (**B**) ASTRAL quartet-score analyses for branches 1 to 7 (A). Quartet scores were calculated for the three possible arrangements (q1 to q3) for the respective branch. The principal quartet trees are depicted, with q1 representing the species tree. Branch nos. 2 and 3 receive only limited quartet scores, and no quartet can be significantly rejected.

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A placement of the gray whale outside rorquals is supported by 3507 GF trees (10.3%). A consensus network analysis (*23*) of the GF trees yields a large cuboid structure of connecting alternative branches in the center of the network that indicates conflicting signals for the position of the gray whale inside rorquals (Fig. 2). At a threshold for conflicting edges of 11%, the grouping of the humpback and fin whale, the sei and blue whale, and the bowhead and North Atlantic right whale is unambiguous. At lower thresholds, the phylogenetic signal becomes more complex, indicating additional phylogenetic conflict in the data (fig. S7).

Gene flow analyses

D statistic (*24*) and D_{FOIL} (*25*) analyses identified several gene flow signals among rorquals (Fig. 3A and data S1 and S2). We find significant gene flow signals between minke whale and the ancestors of the blue and sei whale and those of the fin and humpback whale, respectively. The D_{FOIL} analyses find a strong signal for gene flow between the ancestor of the blue and sei whale and the ancestor of the fin and humpback whale, which is likely a phylogenetic signal related to a placement of placing the gray whale into different positions (Fig. 3A and data S1 and S2). In addition, signal for recent gene flow was inferred reciprocally from the blue whale to the fin and humpback whale for about 1 to 1.5% of the genome. The *D* statistic analyses also identified numerous signals for gene flow between the ancestor of the blue/sei whale and gray whale and that of the humpback whale and gray whale. Note that the *D* statistic and D_{FOIL} analyses depend on the species tree as in Fig. 1A and the signal may vary for other constellations. Our interpretation, therefore, focuses on signals that are independent of the evolutionary placement of gray whales.

In addition to character-based parsimony analysis, gene flow may preferably be studied by topology-based ML analysis using PhyloNet (*26*). PhyloNet identifies a statistically significant signal for gene flow between the minke whale and the ancestor of the other rorquals (Fig. 3B). With equal likelihood probability, gene flow occurred from the ancestor of the humpback and fin whale to that of the minke whale (Fig. 3C). Furthermore, with a topology change of the gray whale as a sister group to blue and sei whale, gene flow occurs from the ancestor of the blue and sei whale to that of the minke whale (Fig. 3D). Each of the three reticulations shows inheritance probabilities of about 33%, resembling the quartet-score distribution of the coalescent tree analyses (Fig. 1B).

Genetic diversity and population size history

Genome-wide heterozygosity varies considerably among baleen whales (Fig. 4A and fig. S8). At approximately 5×10^{-4} heterozygous sites per nucleotide, estimates were lowest for the gray whale, the minke whale, and the two sei whales. The blue whale genome shows the highest

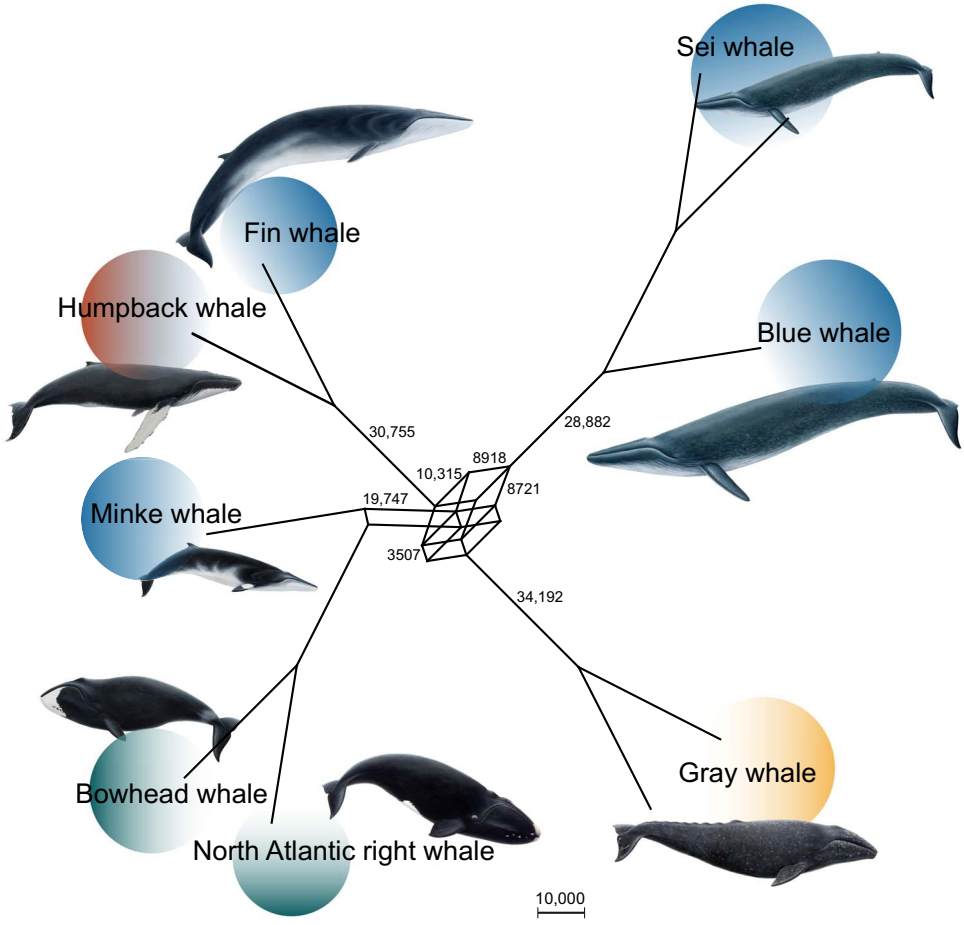

Fig. 2. Median network of 34,192 GF ML trees with 11% threshold. Conflicting evolutionary signals characterize the center of the network, which is equivalent to branch no. 3 in the species tree (Fig. 1). In addition, placing the minke whale has some conflicting signal, but the elongated rectangle indicates a higher degree of resolution. The number of supporting GFs is shown for selected splits. Colored circles indicate taxonomic classification. Blue, *Balaenoptera*; red, *Megaptera*; yellow, *Eschrichtius*; green, *Balaena* and *Eubalaena*.

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degree of heterozygosity, which is elevated even when compared to other mammals (*27*). Estimates for heterozygosity in downsampled genomic data of blue whale were similar, minimizing the effects of potential artifacts by higher sequence coverage (fig. S9). The history of the effective population size (N_e) over the last 5 million years (Ma) was modeled from the distribution of heterozygous sites across the genome using a pairwise sequentially Markovian coalescent (PSMC) (*28*) analysis (Fig. 4B and fig. S10). Ancestral effective population sizes for all baleen whales, particularly the large blue, fin, and humpback whales, were notably higher during the Plio-Pleistocene transition (PPT; 2.6 Ma ago) than recent estimates (Fig. 4B). After the mid-Pleistocene transition (MPT), N_e of most baleen whales was relatively stable, until approximately 100 thousand years (ka) ago, the time of the last interglacial. After this time, baleen whale populations decreased. In contrast, gray whale population size remained stable during the interglacial, and its population size even increased in more recent times. The blue whale maintained a larger population size than other whales, but their numbers decreased at 400 ka ago after the MPT. The minke and fin whale population increased somewhat at 200 to 300 ka ago, followed by a steady decline. The N_e of the humpback whale was rather constant since 1 Ma ago and then shows a decline by two-thirds of its population at some 30 ka ago. Our estimates of historical population sizes of the fin and minke whale are consistent with previous analyses (*15*).

Divergence time estimates

The phylogenomic reconstruction of a paraphyletic position of Cetacea among Artiodactyla and the placement of the Hippopotamidae are, for the first time, supported by genomic sequence data analyses (Fig. 5). The divergence times are based on five calibration points (table S8). Hippopotamidae diverged at 53.5 Ma ago, close to the appearance of archaeocetes in the fossil record at 50 Ma ago (*29*). Rorquals diverged in the late Miocene, between 10.48 and 4.98 Ma ago (table S9). The divergence time between baleen and toothed whales at 30.5 Ma ago coincides with the Eocene/Oligocene transition at 33 Ma ago (*30*), which probably triggered the radiation of modern whales.

DISCUSSION

Our genome analyses have shown that the evolution of Balaenopteridae sensu lato (hereafter referred to as rorquals) is not characterized by an ordered dichotomous divergence of lineages as would be expected with respect to speciation in most other mammals. Coalescent-based analyses of more than 600-Mbp genomic data and network analyses show that the genomes of rorquals are characterized by contradicting genealogies for their central divergence. Thus, the evolution of rorquals appears to be a process of gradual divergences that likely gave rise to three lineages almost simultaneously: (i) blue plus sei whales, (ii) gray

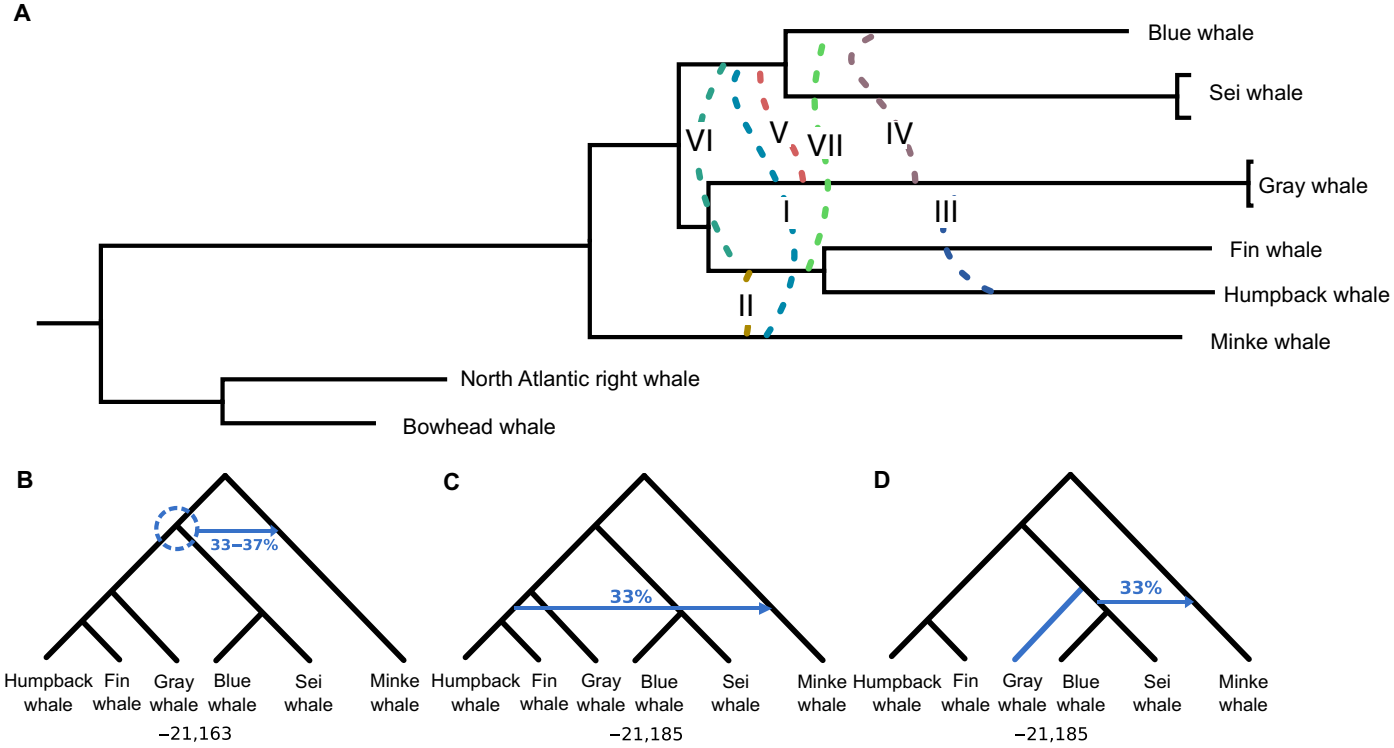

Fig. 3. Gene flow signals for baleen whales inferred by the *D* statistic, D_{FOIL}, and PhyloNet. (**A**) The species tree of baleen whales with gene flow signals detected by the *D* statistic and D_{FOIL} indicated by dashed lines. Signals I to IV were inferred by the *D* statistic, and signals V, VI, and VII were detected by D_{FOIL} and were partially corroborated by the *D* statistic. Note that D_{FOIL} cannot infer gene flow involving the minke whale. (**B** to **D**) Rooted networks for the Balaenopteridae sensu lato phylogeny with reticulations inferred from PhyloNet based on 34,192 20-kbp GFs. Reticulations are shown as blue arrows with inheritance probability denoted above or below. Log-likelihood scores are shown below the networks. Notably, inheritance probability around 33% resembles the distribution of quartet scores and the phylogenetic signals from GFs (Fig. 1). (B) The three best networks indicated a reticulation originating at the circled three branches to minke whale. Similar likelihood scores do not allow the identification of a single origin of gene flow; therefore, the networks were merged, and a range of inheritance probabilities is given. (C) The fourth best network has only a marginally poorer likelihood score and indicates a reticulation between the ancestor of the fin and humpback whale and that of the minke whale. (D) The fifth best network has the same likelihood as (C) and finds an alternative placement of gray whale (blue branch) and reticulation from the ancestor of the blue and sei whale to that of the minke whale.

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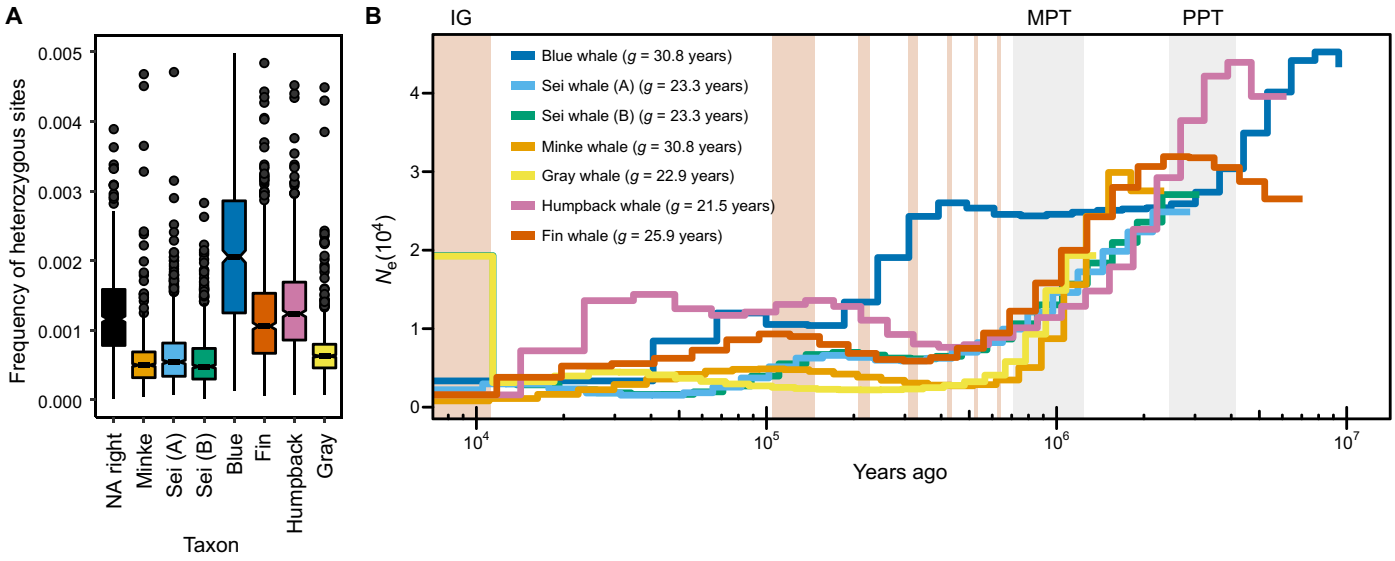

Fig. 4. Demographic history and genome-wide heterozygosity. (**A**) Genome-wide heterozygosity estimated from genomic 100-kbp windows. (**B**) Historical N_e using the PSMC analyses for all baleen whale genomes. The *x* axis shows the time, and the *y* axis shows N_e. Plots were scaled using a mutation rate (μ) of 1.39×10^{-8} substitutions nucleotide^{-1} generation^{-1} and species-specific generation times (*g*). Generation times are noted next to the species names. Light brown shading indicates interglacials (IG) in the Pleistocene and Holocene, and gray shading indicates the MPT and the PPT.

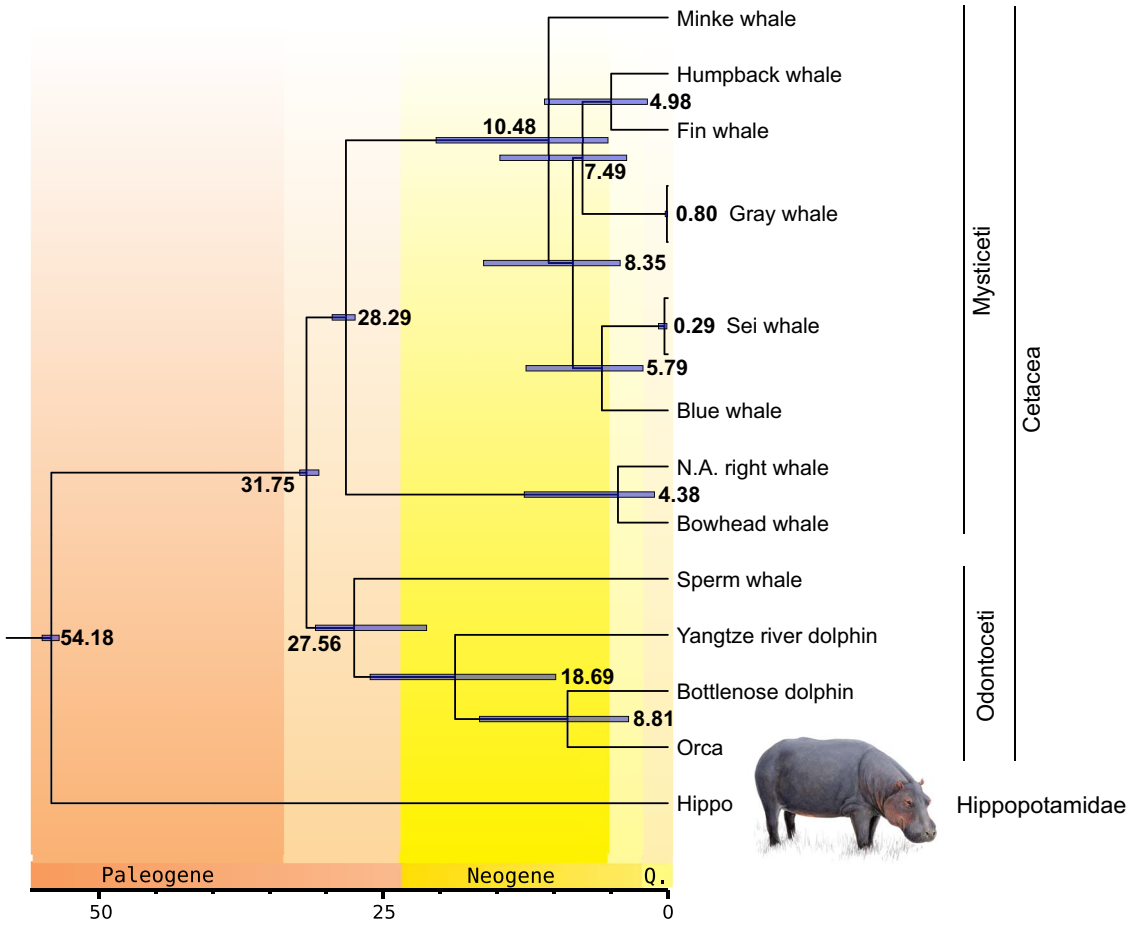

Fig. 5. Divergence time tree of Cetancodonta (*56*) including the newly sequenced baleen whales, estimated from 234,947 amino acid sites (2778 orthologs). Rorquals diverged in the late Miocene, 10.5 to 7.5 Ma ago. Four other cetartiodactyl species were also included but not shown due to space constraints; the dog (*Canis lupus familiaris*) was used as an outgroup. Five calibration points were used for dating (table S8) (*29*, *56*–*60*).

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whale, and (iii) fin plus humpback whales. The early rorqual radiation is therefore best understood as a phylogenetic network because different fragments of the rorqual genomes support three different evolutionary histories. This provides the reason why the evolution of rorquals was previously differently reconstructed and poorly supported by molecular analyses of smaller data sets (*5*–*8*). Their evolutionary reconstruction needed to be constrained by morphological data to yield a traditional bifurcating tree among rorquals (*2*).

The apparently unequivocal support for the species tree by the MSC analyses is likely a consequence of a slight imbalance of the evolutionary signal that preferably places the gray whale together with the fin whale and humpback whale. Within the massive amount of genome-scale data, even a minor bias can lead to significantly resolved branches, despite the underlying conflict (*31*). Therefore, inspection of quartet scores in a coalescent species tree and network and CONSENSE analyses are crucial in identifying and depicting conflict in the evolutionary signal.

Rorqual taxonomy

Despite the conflict for the early divergence among rorquals, other divergences are well resolved by genome analyses that find the humpback whale closely related to the fin whale within the genus *Balaenoptera*. This is consistent with previous mitogenomic studies (*5*, *7*, *21*) and makes a separate genus, *Megaptera*, obsolete. If the rules of scientific nomenclature are strictly followed in accord with the phylogenetic relationships, the preferred name of the humpback whale should be *Balaenoptera novaeangliae*.

Because gray whales are morphologically, behaviorally, and ecologically distinct from other balaenopterid whales, placing them in a separate family (Eschrichtiidae) distinct from Balaenopteridae sensu stricto seemed natural (*1*, *32*). This classification has been questioned by some molecular analyses (*5*, *21*), and the current genomic analyses resolve this issue conclusively. Despite their derived morphology, gray whales fall unquestionably within the genus *Balaenoptera*, challenging their status as a separate family or even as a separate genus. Notably, the first described specimen of a gray whale was named *Balaenoptera robusta* (*33*) but later classified as own family and genus by J.E. Gray in 1865 in honor of the zoologist D. F. Eschricht (*32*). Consequently, we suggest that the originally proposed scientific name of the gray whale should be resurrected, with its name included in the Balaenopteridae.

Mechanisms of the rorqual radiation

The radiation of extant rorquals is documented by a rich fossil record with a notable diversity of evolutionary distinct lineages, most of which are now extinct. Speciation is generally assumed to occur when biological or geographic isolation results in reproductive isolation (*34*), and it may be difficult to conceive how whales could diverge. Compared to the terrestrial environment, the marine realm is a three-dimensional continuum, almost devoid of barriers that could aid allopatric speciation for highly mobile organisms such as whales. Mixing of gene pools among rorquals can still occur, and such a process would hinder diversification and consequently speciation (*9*). Even some 8 Ma (or about 400,000 generations ago) after their initial divergence, some baleen whale species can still hybridize, which might also be facilitated by their strikingly uniform karyotypes (*11*).

However, ongoing sympatric speciation in marine mammals by the formation of discrete ecotypes has been suggested for the orca or killer whale (*Orcinus orca*) (*35*). For example, the so-called "transient" and "resident" ecotypes specialized to prey on mammals and fish, respectively (*35*). Similarly, rorquals have evolved different feeding strategies. Whereas most baleen whales feed on pelagic prey such as zooplankton and small fish, the gray whales have evolved to feed on benthic invertebrates by scooping up the seafloor. This opened a new ecological niche to which the gray whale adapted, leading over time to sympatric speciation. The adaptation to the benthic food source also led to notable morphological changes, consequently placing the gray whale into an own family. This differentiation may be triggered by climatic change and other environmental disturbances. These different ecological specializations could have led to a speciation continuum in the past that is similar to the one observed in orcas today.

Genomic analyses find the divergence times of baleen whales to be somewhat younger but within the range of previous estimates (*5*, *8*, *21*). The rorqual radiation coincides with the late Miocene cooling at ~7 Ma ago (*36*). This global cooling affected the marine environment by the onset of the current equator-pole temperature gradient. The beginning of the modern oceanic circulation increased productivity in the temperate and polar oceans (*36*), which may have affected cetacean evolution into different ecotypes.

Network-like evolution in whales

It seems counterintuitive that even whole-genome data do not fully resolve the evolution of whales and other mammals in a bifurcating pattern (*12*). However, speciation being a continuous process with possible hybridization, rather than a strict dichotomous event, has already been recognized by Darwin (*37*) and has recently gained new attention (*38*). In sympatric speciation, genomes can be homogenized by gene flow, and only a few genes need to be under divergent selection to form new species (*38*). Genome analyses sometimes fail to support the idea that speciation by reproductive isolation can fail to yield a fully resolved bifurcating tree, which has been the ultimate goal of evolutionary studies for many years. The analysis of genome sequences rather allows observing and comprehending evolutionary incongruence to translate this into new evolutionary hypotheses that might be better depicted as networks (*39*). Recognizing that "divergence with genetic exchange" is a widespread phenomenon in animals (*9*) makes it necessary to review the biological species concept. Instead of relying on reproductive isolation (*34*), a modern species concept should incorporate selective processes that maintain species divergence even under gene flow (*12*).

Signals for introgressive hybridization

Signals for gene flow confirm sightings and reports of current hybridization in whales (*10*, *40*, *41*). The signal for gene flow between blue and fin whale confirms introgression in these species. Other reports on hybrids between humpback and blue whales (*40*) or between bowhead and right whales (*42*) could not be confirmed by the present genome analyses. The hybridization between these species is likely restricted to few individuals or populations and did not lead to introgression. Further sequencing efforts will give more detailed insights into the extent of introgression of baleen whales and potential ecological implications.

In recent genomic studies of bears, humans, and many other animals, gene flow from introgressive hybridization has been identified as a cause for phylogenetic incongruence (*9*, *12*). Postspeciation gene flow can be analyzed in genomic data with a variety of methods (*43*). The *D* statistic and its derivative are undoubtedly the widest applied methodology (*24*, *25*), but these approaches assume a fully resolved species tree. If the species tree includes polytomies or, based on inappropriate statistical methods, is misidentified (*44*), then the basic assumption of the *D* statistic may be violated and the results can be misleading. Therefore, in case of phylogenetic uncertainties, gene flow

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analyses should, in addition, apply methods that do not require a known topology such as PhyloNet that infers introgression signals from a set of gene trees (*26*). However, alternative methods can be computationally intractable for complex phylogenies or a large number of loci.

Demographic history

Genome data from a single individual allow the reconstruction of the effective population size of its species for some 1 to 2 Ma back in time (*28*). These studies have shown that the demographic histories of many mammals have been influenced by climatic oscillations in the Pleistocene [for example, sheep (*45*)]. However, baleen whales maintained relatively stable effective population sizes after the MPT, despite major oscillations in the global climate consequently affecting ocean circulation, upwelling, and marine productivity. The general congruence of population size histories of different baleen whale species indicates that they were similarly affected by these factors. Differences in sequence depth may limit the comparison of absolute N_e between our samples; however, chronology of the curves is not expected to be affected (*46*). Industrial whaling has been too recent to leave a noticeable signal of a declining N_e in the PSMC analyses, especially for long-lived species with long generation times like rorquals. However, compared to other mammals, rorquals, particularly the blue whale, have a comparatively high degree of genome-wide heterozygosity (*27*). The impact of whaling on the genetic diversity of baleen whales may become apparent only after several generations and require population-scale studies for a detailed assessment (*47*).

CONCLUSION

Genome data analyses finally resolved the evolutionary history of baleen whales, even if it is not a bifurcating tree that most had expected. The evolution of rorquals can only be accurately understood by phylogenetic networks because a forced bifurcating tree or a hard polytomy would ignore the accumulated evolutionary history that is recorded in their genomes. It is evident that the central rorqual radiation was not along a progressively ordered process. On the contrary, speciation with gene flow is indicated by the nearly equal probabilities for different evolutionary histories across rorqual genomes. In addition, hybridization between blue and fin whales left genome-wide signals of introgression. The gray whale may constitute a striking example of sympatric speciation related to adaptation to and occupation of a particular niche, bottom feeding, as compared to the pelagic feeding of other rorquals. Our results indicate that sympatric speciation should not be neglected as a mode of speciation in highly connected habitats, such as the marine environment.

MATERIALS AND METHODS

DNA isolation and sequencing

Cell cultures (established by the first author, 1969 to 1974) were grown in Dulbecco's modified Eagle's medium supplemented with 10% fetal bovine serum under standard conditions. DNA of *H. amphibius* was extracted from muscle tissue of a naturally deceased individual, provided by M. Bertelsen (Copenhagen Zoo). DNA was isolated from cells or tissue using a standard phenol-chloroform method. Sequencing libraries were prepared with insert sizes between 300 and 500 bp and sequenced using Illumina HiSeq 2000, 2500, and 4000 technology. The minke whale genome data were obtained from the short read archive (accession no. SRR896642) (*15*). Sequencing library information and mapping statistics are given in table S1. Quality control was performed using FastQC (www.bioinformatics.babraham.ac.uk/projects/fastqc/), and reads were trimmed. All cell culture work and DNA extractions from tissues were performed according to the ethical guidelines and permission of the respective institutions.

Paired-end reads were mapped to the bowhead whale genome (*B. mysticetus*) (*16*), with BWA mem version 0.7.12-r1039 (*48*), and duplicates were marked with picard (https://github.com/broadinstitute/picard). The bowhead whale was used as reference genome because it avoids a mapping bias that can affect phylogenetic analyses. The minke whale is phylogenetically placed inside baleen whales, and a possible mapping bias against its genome is likely to affect phylogenetic and gene-flow analyses. Scaffolds shorter than 100 kbp were excluded. Repetitive sequences were annotated for the bowhead whale genome by RepeatMasker (*17*). From the mapped reads, single-nucleotide variants (SNVs) and short insertion or deletions (InDels) were called by freebayes v0.9.20-16-g3e35e72 (*49*) with a minimum coverage of four reads and settings: –-monomorphic –min-mapping-quality 20, –C 4, –F 0.3. Consensus sequences were created from VCF-files using custom perl scripts. InDels were removed, and ambiguously called sites were masked as "N."

For sequencing the hippopotamus genome, paired-end and mate-pair libraries were constructed with different insert sizes sequenced on Illumina HiSeq 2000/2500 sequencers (table S4). Because of high levels of duplications, mate-pair libraries were deduplicated. All libraries were trimmed for adaptors and low-quality regions, requiring a minimum read length of 90 bp after trimming. All libraries were assembled into contigs using Minia with $k = 49$ (*19*). Contigs were scaffolded with SSPACE (https://github.com/nsoranzo/sspace_basic) using the mate-pair libraries. Finally, GapCloser (http://soap.genomics.org.cn/) was run with all libraries. Scaffolds shorter than 1 kbp were excluded from the final genome assembly of the hippopotamus. Novel repetitive elements were identified with RepeatModeler (www.repeatmasker.org/RepeatModeler/).

The genome assembly was screened for repetitive sequences using RepeatMasker and the previously created de novo library of identified repeats from RepeatModeler and the RepBase Mammalia library. To account for nonoverlapping detected repeats, we combined and applied the genome masks to the genome sequence. Protein coding genes were predicted ab initio with AUGUSTUS v.3.1 (*20*) using settings –UTR -species human.

Phylogenomic analysis of baleen whales

Consensus sequences of all genomes were aligned per scaffold, and heterozygous sites and repetitive regions were removed. Per-scaffold alignments were split into nonoverlapping GFs of 10, 20, and 100 kbp, respectively. Scaffolds that were shorter than the GF size after removal of ambiguous sites were excluded.

Estimating phylogenetic information in GFs

To analyze the phylogenetic information content of the GFs, we randomly sampled 5000 GFs to count the number of parsimony informative sites and to estimate the genetic distance between the two closest related whales, that is, the bowhead and the North Atlantic right whale. On the basis of real GFs, we simulated GFs between lengths of 1 and 100 kbp to determine which length carries sufficient phylogenetic information to statistically reject alternative topologies (fig. S1). Topology testing was performed using the AU test (*18*).

Species-tree inference and analysis of phylogenetic conflict

JModelTest2 (*50*) identified the suitable nucleotide substitution model by evaluating random 20-kbp GFs. For each GF, phylogenetic trees were

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computed with RaxML (*51*) using ML and the GTR + G substitution model that was identified as best fit. Each ML analysis was bootstrapped with 100 replicates. From all 20-kbp GF trees, ASTRAL 4.10.5 (*31*) computed a species tree under the MSC model (exact method) returning quartet scores and posterior probabilities. The species tree was rooted with the bowhead whale and North Atlantic right whale that are outside Balaenopteridae. CONSENSE from the PHYLIP package (*22*) explored conflict among the gene trees by identifying identical splits in a set of given gene trees and summarizing their frequency. Consensus networks of the GF trees were generated using SplitsTree4 (*23*) with different median thresholds. Phylogenetic consensus networks summarize gene tree discordance by drawing alternative edges for each observed split.

Phylogeny of whale mitochondrial genomes

We reconstructed the mitochondrial (mt) genomes from the whale individuals reported herein by mapping the reads to conspecific published mt genomes and generated consensus sequences as described for the nuclear genomes. Mt sequences were aligned to 19 published mt sequences of whales. Accession numbers of mt genomes used as reference for mapping and the phylogenetic analysis are shown in fig. S4. A Bayesian phylogenetic tree was reconstructed using MrBayes version 3.2.2. The analysis was run for 1,200,000 generations with default priors, using the "invgamma" substitution model and an arbitrary burn in of 25% of the samples.

Gene flow analyses

The *D* statistic compares the number of biallelic ABBA and BABA sites in a four-taxon phylogeny and requires a phylogenetic topology following (((H1, H2), H3), O), with H1 to H3 being ingroups and O being the outgroup. For the analyses, the consensus sequences of baleen whales were fragmented into nonoverlapping 100-kbp windows. We applied the *D* statistic to all asymmetric four-taxon phylogenies that can be extracted from the species tree. This resulted in 33 gene flow analyses, such as "(((blue whale, sei whale), fin whale), minke whale)." The direction of gene flow can be estimated in a derivative of the *D* statistic, the D_{FOIL} analysis (*25*), downloaded 15 September 2015 from https://github.com/jbpease/dfoil. The test requires an asymmetric five-taxon tree with a specific topology; therefore, not all combinations of five whale taxa could be analyzed. The D_{FOIL} analyses used the same genomic windows as the *D* statistic analyses.

Our taxon sampling allowed the analysis of the following topologies when considering the estimated species tree as correct because the D_{FOIL} analyses assume a symmetrical five-taxon topology: (i) (((blue, sei), (fin, hump)), NA right); (ii) (((blue, sei), (fin, gray)), minke); (iii) (((blue, sei), (hump, gray)), minke); (iv) (((blue, sei), (hump, gray)), NA right); (v) (((blue, sei), (hump, gray)), bowhead); (vi) (((blue, sei), (fin, gray)), NA right); (vii) (((blue, sei), (fin, gray)), bowhead); (viii) (((blue, sei), (fin, hump)), bowhead); NA right refers to the North Atlantic right whale, whereas the remaining whales are indicated by the first part of their common names.

Maximum likelihood inference for reticulation with PhyloNet

PhyloNet (*26*) is specifically developed to reconstruct reticulated phylogenies from a set of gene trees. We used the ML approach to analyze a set of every 10th GF ML tree, that is, 3419 trees in a coalescent framework that accounts for ILS while allowing different numbers of reticulations (*26*). Subsampling of trees reduced complexity and computational demand. In addition, the bowhead whale, North Atlantic right whale, and sei whale individual "B" were pruned from the input gene trees because their phylogenetic position is unambiguous. The "InferNetwork_ML" method was run with 50 iterations, yielding the five networks with the highest likelihood scores. Analyzing networks with more than one reticulation were too complex and not interpretable from the extended Newick format.

Demographic history

Changes in N_e for the baleen whales were inferred from genome sequences using the PSMC (*28*). We applied PSMC v0.6.5-r67 with input files generated using Samtools mpileup version 1.2 (www.htslib.org) and by applying a minimum mapping and base quality of 30. Using vcfutils, minimum and maximum depth of coverage thresholds were set to 0.5 and 2× the sample's average coverage (table S1). PSMC was run with 25 iterations, an N_0-scaled maximum coalescent time of 20, and a ρ/θ ratio of 5, and the 64 time intervals were parameterized as "4 + 25 × 2 + 4 + 6." PSMC plots were scaled with a mutation rate of $\mu = 4.5 \times 10^{-10}$ mutations bp^{-1} year^{-1} that has been determined for whales (*52*).

Bootstrapping was performed on whole scaffolds. Species-specific predisturbance generation times were used to scale the PSMC plots (*53*). Industrial whaling took place only during the last 200 years, so predisturbance generation times are more accurate for the time frame covered by PSMC. The generation times are shown in Fig. 5.

Genome-wide heterozygosity

To estimate the genome-wide heterozygosity, we randomly sampled 1000 100-kbp nonoverlapping windows for each genome. For these windows, heterozygous SNVs were extracted from the complete set of called variants. Heterozygous sites were excluded if the distance to a called InDel was 10 bp or less or if the sequencing depth at the site was less than 0.5 or 2× the mean sample coverage. This avoids artifacts from assembly errors. For each window, the frequency of heterozygous sites was calculated. In addition, genome-wide heterozygosity and genome-wide sequencing error were inferred using mlRho (*54*). To exclude the potential effects of higher sequencing coverage in the blue whale, the BAM file was downsampled using GATK (genome analysis tool kit) and genome-wide heterozygosity was estimated for ~10× sequencing data.

Cetartiodactyla phylogenomics

Protein sequences for different representative species among Cetartiodactyla were retrieved from ENSEMBL and RefSeq (table S7). For data obtained from RefSeq, Samtools extracted the CDSs from whole-genome sequences using the annotation provided as a General Feature Format (GFF) file.

The annotated CDS for the bowhead whale was used to extract and translate the corresponding genomic regions from baleen whale genomes that were mapped to the bowhead whale Proteinortho version 5.11 screened protein sequences from all genomes listed in table S7. The baleen whale genomes were mapped to the bowhead whale genome and thus their CDSs have the same genomic coordinates. Therefore, the protein sequences of the baleen whales were added after orthology detection based on orthologous proteins identified in the bowhead whale. All proteins for which orthologs were identified in at least nine species were selected, and their sequences were extracted. Protein sequences were aligned individually and trimmed to exclude ambiguously aligned sites. The trimmed alignments were concatenated and used to date the

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cetartiodactyl species tree with MCMCTree (*55*) using five calibration points across the tree of Cetartiodactyla (table S8).

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/4/4/eaap9873/DC1

fig. S1. Possible tree topologies for baleen whales that were evaluated by the AU test.
fig. S2. Phylogenetic content of GFs.
fig. S3. AU test for increasing GF sizes.
fig. S4. MSC-based species trees generated by ASTRAL using 34,192 GFs, with each GF being 20 kbp long.
fig. S5. Phylogenetic tree from mitochondrial genomes for baleen whales.
fig. S6. A majority-rule consensus tree from 34,192 individual GF ML trees (table S6) calculated with the program CONSENSE of the PHYLIP package.
fig. S7. Consensus networks for baleen whales from 34,192 gene trees (10-kbp GF) at different minimum thresholds of gene trees to form an edge.
fig. S8. ML estimates of genome-wide heterozygosity estimated with mlRho.
fig. S9. Blue whale heterozygosity for different sequencing depth.
fig. S10. Demographic histories for each individual whale genome with 100 bootstrap replicates.
table S1. Sequencing and mapping statistics.
table S2. Occurrences of repetitive elements in the bowhead whale genome.
table S3. Number of called substitutions for each whale genome.
table S4. Library and sequencing information for the hippopotamus genome assembly.
table S5. Summary of repetitive elements in the hippopotamus genome.
table S6. A majority-rule consensus analysis of 34,192 individual GF ML trees.
table S7. Common names, scientific names, accession numbers, and source database of additional genomes that were included in the divergence time analyses.
table S8. Calibration points used for the divergence time tree, node age estimates in million years ago, and references.
table S9. Divergence time estimates for Artiodactyla and Cetacea for nodes in the divergence time tree (Fig. 5).
data S1. *D* statistics results.
data S2. D_{FOIL} results.

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Whole-genome sequencing of the blue whale and other rorquals finds signatures for introgressive gene flow

Úlfur Árnason, Fritjof Lammers, Vikas Kumar, Maria A. Nilsson and Axel Janke

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Changes in the Abundance of Whalebone Whales in the Pacific and the Antarctic since the Cessation of their Exploitation

A. A. Berzin and V. L. Vladimirov

Pacific Research Institute of Fisheries and Oceanography (TINRO) Vladivostok, USSR

ABSTRACT

Sightings data for protected species in the Pacific and Antarctic from 1976–79 are presented. Although the state of the baleen whale populations remains serious, there are indications that some populations are now increasing e.g. the Okhotsk Sea population of bowhead whales, blue and fin whales in the North and South Pacific and humpback whales around New Zealand.

INTRODUCTION

Berzin (1978) summarised data obtained from research vessels and from the whaling fleets *Dalniy Vostok* and *Vladivostok* in 1973 and the *Sovietskaya Rossiya* from 1973–76, on the distribution and abundance of the protected species of whalebone whales in the North Pacific. This analysis revealed the critical state of some of these stocks, in particular the Okhotsk Sea-Korean gray whales (*Eschrichtius robustus*) and the North Pacific humpback whales (*Megaptera novaeangliae*). The improvement in the state of some of the other stocks, e.g. the Chukotka-Californian gray whales and some of the rorquals in both the North Pacific and Antarctic is testimony to the necessity of timely action by the International Whaling Commission (IWC).

On the recommendation of the IWC Scientific Committee, Soviet whalers now carefully record data on the distribution and abundance of Protected Stocks in both Hemispheres. In this paper we have summarized data obtained from the *Dalniy Vostok* and *Vladivostock* in the North Pacific from 1976–78; from the *Sovietskaya Rossiya* in the Southern Hemisphere from 1977–79; from a helicopter survey in the northwest Okhotsk Sea in 1979 (Berzin and Doroshenko, 1981); and research cruises by the whaling boats *Avangard* in the Bering and Chukchi Seas and the *Recordniy* in the waters off Southern Australia (Blokhin, 1981).

NORTH PACIFIC

(a) Balaenopterids

The sightings data from 1976–79 confirm the trends noted by Berzin (1978). The balaenopterids including the blue whale (*B. musculus*), which were considered endangered species, are apparently increasing and in recent years they have been seen thoughout the operational area. For example blue whales (ranging from 1–16 individuals) were sighted almost every day in the area between 37° to 45°N and 177°E–150°W by the *Dalniy Vostok* in 1978 and in fact they were seen in greater numbers than any other protected species (Fig. 1) The United Kingdom's

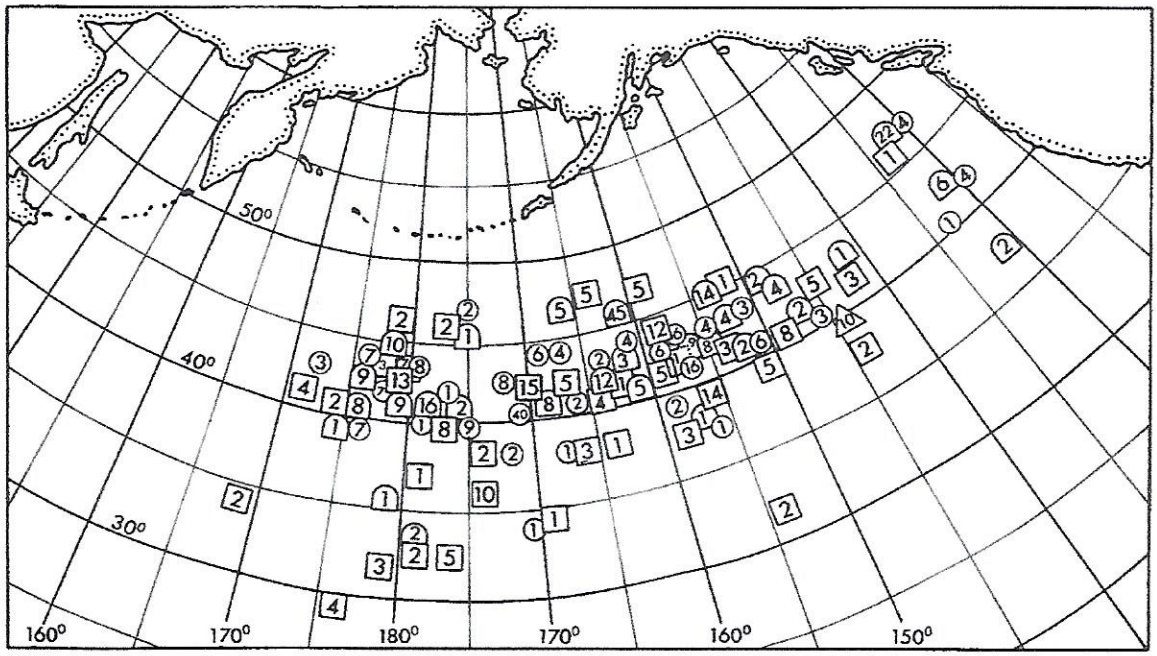

Fig. 1. Sightings of protected whales in the North Pacific, 1976–78. ○: blue whales; ⌂: fin whales; △: humpback whales; □: sei whales.

submission to the 2nd CITES Meeting (UK, 1979) states that the initial population of blue whales in the North Pacific was about 5,000 and that the present population numbers 1,400–1,900 (Table 1). Table 1 also shows that the initial fin whale population was about 10 times the blue whale population as is its present population size of 14–19,000. The increase in the numbers of blue, fin and sei whales seen in the North Pacific (Table 2) suggests that these species are recovering under the protection given by the IWC.

Table 1

Abundance of whalebone whales in the North Pacific (000s) based on data presented to the Second Meeting of the Conference of the parties to CITES in 1979 (UK, 1979) and Berzin and Yablokov, 1978 (and see text)

Species	Pre-exploitation	Present abundance
Blue whales	5.0	1.4–1.9
Fin whales	42.0–45.0	14.0–19.0
Sei whales	42.0–50.0	8.6–21.0
Bryde's whales	20.0–30.0	~18.0
Humpback whales	10.0–15.0	1.2–1.6
Gray whales		
(a) Chukotka – Californian	15.0	12.0–15.0
(b) Okhotsk Sea – Korean	1.0–1.5[1]	0.1–0.2
Bowhead whales		
(a) Bering – Chukchi Seas	18.0	2.26
(b) Okhotsk Sea	6.5[2]	0.1
Atlantic right whales		
(*Eubalaena glacialis*)	10.0	0.22–0.5

[1] Estimate for 1910 after some exploitation had occurred.
[2] Considered too high by Berzin and Doroshenko (1981).

(b) Humpback whales

During the period of observation there has been no increase in the number of humpback whales sighted. Although large areas of the North Pacific have been covered, very few humpback whales have been seen. No humpbacks were seen in 1976 and 1978. In 1977 only one group of ten individuals was observed (on June 5 at 41°40'N, 146°37'W). In 1979 four single whales were seen. Humpbacks have not been seen near the Kuril Islands for many years, an area where they were formerly abundant. Humpback whales are more abundant in Hawaiian coastal waters and in the southern waters of the Gulf of Alaska. These whales may be part of the same population (IWC, 1980, p. 105).

There are insufficient data to estimate the present population size, but it is clear that some previously abundant populations in the North Pacific remain in a critical state.

(c) Bowhead whales

The presence of bowhead whales (*Balaena mysticetus*) in the western Okhotsk Sea was confirmed in 1974 during the research cruise of SRTM *Tamango* (Berzin and Kuzmin, 1975; Berzin, 1978). This area was again covered in August 1979, this time using a helicopter. The bowhead whales were mainly observed in the same areas they had been seen in in 1967 and 1974 (Berzin and Doroshenko, 1981). The largest concentrations were seen in the western part of Ulbanskiy Zaliv (up to 20 whales); in Zaliv Akademii (13 whales); and in the northwestern part of Tugurskiy Zaliv (7 whales). A total of 55 (including 5 cows with calves) bowhead whales was seen during this helicopter survey of the western Okhotsk Sea. This slightly exceeds the number (35 whales) seen in 1974 (Berzin and Doroshenko, 1981). If the much greater speed of the helicopter is taken into account then the number of whales appears even greater than the number seen on the 1974 cruise in larger area. These data suggest that this population of bowhead whales is gradually increasing.

There have been many studies on the population size of the Bering – Chukchi Sea stock of bowhead whales (e.g. McVay, 1973; Berzin, 1974; Marquette, 1976; Tillman, 1977). These studies have primarily been based on observations which have recently been conducted each year off the Alaskan coast (Braham and Krogman, 1977; Braham *et al*, 1979; Braham *et al*, 1980). Only occasional sightings have been made in the Soviet zone of the Chukchi Sea near the continental coast (Berzin, 1974; Kuzmin and Berzin, 1975; Fedoseyev and Goltsev, 1975; Berzin and Votrogov, 1978). Before 1979, there was no reliable information about the abundance and distribution of bowhead whales in other areas of the Chukchi Sea. Moreover it was not clear whether the whales which migrated along the Chukotka coast in spring remained in these and more northerly waters in the summer or whether they migrated past Mys Dezhneva and into Alaskan coastal waters as was supposed by observers and whalers from Chukotka (Berzin and Votrogov, 1978).

It was for these reasons that the 1979 joint USSR–USA research cruise was so important. The Soviet whaler *Avangard* undertook a four week cruise in October 1979 with the aim of studying the distribution of whales in the Bering and Chukchi Seas. A significant part of the western Chukchi Sea was covered between 5 and 22 October. The first bowheads were observed in pancake ice near Herald Island on 12 October (a group of two whales and two single whales). The number of bowheads increased as the vessel moved south. On 14 October ten bowheads (mainly single whales) were observed at 70°31'N and 176°16'E. On 16 October large numbers of bowheads (70 whales) were observed near Mys Vankarem. The density of whales in this area was very high—1.0 whales per square mile

Table 2

Number of blue, fin and sei whales in the North Pacific, 1976–79, seen by Soviet fleets (data from USSR Progress Reports) and sightings per unit effort (SPUE)

		Blue		Fin		Sei	
Year	Effort	No. seen	SPUE	No. seen	SPUE	No. seen	SPUE
1976	3,202	2	0.001	12	0.004	7	0.002
1977	3,647	28	0.008	121	0.033	54	0.015
1978	2,646	108	0.041	106	0.040	109	0.041
1979	2,417	90	0.037	173	0.072	140	0.058

(Doroshenko, 1979) and includes sightings of cows with calves. Dense concentrations were noted as far as Kolyuchinskaya Inlet but no whales were seen from there to the Bering Strait. In all, 137 bowhead whales were seen. In view of the heavy seas and poor visibility encountered during the cruise which caused considerable variability in sighting efficiency, and the fact that a systematic survey was not attempted, the approximate estimation of about 1,500 whales in the area covered in the south western Chukchi Sea must be viewed with caution. The currently accepted best estimate for the Bering Strait bowhead stock by the IWC is that of Braham *et al.* (1979): 1,783–2,865 with a mean of 2,264 (IWC, 1980). Bockstoce and Botkin (1980) roughly estimated the current population size of bowhead whales in the Bering and Chukchi Seas to be about 3,000.

(d) Gray whales

There remains much concern over the state of the Okhotsk Sea-Korean stock of gray whales (Brownell and Chun, 1977; IWC, 1981). No gray whales were seen during the helicopter survey over coastal waters of the western Okhotsk Sea in the Shantar – Sakhalin area in August, 1979. The observation of a gray whale on 1 October 1979 (the last gray whale seen in this area had been in August 1974—Berzin and Kuzmin, 1975) by the TINRO research vessel *Ucheny* is thus particularly interesting. It was seen in the coastal waters (250–300 m from the shore) of the southeastern part of Kamchatka, about 2 miles north of Mys Sopochniy (M. K. Mamivov, pers. comm.). This does not conflict with the proposal that the Japanese part of the Okhotsk Sea – Korean population (or an independent population?) which once bred in the inland Sea of Japan, migrates along the eastern coast of Japan from the Kuril Islands (Omura, 1974). These whales have been previously seen off the south-eastern coast of Honshu Island (Nishiwaki and Kasuya, 1970), off Shikotan (A. N. Belkin, pers. comm.) and off the Shiashkotan Islands (Mizue, 1951).

SOUTHERN HEMISPHERE (Figs 2–4)

Observations of whalebone whales in the Southern Hemisphere by Soviet vessels vary considerably from year to year (Berzin, 1978) due to changes in effort and area of sightings. A brief account of sightings from Soviet vessels in recent years is given in this section.

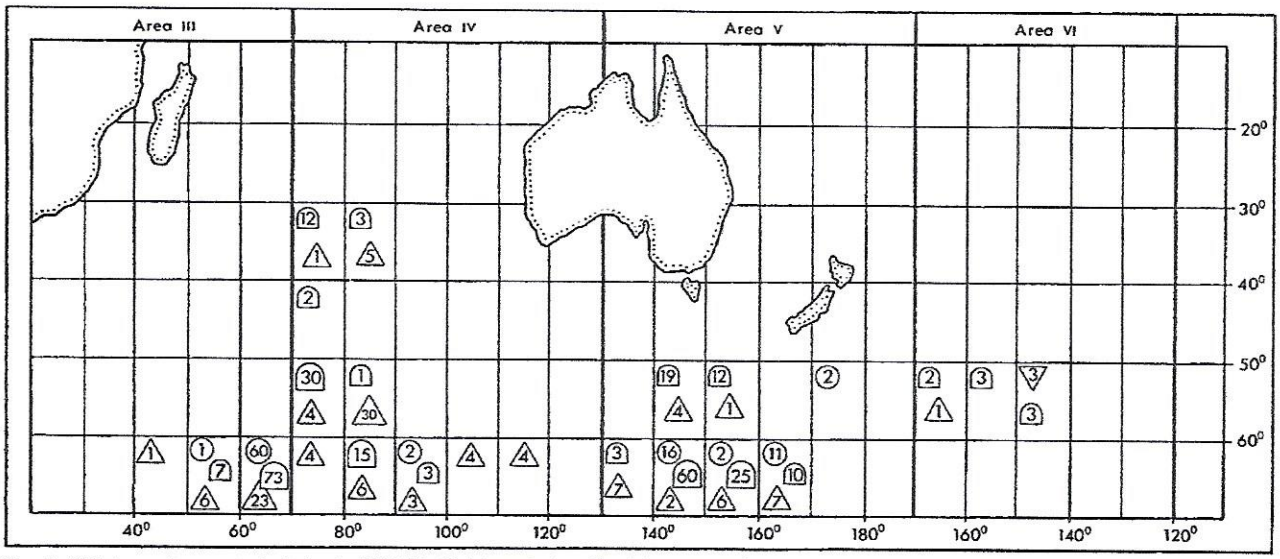

Fig. 2. Sightings of protected whales in 1976/77. ○: blue whales; ▽: right whales; ∩: fin whales; △: humpback whales.

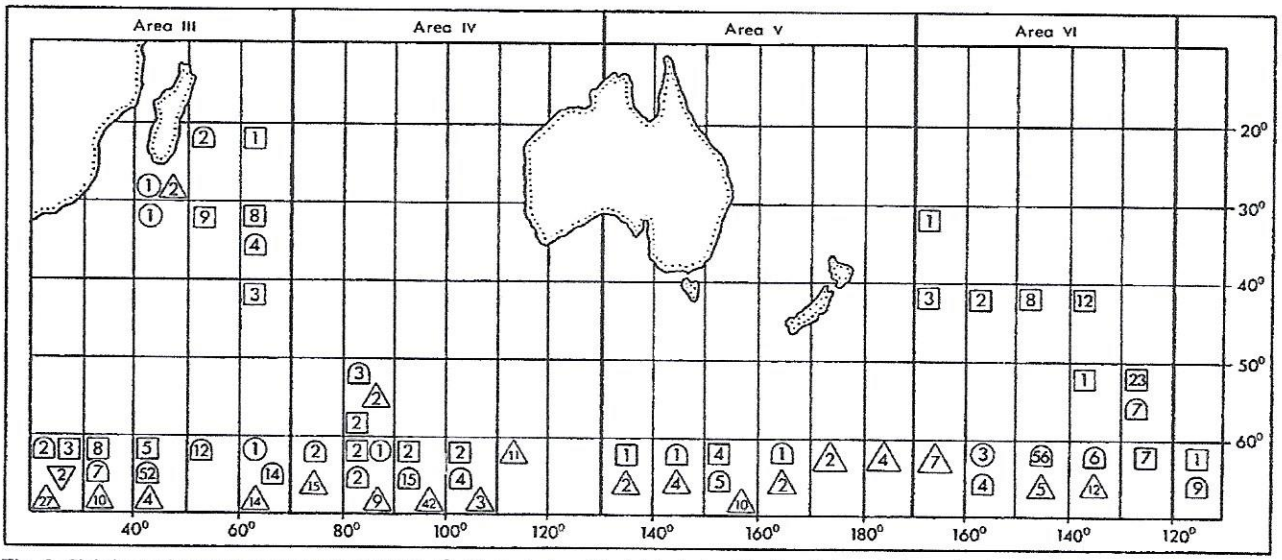

Fig. 3. Sightings of protected whales in 1977/78. ○: blue whales; ▽: right whales; ∩: fin whales; △: humpback whales; □: sei whales.

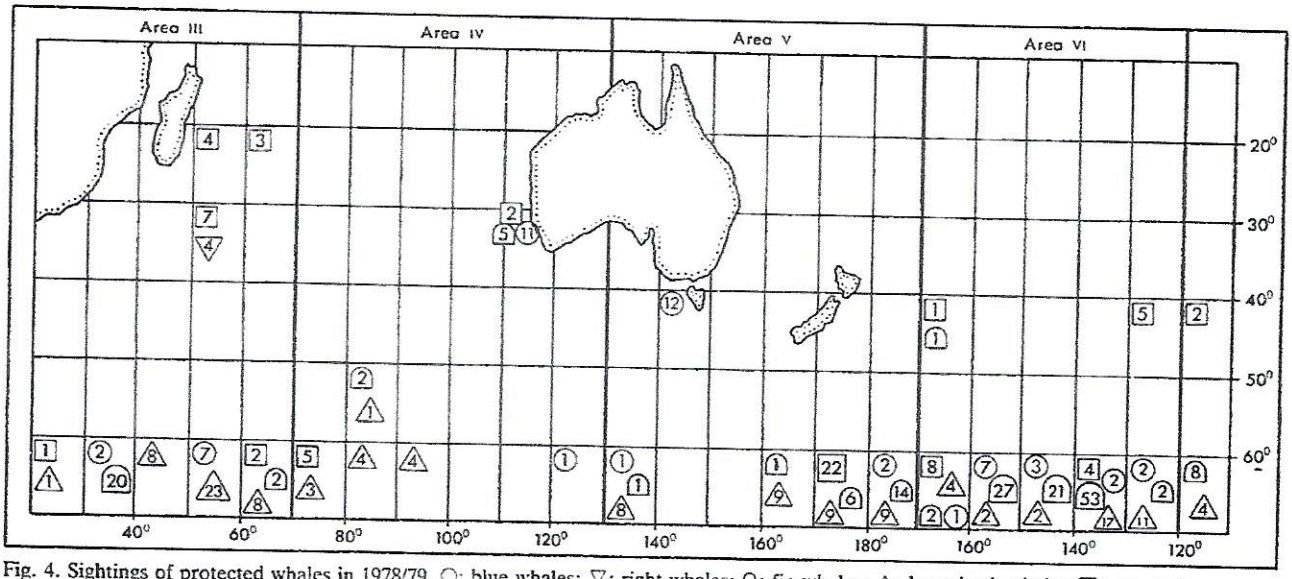

Fig. 4. Sightings of protected whales in 1978/79. ○: blue whales; ▽: right whales; ∩: fin whales; △: humpback whales; □: sei whales.

(a) Blue and fin whales

Blue whales have been sighted reasonably consistently by Soviet vessels in recent years. In 1978/79, blue whales were seen in each 10° square in Area VI, Zone B (Fig. 4). During the IWC/IDCR research cruise of the whaler *Recordniy* in March and April 1979, relatively large numbers of blue whales were seen. On 6/7 March eleven blue whales (which Berzin considers were possibly pigmy blue whales, *B. m. brevicauda*) were observed on the way from Tasmania to southern Australia on 24/25 March, twelve blue whales (including large individuals of up to 27 m) were seen off the southwestern coast of Western Australia (Fig. 4). Five fin whales and two right whales were observed in the same area (Blokhin, 1981). Large groups of fin whales (up to 30–50 whales) have been seen in recent years (Figs 2–4).

(b) Humpback whales

There is an increasing trend in the number of humpback whales seen off New Zealand: they were observed in Zone B in each 10° square from 130°E–160°W in 1977/78 and from 160°E to 110°W in 1978/79 (Figs 3 and 4). In fact in Series B they have been seen in almost every 10° square from Areas III to VI.

(c) Sei whales

The low abundance of sei whales in the Indian Ocean remains of serious concern particularly in the central area where they used to be common but where now only single animals are seen. In 1978/79 during the two weeks when sperm whaling was carried out by *Sovietskaya Rossiya* in the area between 20°–40°S, only 14 sei whales were seen.

CONCLUSION

The designation of Protection status to many populations by the IWC and the cessation of pelagic whaling has created the most favourable conditions for the recovery of stocks once considered endangered.

The examination of recent Soviet sightings data in the North Pacific and Antarctic suggests that many of the depleted whalebone whale populations are gradually recovering.

We have confidence that present management policies will not only preserve and allow the recovery of all the existing whale stocks but will also ensure their rational utilisation for the benefit of all mankind.

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Probable Extinction of the Korean Stock of the Gray Whale (Eschrichtius robustus)
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In summary, these data provide the first information regarding blood physiology of the spotted skunk. The values obtained seem to be in general agreement with those obtained for other mammals.

The authors would like to thank Mr. Tom Mabry for help in capturing the skunks, Miss Marie Tullos for aid during bleeding, and the Drs. Pathology Service, Jonesboro, Arkansas, for their generous use of the SMA 12/60 Autoanalyser. This study was financed, in part, by a University of Arkansas at Little Rock Faculty Research Grant.

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Gary A. Heidt and James Hargraves, *Dept. of Biology, University of Arkansas at Little Rock, Little Rock, 72204.* *Submitted 24 April 1973. Accepted 21 August 1973.*

PROBABLE EXTINCTION OF THE KOREAN STOCK OF THE GRAY WHALE (*ESCHRICHTIUS ROBUSTUS*)

Disappearance of the Korean stock of gray whale (*Eschrichtius robustus*) has been hypothesized for several years. My observations support this hypothesis. This stock ranged from the northern part of the Sea of Okhotsk to the southern tip of the Republic of Korea. The last individual gray whale of this stock apparently was taken from the eastern coast of Korea in 1933 (Mizue, 1951). Since that time, many conservationists and marine mammalogists had hoped for a recovery of gray whale in this area. The extermination of this stock, however, can be confirmed only by repeated negative findings.

The Korean stock of gray whale, the western counterpart of the California gray whale, once migrated between its summer feeding grounds in the northern part of the Sea of Okhotsk and its winter calving grounds among the islands of the southern tip of the Republic of Korea. They followed the shore line closely and could be seen off the coast of central Korea from November through January on their southern migration and from March through May on their northern migration (Andrews, 1914). The Korean stock was relatively unexploited until about 1899. The Oriental Whaling Co., Ltd. of Osaka, Japan, caught 1474 gray whales from 1910 to 1933 off Ulsan, Korea. Rice and Wolman

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(1971) suggest that with such a rapid decline the Korean stock of gray whale numbered only 1000 to 1500 whales in 1910.

Since 1933, three gray whales have been captured in the Western Pacific. One of these was captured off the northern Kuril Islands in 1942 (Mizue, 1951). The other two were captured off the coast of southern Japan at 135°55′E, 33°29′N and 136°01.7′E, 33°43′N, in 1959 and 1968, respectively. The 1968 specimen was a young female which resembled members of the California stock in morphological features (Nishiwaki and Kasuya, 1970). The skulls of the other two specimens were not examined or saved. Because these specimens were not captured in the normal migratory path of the Korean stock of gray whale, but were captured to the east of the migratory path, in an area where the Korean stock was not known to have ventured, it is my opinion that these three gray whales should be regarded as strays from the Bering Sea, that is from the California stock.

During 1970–71 and 1971–72, I searched the coast of the Republic of Korea from Pohang to Cheju Island in taxi, boat, and on foot for the missing gray whale, but found none. During January of 1972, I made a short cruise around the southern tip of the Republic of Korea and saw no whale of any species. I visited Ulsan, Korea, which was, and now again is, the whaling center for the Republic of Korea, and saw 16 whaling vessels ranging in size from 20 tons on up to 100 tons. During 1970 a total of 740 whales were taken; 715 of these were minke or small whales. Fishermen and ships captains, whom I or my wife talked to, had never seen a whale that fit the description of the gray whale. No one had ever heard of a whale that enters the waters among the islands at the southern tip of Korea. Whaling has been increasing in the Republic of Korea for many years (Yearbook of Fisheries Statistics, 1971) and because they are not a member of the International Whaling Commission it seems likely that any species is taken.

Based on the foregoing reports and observations the Korean stock of gray whale has apparently disappeared. This extinction should be carefully considered in order to take positive scientific steps to safeguard remaining whale stocks from excessive exploitation and possible extinction.

Acknowledgments.—I am greatly indebted to Raymond M. Gilmore, San Diego Natural History Museum, for guidance before my trip to Korea and for assistance in preparation of this paper. I wish to thank Erling O. Oswald, Project Manager of the Coastal Fishing Training Center, Pusan, Korea, for providing hospitality and information. I also wish to thank Masaharu Nishiwaki, Ocean Research Institute, Tokyo, Japan, for providing valuable manuscripts.

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Steven L. Bowen, *Biology Department, California State University, San Diego, 92115.*
Submitted 21 September 1972. Accepted 15 April 1973.

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POPULATION ASSESSMENT OF WESTERN NORTH PACIFIC GRAY WHALES (*ESCHRICHTIUS ROBUSTUS*)

AMANDA L. BRADFORD

A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

University of Washington

2003

Program Authorized to Offer Degree: School of Aquatic and Fishery Sciences

University of Washington
Graduate School

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ABSTRACT

POPULATION ASSESSMENT OF WESTERN NORTH PACIFIC GRAY WHALES (*ESCHRICHTIUS ROBUSTUS*)

AMANDA L. BRADFORD

Chair of the Supervisory Committee:
ASSOCIATE PROFESSOR GLENN R. VANBLARICOM
School of Aquatic and Fishery Sciences

Two geographically and genetically distinct populations of gray whales (*Eschrichtius robustus*) occur in the North Pacific, referred to as the eastern and western populations. Subjected to intensive modern commercial whaling during portions of the 19th and 20th centuries, the western population was proposed to be extinct during the early 1970's. This population presently remains in small numbers and is considered one of the world's most endangered populations of large whales. The need for increased conservation efforts indicates the appropriateness of a quantitative western gray whale population assessment. Since 1997, ongoing studies of western gray whales have resulted in a photographic dataset that can be used for mark-recapture survival estimation. A robust design model was fitted to 116 individual whale encounter histories spanning 22 monthly capture occasions from 1997 to 2002. Constant non-calf and calf (first-year post-weaning) survival and random temporary emigration were assumed. Models incorporating individual heterogeneity in residency patterns and higher temporary emigration probabilities for younger whales provided better fits to the data. Non-calf and calf survival were estimated as 0.952 (SE=0.0151, 95% CI=0.912-0.975) and 0.709 (SE=0.1178, 95% CI=0.443-0.882), respectively. These survival estimates and other life history parameters were utilized in conjunction with the Lotka equation to calculate the 1997-2002 population growth rate of western gray whales. A Monte Carlo simulation method was employed (n=10,000 trials) to account for uncertainty in the life history parameters. A range of possible fecundity values was examined to estimate a *conservative*, *intermediate*, and *liberal* rate of population growth. These growth rates were estimated as 0.026 (SD=0.0190, 5th-95th Percentiles=-0.008-0.054), 0.031 (SD=0.0194, 5th-95th Percentiles=-0.003-0.061), and 0.036 (SD=0.0198, 5th-95th Percentiles=0.001-0.066), respectively. Each calculated growth rate and historical catch data were fitted to the generalized logistic equation in a 20th century back calculation of the western gray whale population. A Bayesian statistical method and the Sample-Importance-Resample algorithm (n_1=2,000,000 initial samples; n_2=5,000 resamples) were used to estimate model parameters and indices of population status. Back calculation results suggest that the western gray whale population is currently growing at its maximum net recruitment rate, the carrying capacity of the population is undefined, the population is currently *at most* between 8-9% of its original size, and the population has been highly depleted for over half of the 20th century. Current threats and low-density population effects could inhibit the recovery of western gray whales, emphasizing the necessity of concerted international protection and conservation planning for this critically endangered population.

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DEDICATION

At the risk of appearing overly sentimental, I would like to dedicate this work to the western population of gray whales. First and foremost, as a scientist, my hope is that this effort can be used objectively in the formulation of increased protection and conservation measures that are needed to promote the recovery of this critically endangered population. However, a particularly interesting aspect of studying such an extremely small population of recognizable individuals is that I have spent a significant amount of time over the years in the company of known whales. Memories of countless encounters with Pirate, Otter, Svetlana, Ponchik, Tooman, Speedy, Vova, and many other whales are permanently etched in my heart and mind. Out of respect and gratitude for such a privilege, concurrent with my scientific aspirations, I will be anxiously rooting for this population – as a *person*, who sincerely wishes western gray whales the opportunity to thrive in the years to come.

CHAPTER 1

THE WESTERN POPULATION OF GRAY WHALES

INTRODUCTION

The present status of the two extant gray whale populations in the North Pacific Ocean is a study in contrasts. The eastern gray whale population, reduced by commercial harvesting to a few thousand individuals by the end of the 19th century, has rebounded in size to levels most likely approaching carrying capacity. The western population, also depleted by commercial whaling during portions of the 19th and 20th centuries, was suggested to be extinct during the early 1970's. This population currently exists in small numbers and is considered one of the world's most endangered populations of large whales. The present thesis project explores the demography and population dynamics of western gray whales, offering a quantitative description of this population for incorporation into future conservation and management plans.

BACKGROUND

Two populations of gray whales (*Eschrichtius robustus*) occur in the North Pacific, the eastern (California/Chukchi) population and the western (Korean/Okhotsk) population (Rice and Wolman, 1971). The two populations can be differentiated genetically at the population level, and should be considered geographically and genetically distinct population units (LeDuc *et al*., 2002). Historically, gray whales also occurred in the eastern and western North Atlantic, possibly as two populations, but were extinct by the early 18th century (see Lindquist, 2000 for a review). Although the direct

cause of their extinction is unknown, it has been linked to human activity (Mitchell, 1973).

Eastern gray whales have long been known to migrate along the western coast of North America from winter breeding grounds off Baja California to summer feeding grounds in the Bering and Chukchi Seas (e.g., Pike, 1962; Rice and Wolman, 1971). Western gray whales, also annual migrators, return to summer feeding grounds in the Okhotsk Sea (Berzin, 1990). Winter breeding grounds for this population are unknown, but are suspected to be along the coast of southern China (Wang, 1984; Omura, 1988; Kato and Kasuya, 2002).

Throughout their range, gray whales typically do not occur outside the shallow waters of the continental shelf. Their coastal distribution made them accessible to both aboriginal and commercial whalers (see Table 1.1 for definitions of whaling terminology used frequently in this text: Aboriginal Whaling, Commercial Whaling, Japanese Hand Harpooning, Japanese Net Whaling, Modern-type Whaling, and Yankee-type Whaling). Both populations were subject to intensive commercial whaling during portions of the 19th and 20th centuries. Yankee-type commercial whaling of eastern gray whales reportedly began in 1846 (Scammon, 1874). Prior to that time, eastern gray whales were taken solely by aborigines, although the extent and duration of the aboriginal whaling is unknown (Mitchell, 1979). By the late 19th century, the eastern population was reduced to levels of commercial 'extinction' (Henderson, 1972, 1984), and was suggested to number anywhere from 2,000 to 10,000 individuals (see Scammon, 1874; Henderson, 1972, 1984; Ohsumi, 1976; Reilly, 1981 for various estimates). After receiving

international protection (see below), recovery of the population was observed (Reilly, 1992). Abundance estimates of approximately 26,600 whales in 1997/98 (Hobbs and Rugh, 1999) and 18,800 and 17,400 in 2000/2001 and 2001/02, respectively, (Rugh *et al*., 2002) suggest that this population is above its pre-commercial exploitation population level (i.e., 1846 population size) and is possibly equilibrating at its current carrying capacity (Reilly, 1992; LeBoeuf *et al*., 2000; Moore *et al*., 2001; Rugh *et al*., 2002).

Before the onset of modern-type commercial whaling in 1891 (Kato and Kasuya, 2002), western gray whales were subject to a long but poorly documented history of takes. Groups of maritime Koryak natives along the northeastern Okhotsk Sea hunted whales, presumably including western gray whales (Krupnik, 1984). In Japan, western gray whales were probably taken by hand harpooners dating back to the late 16th century, and were definitely taken by net whalers beginning in the late 17th century (Omura, 1984). Omura (1984) estimates that Japanese net whalers took 50-60 gray whales annually during the net whaling period (1675-1890). However, Japanese net whalers caught at least 78 western gray whales between 1891 and 1899, concurrent with the spread of modern whaling techniques (Tada, 1978; Omura, 1984; Park, 1987; Kato and Kasuya, 2002). From the middle to the late 19th century, Yankee-type pelagic whalers operating in the Okhotsk Sea also caught western gray whales, taking possibly around 500 individuals during this period (Henderson, 1984).

A Russian whaling company initiated modern-type commercial whaling for western gray whales off the coast of the Korean peninsula in 1891 (Kato and Kasuya, 2002). Russian western gray whaling there lasted until 1904 (Kato and Kasuya, 2002),

although Yablokov and Bogoslovskaya (1984) noted that western gray whales were sporadically hunted by Russians near Peter the Great Bay, Russia, during World War II (WWII). Modern whaling began in Japan in 1898 (Omura, 1984), although few western gray whales were caught there (less than 3% of total commercial catches; Appendix A), as they were no longer abundant (Omura, 1984). Instead, Japanese modern whalers began operating off the northeastern and southeastern Korean coasts in 1900, where they worked until the end of WWII in 1945 (Kasahara, 1950; Kato and Kasuya, 2002). The majority of modern commercial western gray whale catches occurred during this operation (Figure 1.1; Appendix A).

Modern western gray whaling off the Korean peninsula was resumed following WWII by the Republic of Korea (South Korea), although the dwindling catch numbers (Figure 1.1) reflect the depleted status of the population (Brownell and Chun, 1977; Kato and Kasuya, 2002). Although western gray whales had previously been taken by the Japanese in the vicinity of the Democratic People's Republic of Korea (North Korea), nothing is known about whaling in these waters subsequent to WWII (Kato and Kasuya, 2002). Little is known about Chinese modern commercial whaling, but records exist of at least 14 takes in the waters adjacent to China (Appendix A; Kasahara, 1950; Mizue, 1951; Wang, 1978, 1984; Omura, 1988; Kato and Kasuya, 2002). Wang (1984) indicated that half of these whales were caught by Japanese whalers. In total, a minimum of 1,868 western gray whales were taken in the 20th century, the period when they were taken predominately by modern commercial whalers (Figure 1.1; Appendix A).

Gray whales were first accorded international protection in 1937 with the International Agreement for the Regulation of Whaling (Committee for Whaling Statistics, 1942; Reeves 1984). At the time, none of the range states of western gray whales (Russia, Japan, North Korea, South Korea, and China) were signatories to this agreement (Committee for Whaling Statistics, 1942; Reeves, 1984). When the International Convention for the Regulation of Whaling was established in 1946, gray whales legally became a protected species exempt from commercial whaling by the International Whaling Commission (IWC) (International Whaling Commission, 1950; Scarff, 1977; Reeves, 1984). Russia was a signatory to this agreement (International Whaling Commission, 1950), and Japan formally adhered by 1951 (International Whaling Commission, 1951). South Korea and China did not join the IWC until 1978 and 1980, respectively (International Whaling Commission, 1980, 1982). North Korea is presently not an IWC member.

Each gray whale population remained an IWC *Protected Stock* until 1978, when eastern gray whales were reclassified as a *Sustained Management Stock* (International Whaling Commission, 1979; Reeves, 1984). Both populations are listed in *Appendix 1* (i.e., most endangered) of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Russia, Japan, South Korea, and China are all CITES member parties. Despite international protection of western gray whales throughout most of their range, at least one direct take occurred between 1980 and the present (Brownell and Kasuya, 1999).

The western gray whale population has failed to exhibit the successful recovery demonstrated by its eastern counterpart (Clapham *et al*., 1999; Weller *et al*., 2002c). Western gray whales were proposed to be extinct during the early 1970's (Bowen, 1974), but they do survive as a remnant population (Brownell and Chun, 1977; Blokhin *et al*., 1985; Weller *et al*., 1999; 2002c). Blokhin (1996) and Vladimirov (1994) reported population estimates of 100 and 250 whales, respectively. However, these estimates were not quantitatively derived. Recent studies indicate that the population may currently consist of approximately 100 individuals (Figure 1.2; Wade *et al*., 2003). The current depleted status of western gray whales is possibly a result of intense harvesting prior to the onset of modern-type whaling (Omura, 1984), a prolonged period of modern commercial whaling (Kato and Kasuya, 2002), a pre-exploitation population level that may never have been very large in size (Yablokov and Bogoslovskaya, 1984), or more likely, a combination of these factors.

In 2000, the World Conservation Union (IUCN) designated western gray whales as *Critically Endangered*, that is, "…facing an extremely high risk of extinction in the wild in the immediate future, as defined by criteria (A to E)" (Hilton-Taylor, 2000). Western gray whales are listed according to *Criterion D*, which states that the "population [is] estimated to number less than 50 mature individuals." Mature is defined as "…capable of reproduction." For western gray whales, the number of mature individuals is approximately 47 (see Weller *et al*., 2002c for details of the estimation). The small population size and low number of mature individuals emphasize the western

gray whale's status of one of the world's most endangered populations of large whales (Clapham *et al*., 1999; VanBlaricom *et al*., 2001; Weller *et al*., 2002c).

Whereas eastern gray whales are one of the better-studied baleen whale populations, western gray whales have only recently come under concerted study (Brownell *et al*., 1997; Weller *et al*., 1999, 2000, 2001, 2003a, 2003b; Würsig *et al*. 1999, 2000). Initiated in 1997, an ongoing study of western gray whales takes place on their only presently known summer feeding ground, located off the northeastern coast of Sakhalin Island, Russia, in the near-shore waters proximate to Piltun Lagoon (Figure 1.3). This research has documented the regular use of the feeding ground by western gray whales of both sexes and multiple age classes, including reproductive females and their weaning calves. The Piltun study is being conducted by Texas A&M University (TAMU) and the National Marine Fisheries Service (NMFS), in collaboration with the Kamchatka Institute of Ecology and Nature Management (KIENM)[1].

PROJECT OBJECTIVES

This thesis project uses available population data and life history information to examine the demography and population dynamics of western gray whales. Specific objectives of the population assessment are: 1) mark-recapture estimation of non-calf and calf survival and associated mark-recapture parameters (Chapter 2); 2) Monte Carlo simulation estimation of current population growth rate (Chapter 3); and 3) Bayesian back calculation of the population to determine the population level prior to concerted

[1] Over the six years of the TAMU, NMFS, and KIENM study, I have participated in data collection and analysis for five and six years, respectively.

modern commercial whaling (Chapter 3). Given a previous lack of quantitatively based knowledge regarding western gray whale demography and population dynamics, results from the assessment will be a valuable contribution to conservation efforts of this critically endangered population. This project is one component of the aforementioned larger study being carried out by TAMU, NMFS, and KIENM.

Table 1.1. Definitions of terminology used frequently in this text to describe gray whaling. Definitions were adapted from Mitchell and Reeves (1980) unless noted otherwise.

Term(s)	Definition
Aboriginal Whaling	Whaling conducted by endemic local people, for a period generally exceeding their documented history, who consume the products locally.
Commercial Whaling	Whaling conducted by anyone for the primary purpose of selling the products in a cash economy.
Japanese Hand Harpooning	Whaling conducted by Japanese villagers who formed small teams of vessels and took whales using hand harpoons*.
Japanese Net Whaling	Whaling conducted by Japanese villagers who formed large, coordinated fleets and used nets to secure whales for subsequent harpooning*.
Modern-type Whaling (Norwegian-type Whaling, Modern Whaling)	Whaling based on mechanical means of transport (i.e., gas, diesel, or steam-powered vessels) and the use of firearms and explosives to take whales.
Yankee-type Whaling (19th Century Whaling)	Whaling conducted from oar- and/or wind-driven vessels that involved the use of harpoons and lances to take whales.

*Definition adapted from Omura (1984).

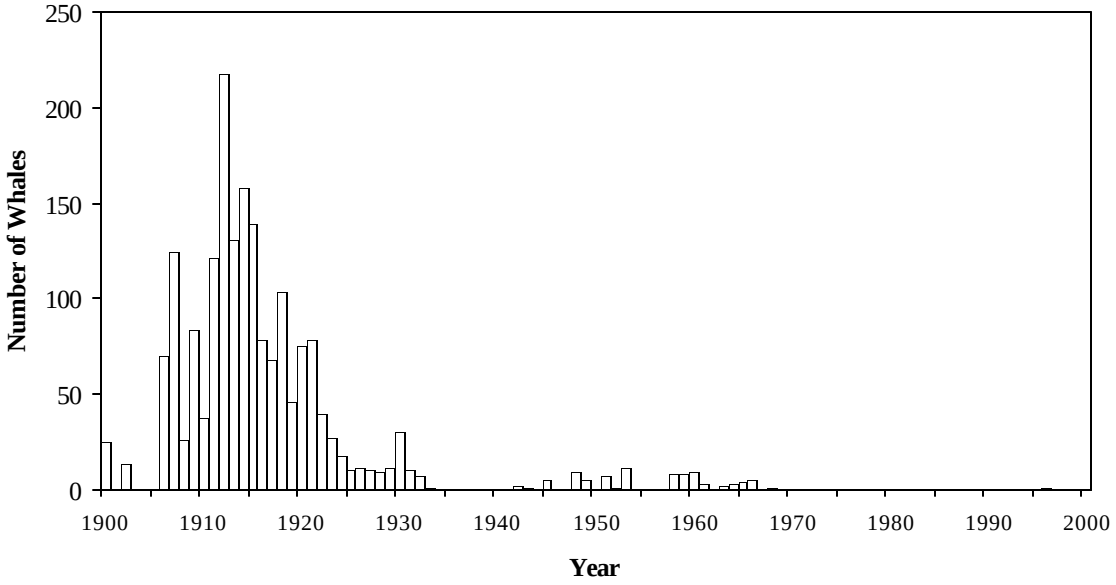

Figure 1.1. Minimum numbers of western gray whales caught during the 20th century, predominantly by modern-type commercial whalers off the Korean peninsula. Catch history compiled from Andrews (1914), Kasahara (1950), Mizue (1951), Nishiwaki and Kasuya (1970), Brownell and Chun (1977), Tada (1978), Wang (1978, 1984), Omura (1984, 1988), Park (1987), Brownell and Kasuya (1999), and Kato and Kasuya (2002). See Appendix A for details of catches.

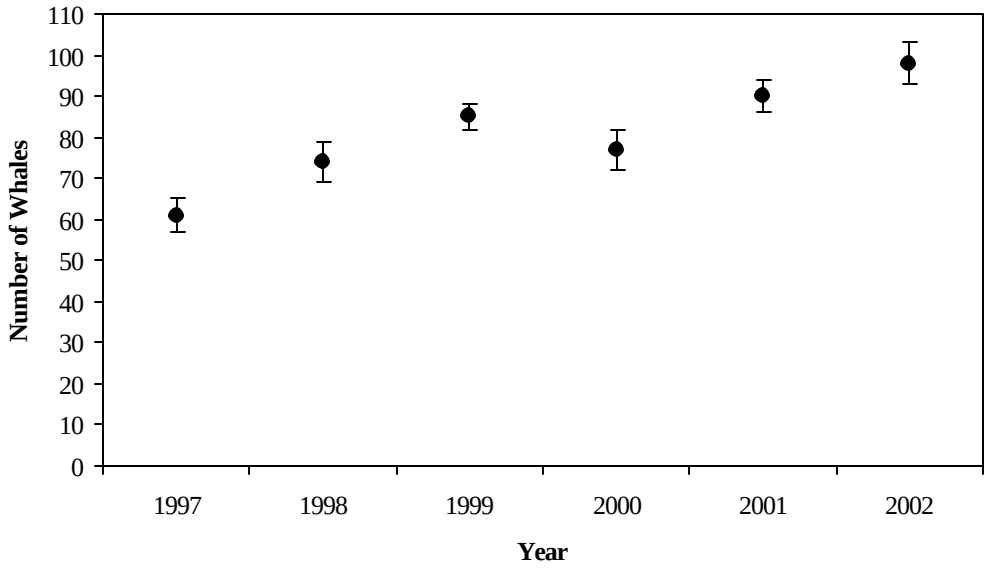

Figure 1.2. Yearly estimates of the number of western gray whales associated with the Piltun study area from 1997 to 2002 determined using closed-capture mark-recapture techniques (Wade *et al*., 2003). The trend in the estimates is considered to overestimate the present population growth rate, although the 2002 estimate is thought to closely approximate current population size. Circle = point estimate. Bars = standard error.

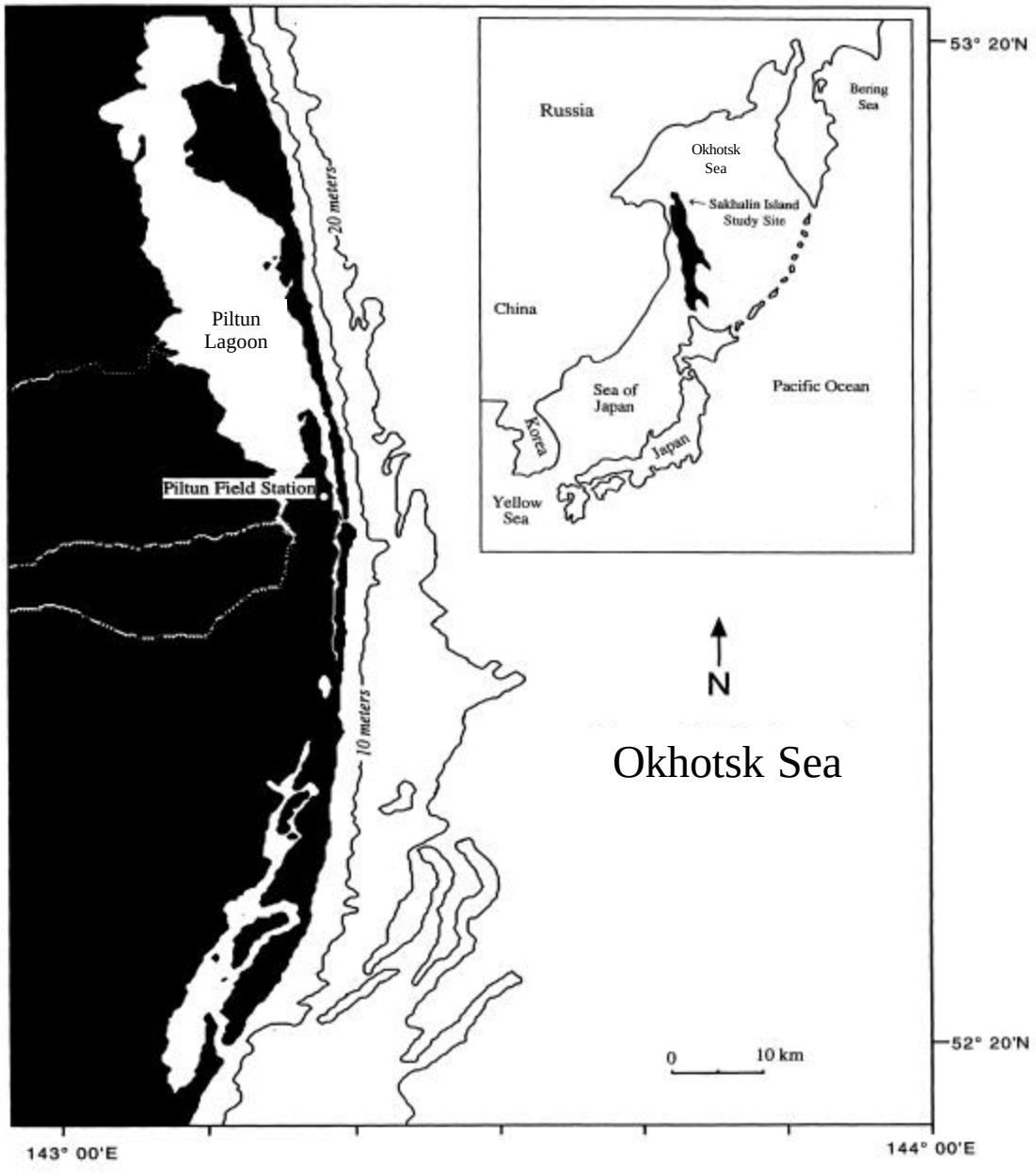

Figure 1.3. Map of the Piltun study area. Inset shows relative location of Sakhalin Island in the Okhotsk Sea.

CHAPTER 2

SURVIVAL ESTIMATES OF WESTERN GRAY WHALES INCORPORATING INDIVIDUAL HETEROGENEITY AND TEMPORARY EMIGRATION[2]

INTRODUCTION

The use of marked individuals and mark-recapture theory in assessing biological populations is well documented (see Pollock, 1991 for review). In many whale populations, individuals can be identified from photographs of their natural markings (e.g., scars and pigmentation patterns) in a method known as photo-identification (see Hammond *et al*., 1990 for overview). In the application of mark-recapture theory to photo-identification methodology, the first photographic sighting of an individual constitutes the *mark* and subsequent sightings the *recaptures*. The complete individual sighting record serves as the *encounter history* (White and Burnham, 1999). Encounter histories are fitted to an appropriate mark-recapture model (see Seber, 1982 for examples) to estimate the population parameter of interest. Mark-recapture photo-identification studies can be used to estimate the abundance (e.g., Hammond, 1986), survival (e.g., Buckland, 1990; Caswell *et al*., 1999), and fecundity (e.g., Barlow and Clapham, 1997) of whale populations. However, for most mark-recapture whale studies, care must be taken to reduce bias in the parameter estimates that can arise from individual heterogeneity in capture probabilities (Buckland, 1990). Individual

[2] The text of this chapter has been submitted to the Scientific Committee of the IWC with the following citation: A. L. Bradford, P. R. Wade, A. M. Burdin, Y.V. Ivashchenko, G. A. Tsidulko, G. R. VanBlaricom, R. L. Brownell, Jr., and D. W. Weller. 2003. Survival estimates of western gray whales (*Eschrichtius robustus*) incorporating individual heterogeneity and temporary emigration. Paper SC/55/BRG14 submitted to the International Whaling Commission (unpublished).

heterogeneity in capture probability can occur if some whales are more easily identified (e.g., possess distinctive markings or are more approachable) or spend more time in the study area than other whales (Buckland, 1990).

Gray whales (including calves) are individually identifiable by natural pigmentation patterns and in some cases scarring from dead barnacles. Numerous multi-year studies have shown photo-identification to be a reliable and effective research technique for this species (Hatler and Darling, 1974; Darling, 1984; Swartz, 1986; Jones 1990; Weller *et al.*, 1999). Photo-identification has been the main research tool of the TAMU, NMFS, and KIENM western gray whale study being conducted off Piltun Lagoon, Sakhalin Island, Russia (Figure 1.3). Photo-identification results have demonstrated that many individuals exhibit a consistent annual return and strong seasonal fidelity to the study area, while other whales are absent for all or part of any given field season. The Piltun study has generated the multi-year (1997-2002) photographic dataset used for the mark-recapture survival estimates presented here.

An unusually low return to the Piltun feeding ground of whales first observed as calves has been continuously noted prior to the 2002 field season (Weller *et al.*, 2000, 2001, 2002c, 2003a). Of the 16 calves identified between 1997 and 2000, only six (37.5%) had been resighted subsequent to their year of weaning (Weller *et al.*, 2003a). Ensuing mark-recapture estimates of calf survival (0.389, SE=0.1255) suggested that survival of post-weaned calves was extremely low (Bradford *et al.*, 2002). With the inclusion of results from 2002, 14 of the 22 (63.6%) calves identified between 1997 and 2001 have currently been resighted post-weaning (Weller *et al.*, 2003b). Five of the eight

returned whales were yearlings (i.e., weaned in 2001), while the remaining three were initially identified in 1997, 1998, and 2000, respectively. Anecdotally, a whale not seen in the study area since it was first observed as a calf during a 1995 pilot study (Brownell *et al*., 1997) was also resighted in 2002 (Weller *et al*., 2003b). These findings indicate that the low calf survival reported in Bradford *et al*. (2002) can partially be attributed to the temporary emigration of some whales first identified as calves, prompting the testing of additional temporary emigration models in the present survival analysis.

METHODS

Photo-identification

For a detailed description of western gray whale photo-identification data collection and analysis protocols, see Weller *et al*. (1999). From 1997 to 2002, 237 photo-identification surveys collected during 22 months produced the 116 individual whale encounter histories analyzed here (Appendix B; Weller *et al*., 1999, 2000, 2001, 2003a, 2003b; Würsig *et al*., 1999, 2000).

Survival Estimation

Pollock's robust design model (Pollock, 1982; Kendall and Pollock, 1992; Kendall and Nichols, 1995; Kendall *et al*., 1995, 1997), combining the Cormack-Jolly-Seber open recapture model (Cormack, 1964; Jolly, 1965; Seber, 1965) and Huggins' closed capture estimator (Huggins, 1989, 1991), was fitted to the encounter histories using maximum likelihood parameter estimation. The field seasons in each of the six years of the study (1997-2002) were treated as the open *primary* sampling periods (i.e.,

mortality is assumed to occur between years). Months within a field season (3, 3, 5, 4, 4, and 3 months in each year, respectively) were treated as the closed *secondary* sampling periods (i.e., mortality is assumed to be zero between months in a year). The following parameters were estimated, although non-calf and calf survival are the primary parameters of interest:

f_g = survival probability of group *g*, where *g* is either non-calf or calf (first-year post-weaning);

$?_{gi}$ = probability of group *g* being unavailable for capture in *primary* period *i*¸ given being alive during period *i* (i.e., temporary emigration), where *g* is either >2-yr-old, <2-yr-old, >3-yr-old, <3-yr-old, >4-yr-old, or <4-yr-old and *i* = 1998, 1999,…, 2002;

p_{ij} = probability of being captured in *secondary* sample *j* of *primary* period *i*, given being alive and in the study area during period *i*, where *j* = June, July,…, October, and *i* = 1997, 1998,…, 2002.

Assumptions of the parameter estimation are: 1) general mark-recapture assumptions for sampling open and closed populations (Seber, 1982); 2) all western gray whales used or passed through the study area during the study period, but not necessarily in each year; 3) constant non-calf and calf survival during the study period; and 4) random temporary emigration (Kendall and Nichols, 1995; Kendall *et al*., 1997) that is either constant, group varying (between whales >2-yr-old and <2-yr-old, >3-yr-old and <3-yr-old, or >4-yr-old and <4-yr-old), time varying, or group and time varying. Thus, one model of survival was tested in conjunction with eight models of temporary emigration:

f (gc)

where gc = group varying between non-calves and calves;

ϕ(.)
ϕ(g2)
ϕ(g3)
ϕ(g4)
ϕ(t)
ϕ(g2+t)
ϕ(g3+t)
ϕ(g4+t)

where	.	=	constant (no group or time influence)
	g2	=	group varying between whales >2-yr-old and <2-yr-old
	g3	=	group varying between whales >3-yr-old and <3-yr-old
	g4	=	group varying between whales >4-yr-old and <4-yr-old
	t	=	time varying by *primary* period
	+	=	additive model.

The >2-yr-old and <2-yr-old group-varying temporary emigration model was developed to account for some of the low return to the study area and reduced apparent survival of whales first sighted as calves (Bradford *et al*., 2002; Weller *et al*., 2000, 2001, 2003a, 2002c), by allowing the temporary emigration probability of yearlings to differ from older whales. Yet, given the return in 2002 of three whales that had been absent from the study area since their respective weaning year of 1997, 1998, and 2000 (Weller *et al*., 2003b), two more explicit models were constructed. In these models, whales first observed as calves were allowed to temporarily emigrate with a characteristic probability for up to two and three years post-weaning (i.e., <3-yr-old and <4-yr-old temporary emigration, respectively). The aforementioned anecdotal return in 2002 of the whale not seen in the study area since it was initially observed as a calf in 1995 (Brownell *et al*. 1997; Weller *et al*., 2003b) suggests that temporary emigration from the Piltun feeding ground can function in the life history of juvenile whales for up to seven years post-weaning. However, estimating juvenile temporary emigration for up to only three years

post-weaning permits the temporary emigration probability of younger whales to differ from older whales, but minimizes potential positive bias to the non-juvenile estimate caused by the incorporation into that probability of young whales not first sighted as calves. Furthermore, few whales would contribute to extending the estimate up to four or five years post-weaning (nine and two, respectively), and a longer interval would exceed the length of the study.

Given the constant survival and variable temporary emigration parameters, the effects of various combinations of time, survey effort, and an individual *residency* covariate were examined in nine models of capture probability:

p(t)
p(T)
p(Eff)
p(Res)
p(t+Res)
p(T+Eff)
p(T+Res)
p(T+Eff+Res)
p(Eff+Res)

where t = time varying by *secondary* period
T = trend over time
Eff = *effort* (time covariate)
Res = *residency* (individual covariate).

Testing for a trend over time in capture probability served to address the hypothesis that capture probability could temporally increase because of improved efficiency in survey ability over the *primary* sampling period. *Effort* is the number of photo-identification surveys conducted each month. *Residency* is defined as the number of days a whale was captured per month divided by the mean number of days all whales

were captured that month averaged over all months that the whale was captured. This value acts as an index of the duration of residency of an individual whale in the study area, given the whale is seen once, and should reduce individual heterogeneity in capture probability (Figure 2.1). In other words, *residency* indicates whether an individual whale tends to remain over long periods in the study area, or to stay for shorter amounts of time before leaving the area. *Residency* is based on the daily sighting records because these data were not used in the parameter estimation. Likewise, the calculation is conditioned on the individual being seen in a given month, so the residency index does not repeat information in the encounter history used to estimate model parameters. In calculating *residency*, scaling to the mean of each month allows the duration of residency detected monthly to be relative to sampling effort. A histogram of residency values used to model capture probability is shown in Figure 2.2.

With the one survival model, the eight temporary emigration models, and the nine models of capture probability, a total of 72 models were fitted to the encounter histories. The analysis was conducted using Program MARK (White and Burnham, 1999). Models were selected using Akaike's Information Criterion (Akaike, 1973) corrected for small sample size (AICc) (Hurvich and Tsai, 1989). Non-calf and calf survival estimates were averaged across the best models in order to account for model uncertainty (Burnham and Anderson, 2002).

RESULTS

Incorporating *residency*, time, and *effort* into models of capture probability provided the best fits to the data (Table 2.1). As expected, capture probability was positively correlated with residency time and also varied by *secondary* sampling period (Figure 2.3). That is, the positive correlation between capture probability and residency time was characteristically represented during each *secondary* sample (Figures 2.3-2.4). The pattern of monthly capture probabilities differed by *primary* sampling period, although capture probability tended to increase and decrease at the beginning and end, respectively, of each yearly field season (Figure 2.4).

The influence of temporary emigration on model selection was secondary to the effect of capture probability (Table 2.1). However, for each representation of capture probability, the constant and group-varying temporary emigration models fit the data better than models allowing temporary emigration to vary by time or group and time (Tables 2.1-2.2). Specifically, allowing temporary emigration to differ between whales >4-yr-old and <4-yr-old was primarily selected in every case of capture probability (Table 2.1). Values of all temporary emigration parameters estimated in combination with the highest weighted capture probability model are shown in Table 2.2. For the constant and group-varying models, >4-yr-old, <4-yr-old, all-whale (constant), >3-yr-old, <3-yr-old, >2-yr-old, and <2-yr-old temporary emigration were estimated as 0.147 (SE=0.0274), 0.407 (SE=0.1054), 0.175 (SE=0.0269), 0.162 (SE=0.0279), 0.293 (SE=0.1018), 0.171 (SE=0.0275), and 0.244 (SE=0.1219), respectively (Figure 2.5). The time-varying temporary emigration estimates exhibited a similar relative relationship as

the constant and group-varying estimates. For each *primary* sampling period, estimates for younger whales were higher than the corresponding estimates for older whales, while the all-whale estimates were only slightly higher than those of older whales (Figure 2.6). The time-varying temporary emigration estimates varied by *primary* sampling period, and were lowest during the 1999 and 2001 field seasons (Figure 2.6).

Non-calf and calf survival estimates were averaged across the 13 best models and a weighted average point estimate, unconditional standard error, and weighted 95% confidence intervals were obtained. Results of model averaging are shown in Tables 2.3-2.4 for non-calves and calves, respectively. Non-calf and calf survival were estimated as 0.952 (SE=0.0151, 95% CI=0.912-0.975) and 0.709 (SE=0.1178, 95% CI=0.443-0.882), respectively (Figure 2.7).

DISCUSSION

Capture Probability

The individual *residency* covariate was included in the 24 best models, indicating that it helped to explain capture probability (Table 2.1). As anticipated, capture probability was higher for whales with longer residency times (Figures 2.3-2.4). In other words, the more often whales used the study area, the more likely they were to be encountered. By allowing capture probability to vary by *residency*, bias resulting from individual heterogeneity was minimized. The seven best models, which received the majority of the AICc weight (see Burnham and Anderson, 2002 for description), allowed capture probability to vary by time and *residency* (Table 2.1). Thus, capture probability

differed between *secondary* sampling periods, but residency pattern was an important factor in determining the capture probability of an individual whale.

During each *primary* sampling period, the monthly capture probabilities tended to increase and then decrease as the field season progressed (Figure 2.4). This pattern could reflect many sources of intra-seasonal variation that similarly affected the monthly capture probabilities of all whales. For instance, weather conditions influenced not only the number of photo-identification surveys conducted each month, but also survey duration and coverage. The typically milder weather conditions during August facilitated more frequent and extensive surveys, which may have contributed to the higher capture probabilities consistently observed during that month. The extremely low June capture probabilities are most likely attributable to the small numbers of completed surveys. However, in this case, the reduced survey effort was probably related more to the late-June arrival of the research team and less to the weather.

Other sources of intra-seasonal variation may have had a more direct effect on the overall distribution and abundance of whales in the study area, resulting in the apparent trend in monthly capture probabilities. For example, prey density and availability in parts of the study area could have declined over each feeding season in response to whale foraging. Alternatively, the preferred prey of whales may have changed during each season, as has been suggested for eastern gray whales off Vancouver Island, British Columbia (Darling *et al.*, 1998). In either scenario, whales would have then had to locate, and possibly spend more time looking for, other concentrations of prey. These alternate foraging locations might have been positioned more towards the periphery or

outside of the study area, which would have generally lowered capture probabilities as the season progressed. This foraging-based hypothesis was offered to explain a seasonal offshore shift in pod distribution detected by shore-based observations of whales in the study area during some years (Ivashchenko, 1999; Würsig *et al*., 1999, 2000). The late-season decrease in capture probabilities may also have been attributable to the movement of some whales out of the study area in preparation for or initiation of the southbound migration, particularly during the lengthy 1999 field season.

Finally, the Piltun feeding ground overlaps with two of nine major multinational oil and gas projects situated offshore of Sakhalin Island, and associated industrial activities have potentially influenced the behavior and distribution of whales in the study area (Würsig *et al*., 1999, 2000; Weller *et al*., 2002d). For instance, whales appeared to shift their distribution away from a region where geophysical seismic surveys were being conducted during August 2001 (Weller *et al*., 2002d). This shift concentrated whales in an easily accessible portion of the study area, and may have been a factor in the high capture probability noted during that month. The effects of other industrial activities (e.g., well-drilling, production operations, shipping and aircraft traffic) have not yet been evaluated, but could have played a part in shaping patterns of capture probability.

Temporary Emigration

Although model selection was primarily controlled by capture probability (Table 2.1), temporary emigration demonstrated a characteristic influence within each representation of capture probability (Tables 2.1-2.2). Namely, in every case of capture probability, the constant and group-varying models of temporary emigration provided

better fits to the data than the time-varying and additive models. This outcome could indicate that temporary emigration probabilities did not vary by *primary* sampling period. However, given that the latter models required the estimation of more parameters, a more likely interpretation is that the data could not support the additional model complexity. That is, the former models were more parsimonious (Burnham and Anderson, 2002).

Out of the constant and group-varying temporary emigration models, the model allowing temporary emigration to differ between whales >4-yr-old and <4-yr-old was always selected, followed by the models of constant, >3-yr-old and <3-yr-old, and >2-yr-old and <2-yr-old temporary emigration (with the exception of the lowest AICc weighted model of capture probability) (Tables 2.1-2.2). Interestingly, the constant temporary emigration model was repeatedly selected over the latter two group-varying models, when the data otherwise suggested that temporary emigration probability was different for younger whales. However, with the large standard errors associated with the estimates for younger whales (resulting from small sample sizes) and the influence of whales three and two years post-weaning on the samples of the corresponding older whale estimate, the data were most likely not able to detect a clear difference between the temporary emigration probabilities of older and younger whales in those two models. Nonetheless, in each of the three group-varying models tested, temporary emigration probabilities were higher for younger whales, particularly for whales <4-yr-old (Figure 2.5).

The order of the time-varying and additive temporary emigration models closely resembled that of the constant and group-varying models. That is, the model estimating

temporary emigration over time for whales >4-yr-old and <4-yr-old was primarily selected, proceeded by the models where estimates were solely time-varying, time-varying between whales >3-yr-old and <3-yr old, and time-varying between whales >2-yr-old and <2-yr-old (Tables 2.1-2.2). Likewise, the relative relationship of the time-varying estimates was analogous to that of the constant and group-varying estimates. Within each *primary* sampling period, the temporary emigration estimates were higher for younger whales than the corresponding estimates for older whales, and the all-whale estimates were somewhat higher than those of older whales (Figure 2.6). All the time-varying estimates of temporary emigration differed between *primary* sampling periods, with the lowest probabilities occurring during the 1999 and 2001 field seasons (Figure 2.6). Potentially, the distribution and density of prey in the study area was higher in those years, resulting in lower temporary emigration probabilities for all whales. Alternatively, industrial activities conducted during those seasons may have influenced the presence of whales in the study area. However, interpretation of this finding is difficult, given the lack of data related to the suggested hypotheses and the aforementioned uncertainty in the time-varying temporary emigration models.

Presumably, the temporary emigration of whales from the study area is related to foraging activity (Weller *et al*., 1999; Burdin *et al*., 2002). The present temporary emigration estimates indicate that higher temporary emigration probabilities may play a significant role in the life history of young whales first sighted as calves for at least up to three-years post-weaning. Age-class segregation of eastern gray whales on their feeding grounds has been noted, with observations ranging from the complete separation of

younger whales (Zenkovich, 1937), to a less straightforward division (Bogoslovskaya *et al*., 1981), to a combination of both patterns (Darling *et al*., 1998). However, many juvenile western gray whales initially identified as calves did return to the study area and represented some of the most frequently sighted whales throughout each field season (Weller *et al*., 1999, 2000, 2001, 2003a, 2003b; Würsig *et al*., 1999, 2000). With the exception of a potential preference for nearshore areas, these young whales did not appear to differ appreciably in overall distribution and habitat use from older whales. Thus, given the constant use of the Piltun feeding ground by juvenile whales and the lack of segregation by age exhibited there, the mechanism prompting relatively high temporary emigration probabilities for younger whales is unclear.

Survival

The survival estimates reported here are the first direct survival estimates for gray whales. The non-calf survival estimate is similar to mark-recapture estimates by Buckland (1990) and Barlow and Clapham (1997) for humpback whales (*Megaptera novaeangliae*) in the Gulf of Maine (0.951, SE=0.010 and 0.960, SE=0.008, respectively). Caswell *et al*. (1999) estimated survival of another highly endangered whale population, the western North Atlantic right whale (*Eubalaena glacialis*), but these time-varying mark-recapture estimates (from about 0.99 to about 0.94) are of crude survival and are not directly comparable to the non-calf survival estimates presented here. Likewise, a mark-recapture estimate of adult western Arctic bowhead whale (*Balaena mysticetus*) survival (0.984) by Zeh *et al*. (2002) and indirect estimates of adult female southern right whale (*Eubalaena australis*) survival off South Africa (0.986) and

Argentina (0.981) by Best *et al*. (2001) and Cooke *et al*. (2001), respectively, are not directly comparable. Finally, the western gray whale non-calf survival point estimate is lower than an indirect estimate of 0.987 by Wade and Perryman (2002) for the eastern gray whale population. However, the level of uncertainty in that estimate makes direct inter-population comparisons premature at this time.

Due to the small size of the western gray whale population, relatively few calves can be produced each year. Thus, the calf survival estimate presented here was expected to be imprecise, as only 22 calves were available in the study area between 1997 and 2001. However, if the estimate is assumed to be accurate, it is markedly lower than a 'reasonable' first-year post-weaning calf survival estimate of 0.875 ($SE \approx 0.047$) suggested by Barlow and Clapham (1997) for Gulf of Maine humpback whales. It is important to note that Barlow and Clapham (1997) were simply attempting to bracket the likely range of calf survival values, and the authors caution that 'little credence' should be placed in their estimate. However, it is the only known direct estimate of first-year post-weaning calf survival available for comparison.

As the data used for the western gray whale survival estimation were collected during the feeding season, the resultant calf survival estimate represents survival of calves during their first year post-weaning. Gabriele *et al*. (2001) estimated the survival rate of central North Pacific humpback whale calves, from the breeding season to the subsequent feeding season, using sighting records of individually identified females with calves. Multiple rates were calculated in order to address the effects of various biases, leading to a minimum and maximum survival estimate of 0.759 and 0.850, respectively

(Gabriele *et al*., 2001). These calf survival estimates characterize survival of humpback whale calves from birth to weaning and are therefore not comparable to the western gray whale calf estimate. Similarly, an indirect estimate by Best *et al*. (2001) of first-year survival (0.913) for southern right whale calves born off South Africa also cannot be compared. The survival rates of western gray whales from birth to weaning and first-year post-birth are currently unknown, but are important for better understanding the dynamics of this population.

The estimate reported here suggests that survival of post-weaned western gray whale calves is considerably low, which could be a result of both natural and anthropogenic factors. Possible sources of natural calf mortality are killer whale predation and insufficient nutritional reserves due to natural changes in prey availability. Potential anthropogenic causes of calf mortality are entanglement in fishing gear within the migratory corridor (see Weller *et al*., 2002c for overview of range), direct catching, and inadequate nutritional reserves because of human-related shifts in prey availability.

Killer whale predation on eastern gray whale calves has been documented (Baldridge, 1972; Goley and Straley, 1994). Although killer whales are frequently sighted in the Piltun study area, aggressive interactions with western gray whales have not been observed. However, Weller *et al*. (2002c) recorded that between 1997 and 1998, at least 33% of the western gray whales identified, including calves, had visible killer whale tooth rakes on their bodies, suggesting that they are threatened by killer whales in some portion of their range (Weller *et al*., 2002c). Heyning and Lewis (1990) summarized the entanglements of eastern gray whales in fishing gear off southern

California from 1980 to 1989. Length measurements were obtained from 16 of the 20 whales found dead after entanglement. Of the 16 measured whales, one was considered a calf (i.e., from 4.4 to 6.0m), 12 were deemed yearlings (i.e., from 6.5 to 8.8m), and three were estimated to be two or three years old (i.e., from 8.9m upwards). These findings suggest that younger whales become entangled in fishing gear more frequently or are less likely to survive entanglement than adults (Heyning and Lewis, 1990). The level of western gray whale entanglement in fishing gear within the migratory corridor is currently unknown. However, Zhou and Wang (1994), Kato (1998), and Kim (2000) have reported incidental catches of other cetaceans in coastal net fisheries off southern China, Japan, and Korea, respectively.

At least one direct take of a western gray whale has occurred in recent years (Brownell and Kasuya, 1999). In 1996, the anterior portion of a gray whale was found floating off Suttsu, Hokkaido, presumably killed by Japanese Dall's porpoise fishermen (Brownell and Kasuya, 1999). Although the Suttsu whale was adult-sized, both non-calves and calves are at risk from an undetermined level of illegal hunting. The discovery of gray whale products in Japanese commercial meat markets in 1999 (Baker *et al*., 2002) further heightens this concern. Unusually thin non-calf western gray whales in the study area have been observed since 1999 (Weller *et al*., 2002b), suggesting possible effects of natural or anthropogenic nutritional deficiencies. The cause of this physical deterioration is unknown (Brownell and Weller, 2001; Weller *et al*., 2002c), but could be having a more severe effect on calves. Furthermore, calves born to thin mothers may be susceptible to reduced survival. Interestingly, although the cause of mortality is

unknown, all three western gray whale strandings on the east coast of Japan reported from 1990 to the present were of young whales less than 9.5m in length (see Yamada *et al*., 2002 for review).

As survival probability is only a measure of 'apparent' survival (i.e., the probability a whale remains alive and available for recapture), an alternative explanation for low calf survival is that whales permanently emigrate from the Piltun feeding area after their first year. Yet, as stated previously, some juvenile whales initially sighted as calves have exhibited pronounced seasonal site fidelity to the study area (Weller *et al*., 1999, 2000, 2001, 2003a, 2003b; Würsig *et al*., 1999, 2000). Additionally, aerial and ship-based surveys of the Okhotsk Sea between 1979 and 1989 found concentrations of gray whales only off the northeastern coast of Sakhalin Island near Piltun Lagoon (Blokhin *et al*., 1985; Berzin *et al*., 1988, 1990, 1991; Berzin, 1990; Blokhin, 1996). The distribution of these sightings encompassed some area outside the boundary of typical photo-identification survey coverage. However, whales in the Piltun study area have been noted to travel more than 50 km in less than 24 hours (Burdin *et al*., 2002). This observation indicates that whales could occur within the distribution documented by previous aerial and ship-based surveys and still be encountered in the study area at some point during any given field season. Furthermore, usable photographic sightings of whales in other parts of the Okhotsk Sea have been matched to whales that regularly use the Piltun feeding ground, and have not yet included any whales first sighted as calves that were not resighted in the study area (Burdin *et al*., 2002; Weller *et al*., 2002a).

Therefore, the study area is regarded as the only known location where western gray whales consistently aggregate to feed (Weller *et al*., 1999).

The present non-calf survival point estimate is somewhat higher than the estimate calculated prior to the 2002 field season (Bradford *et al.*, 2002). However, the new estimate is within the 95% confidence interval of the former estimate. Conversely, the current calf point estimate is nearly twice as high, but exceeds the upper limit of the 95% confidence interval of the previous estimate. Contrasting results from the temporal addition of data are not unexpected for a small population of long-lived animals with demographic variation, highlighting the importance of continuing the long-term western gray whale study. Future data will also facilitate the refined estimation and additional hypothesis testing of temporary emigration probabilities for younger and older whales. Such clarification is important, given the strong influence the various models of temporary emigration had on corresponding estimates of survival in the present analysis. That is, within each case of capture probability, the different models of temporary emigration lead to the broad range of resultant survival estimates (Tables 2.3-2.4). Consequently, if higher temporary emigration probabilities are not really a significant part of the life history of younger whales, then calf survival is actually lower than the model-averaged estimate presented here (Table 2.4).

Estimation of survival probability may give one of the best indications of underlying causes of population declines (Eberhardt and Siniff, 1977). Indications are more likely to come from juvenile survival estimates (Eberhardt and Siniff, 1977), as adult survival is less affected by density dependence in large, long-lived animals

(Goodman, 1981). Continued estimation and temporal evaluation of western gray whale calf survival are needed to make inferences about the status of the population. Similarly, more data are needed to further refine the non-calf estimates. In population modeling of long-lived species, population growth rate is most sensitive to non-calf survival (Goodman, 1981; Taylor and DeMaster, 1993), emphasizing the need for an accurate and precise estimate.

While the survival estimates reported here do not quantitatively determine the status of western gray whales (i.e., degree of depletion and whether the population is growing or declining), they can be used in population modeling that is needed for such an assessment (e.g., Chapter 3). Undoubtedly, a complete assessment should be made before drawing conclusions from these estimates. However, the low calf survival estimate in conjunction with the small population size (Wade *et al*., 2003), small number of reproductive females identified (n=17), and the predominance of a three-year calving interval (Chapter 3; Brownell and Weller, 2002; Weller *et al*., 2003b) already raises questions about the potential for western gray whale recovery.

Table 2.1. Model comparisons (*n*=72) from Program MARK. Delta AICc is the difference in the AICc of a model from the minimum AICc model, AICc Weight is the Akaike Weight (see Burnham and Anderson, 2002 for description), and Deviance is the difference in –2log(Likelihood) of the current model and –2log(Likelihood) of the saturated model. See text for details of parameters and model notation.

Model	AICc	Delta AICc	AICc Weight	No. Parameters	Deviance
f (gc) $?$(g4) p (t+Res)	1904.23	0.00	0.85179	32	1837.62
f (gc) $?$(.) p (t+Res)	1909.66	5.43	0.05642	31	1845.21
f (gc) $?$(g3) p (t+Res)	1909.95	5.72	0.04876	32	1843.34
f (gc) $?$(g2) p (t+Res)	1911.42	7.19	0.02334	32	1844.81
f (gc) $?$(g4+t) p (t+Res)	1912.18	7.94	0.01604	36	1836.86
f (gc) $?$(t) p (t+Res)	1917.46	13.23	0.00114	35	1844.33
f (gc) $?$(g3+t) p (t+Res)	1917.83	13.60	0.00095	36	1842.51
f (gc) $?$(g4) p (T+Eff+Res)	1917.92	13.69	0.00091	28	1859.92
f (gc) $?$(g2+t) p (t+Res)	1919.13	14.90	0.00049	36	1843.82
f (gc) $?$(.) p (T+Eff+Res)	1923.38	19.15	0.00006	27	1867.52
f (gc) $?$(g3) p (T+Eff+Res)	1923.65	19.42	0.00005	28	1865.65
f (gc) $?$(g2) p (T+Eff+Res)	1925.12	20.89	0.00002	28	1867.12
f (gc) $?$(g4+t) p (T+Eff+Res)	1925.73	21.50	0.00002	32	1859.12
f (gc) $?$(t) p (T+Eff+Res)	1931.05	26.82	0	31	1866.60
f (gc) $?$(g3+t) p (T+Eff+Res)	1931.39	27.16	0	32	1864.78
f (gc) $?$(g2+t) p (T+Eff+Res)	1932.70	28.47	0	32	1866.09
f (gc) $?$(g4) p (Eff+Res)	1934.75	30.52	0	22	1889.51
f (gc) $?$(.) p (Eff+Res)	1940.00	35.77	0	21	1896.87
f (gc) $?$(g3) p (Eff+Res)	1940.34	36.11	0	22	1895.11
f (gc) $?$(g2) p (Eff+Res)	1941.75	37.52	0	22	1896.52
f (gc) $?$(g4+t) p (Eff+Res)	1942.07	37.84	0	26	1888.34
f (gc) $?$(t) p (Eff+Res)	1947.05	42.82	0	25	1895.45
f (gc) $?$(g3+t) p (Eff+Res)	1947.48	43.25	0	26	1893.76
f (gc) $?$(g2+t) p (Eff+Res)	1948.65	44.42	0	26	1894.92
f (gc) $?$(g4) p (t)	1990.12	85.89	0	26	1936.40
f (gc) $?$(.) p (t)	1993.32	89.09	0	25	1941.73
f (gc) $?$(g3) p (t)	1994.40	90.17	0	26	1940.68
f (gc) $?$(g2) p (t)	1995.32	91.09	0	26	1941.60
f (gc) $?$(g4+t) p (t)	1996.82	92.59	0	30	1934.52
f (gc) $?$(t) p (t)	2000.02	95.79	0	29	1939.87
f (gc) $?$(g3+t) p (t)	2001.15	96.92	0	30	1938.86
f (gc) $?$(g2+t) p (t)	2001.92	97.69	0	30	1939.62
f (gc) $?$(g4) p (T+Eff)	2002.09	97.86	0	22	1956.85
f (gc) $?$(.) p (T+Eff)	2005.30	101.07	0	21	1962.17
f (gc) $?$(g3) p (T+Eff)	2006.37	102.14	0	22	1961.13
f (gc) $?$(g2) p (T+Eff)	2007.28	103.05	0	22	1962.04

Table 2.1. Continued.

Model	AICc	Delta AICc	AICc Weight	No. Parameters	Deviance
f (gc) $?$(g4+t) p (T+Eff)	2008.64	104.41	0	26	1954.92
f (gc) $?$(t) p (T+Eff)	2011.85	107.62	0	25	1960.25
f (gc) $?$(g3+t) p (T+Eff)	2012.97	108.74	0	26	1959.25
f (gc) $?$(g2+t) p (T+Eff)	2013.73	109.49	0	26	1960.00
f (gc) $?$(g4) p (Eff)	2015.09	110.86	0	16	1982.43
f (gc) $?$(.) p (Eff)	2018.37	114.13	0	15	1987.78
f (gc) $?$(g3) p (Eff)	2019.44	115.21	0	16	1986.78
f (gc) $?$(g2) p (Eff)	2020.34	116.11	0	16	1987.68
f (gc) $?$(g4+t) p (Eff)	2021.08	116.85	0	20	1980.06
f (gc) $?$(t) p (Eff)	2024.31	120.08	0	19	1985.38
f (gc) $?$(g3+t) p (Eff)	2025.43	121.20	0	20	1984.41
f (gc) $?$(g2+t) p (Eff)	2026.16	121.93	0	20	1985.13
f (gc) $?$(g4) p (T+Res)	2083.31	179.07	0	22	2038.07
f (gc) $?$(.) p (T+Res)	2088.99	184.76	0	21	2045.86
f (gc) $?$(g3) p (T+Res)	2089.14	184.91	0	22	2043.91
f (gc) $?$(g2) p (T+Res)	2090.67	186.44	0	22	2045.43
f (gc) $?$(g4+t) p (T+Res)	2090.91	186.68	0	26	2037.19
f (gc) $?$(t) p (T+Res)	2096.53	192.30	0	25	2044.94
f (gc) $?$(g3+t) p (T+Res)	2096.74	192.51	0	26	2043.02
f (gc) $?$(g2+t) p (T+Res)	2098.13	193.90	0	26	2044.40
f (gc) $?$(g4) p (T)	2155.65	251.42	0	16	2122.99
f (gc) $?$(.) p (T)	2158.74	254.51	0	15	2128.16
f (gc) $?$(g3) p (T)	2159.82	255.59	0	16	2127.16
f (gc) $?$(g2) p (T)	2160.68	256.45	0	16	2128.02
f (gc) $?$(g4+t) p (T)	2162.20	257.97	0	20	2121.18
f (gc) $?$(t) p (T)	2165.30	261.07	0	19	2126.37
f (gc) $?$(g3+t) p (T)	2166.48	262.25	0	20	2125.45
f (gc) $?$(g2+t) p (T)	2167.16	262.93	0	20	2126.13
f (gc) $?$(g4) p (Res)	2186.35	282.12	0	16	2153.69
f (gc) $?$(g3) p (Res)	2192.35	288.12	0	16	2159.69
f (gc) $?$(.) p (Res)	2192.48	288.25	0	15	2161.90
f (gc) $?$(g2) p (Res)	2194.00	289.77	0	16	2161.34
f (gc) $?$(g4+t) p (Res)	2194.10	289.87	0	20	2153.07
f (gc) $?$(g3+t) p (Res)	2200.25	296.02	0	20	2159.23
f (gc) $?$(t) p (Res)	2200.30	296.07	0	19	2161.38
f (gc) $?$(g2+t) p (Res)	2201.88	297.65	0	20	2160.86

Table 2.2. Temporary emigration (?) parameters estimated in association with the highest AICc weighted model of capture probability, with resulting estimates and associated standard error.

Model	AICc Weight	Parameter	Estimate	Standard Error
f (gc) $?$(g4) p (t+Res)	0.85179	$?_{>4\text{-yr-old}}$	0.147	0.0274
		$?_{<4\text{-yr-old}}$	0.407	0.1054
f (gc) $?$(.) p (t+Res)	0.05642	$?_{all\text{-}whale}$	0.175	0.0269
f (gc) $?$(g3) p (t+Res)	0.04876	$?_{>3\text{-yr-old}}$	0.162	0.0279
		$?_{<3\text{-yr-old}}$	0.293	0.1018
f (gc) $?$(g2) p (t+Res)	0.02334	$?_{>2\text{-yr-old}}$	0.171	0.0275
		$?_{<2\text{-yr-old}}$	0.244	0.1219
f (gc) $?$(g4+t) p (t+Res)	0.01604	$?_{>4\text{-yr-old},1998}$	0.175	0.0706
		$?_{>4\text{-yr-old},1999}$	0.125	0.0432
		$?_{>4\text{-yr-old},2000}$	0.173	0.0565
		$?_{>4\text{-yr-old},2001}$	0.136	0.0459
		$?_{>4\text{-yr-old},2002}$	0.152	0.0573
		$?_{<4\text{-yr-old},1998}$	0.457	0.1612
		$?_{<4\text{-yr-old},1999}$	0.361	0.1245
		$?_{<4\text{-yr-old},2000}$	0.453	0.1343
		$?_{<4\text{-yr-old},2001}$	0.384	0.1338
		$?_{<4\text{-yr-old},2002}$	0.416	0.1390
f (gc) $?$(t) p (t+Res)	0.00114	$?_{all\text{-}whale,1998}$	0.192	0.0725
		$?_{all\text{-}whale,1999}$	0.152	0.0480
		$?_{all\text{-}whale,2000}$	0.210	0.0593
		$?_{all\text{-}whale,2001}$	0.153	0.0504
		$?_{all\text{-}whale,2002}$	0.183	0.0584
f (gc) $?$(g3+t) p (t+Res)	0.00095	$?_{>3\text{-yr-old},1998}$	0.184	0.0713
		$?_{>3\text{-yr-old},1999}$	0.138	0.0461
		$?_{>3\text{-yr-old},2000}$	0.195	0.0586
		$?_{>3\text{-yr-old},2001}$	0.147	0.0494
		$?_{>3\text{-yr-old},2002}$	0.163	0.0591
		$?_{<3\text{-yr-old},1998}$	0.326	0.1497

Table 2.2. Continued.

Model	AICc Weight	Parameter	Estimate	Standard Error
		$?_{<3\text{-yr-old},1999}$	0.256	0.1104
		$?_{<3\text{-yr-old},2000}$	0.342	0.1326
		$?_{<3\text{-yr-old},2001}$	0.270	0.1254
		$?_{<3\text{-yr-old},2002}$	0.294	0.1220
f (gc) $?$(g2+t) p (t+Res)	0.00049	$?_{>2\text{-yr-old},1998}$	0.187	0.0719
		$?_{>2\text{-yr-old},1999}$	0.146	0.0474
		$?_{>2\text{-yr-old},2000}$	0.210	0.0592
		$?_{>2\text{-yr-old},2001}$	0.150	0.0499
		$?_{>2\text{-yr-old},2002}$	0.173	0.0594
		$?_{<2\text{-yr-old},1998}$	0.280	0.1607
		$?_{<2\text{-yr-old},1999}$	0.223	0.1252
		$?_{<2\text{-yr-old},2000}$	0.309	0.1673
		$?_{<2\text{-yr-old},2001}$	0.229	0.1344
		$?_{<2\text{-yr-old},2002}$	0.261	0.1384

Table 2.3. Model averaging of western gray whale non-calf survival estimates across the best models (*n*=13) showing the weighted average point estimate, unconditional standard error, and weighted 95% confidence intervals (logit transformation).

Model	AICc Weight	Estimate	Standard Error
f (gc) $?$(g4) p (t+Res)	0.85179	0.952	0.0151
f (gc) $?$(.) p (t+Res)	0.05642	0.955	0.0146
f (gc) $?$(g3) p (t+Res)	0.04876	0.953	0.0150
f (gc) $?$(g2) p (t+Res)	0.02334	0.954	0.0148
f (gc) $?$(g4+t) p (t+Res)	0.01604	0.952	0.0160
f (gc) $?$(t) p (t+Res)	0.00114	0.955	0.0152
f (gc) $?$(g3+t) p (t+Res)	0.00095	0.953	0.0158
f (gc) $?$(g4) p (T+Eff+Res)	0.00091	0.952	0.0151
f (gc) $?$(g2+t) p (t+Res)	0.00049	0.954	0.0156
f (gc) $?$(.) p (T+Eff+Res)	0.00006	0.955	0.0146
f (gc) $?$(g3) p (T+Eff+Res)	0.00005	0.953	0.0150
f (gc) $?$(g2) p (T+Eff+Res)	0.00002	0.954	0.0148
f (gc) $?$(g4+t) p (T+Eff+Res)	0.00002	0.953	0.0160
Weighted Average:		0.952	0.0151
Unconditional Standard Error:			0.0151
95% CI for Weighted Average Estimate:		0.912	0.975
Percent of variation attributable to model variation:			0.29%

Table 2.4. Model averaging of western gray whale calf survival estimates across the best models (*n*=13) showing the weighted average point estimate, unconditional standard error, and weighted 95% confidence intervals (logit transformation).

Model	AICc Weight	Estimate	Standard Error
f (gc) $?$(g4) p (t+Res)	0.85179	0.715	0.1181
f (gc) $?$(.) p (t+Res)	0.05642	0.661	0.1060
f (gc) $?$(g3) p (t+Res)	0.04876	0.680	0.1094
f (gc) $?$(g2) p (t+Res)	0.02334	0.669	0.1076
f (gc) $?$(g4+t) p (t+Res)	0.01604	0.716	0.1184
f (gc) $?$(t) p (t+Res)	0.00114	0.661	0.1061
f (gc) $?$(g3+t) p (t+Res)	0.00095	0.680	0.1095
f (gc) $?$(g4) p (T+Eff+Res)	0.00091	0.715	0.1181
f (gc) $?$(g2+t) p (t+Res)	0.00049	0.670	0.1078
f (gc) $?$(.) p (T+Eff+Res)	0.00006	0.661	0.1060
f (gc) $?$(g3) p (T+Eff+Res)	0.00005	0.680	0.1094
f (gc) $?$(g2) p (T+Eff+Res)	0.00002	0.669	0.1076
f (gc) $?$(g4+t) p (T+Eff+Res)	0.00002	0.716	0.1185
Weighted Average:		0.709	0.1167
Unconditional Standard Error:			0.1178
95% CI for Weighted Average Estimate:		0.443	0.882
Percent of variation attributable to model variation:			1.87%

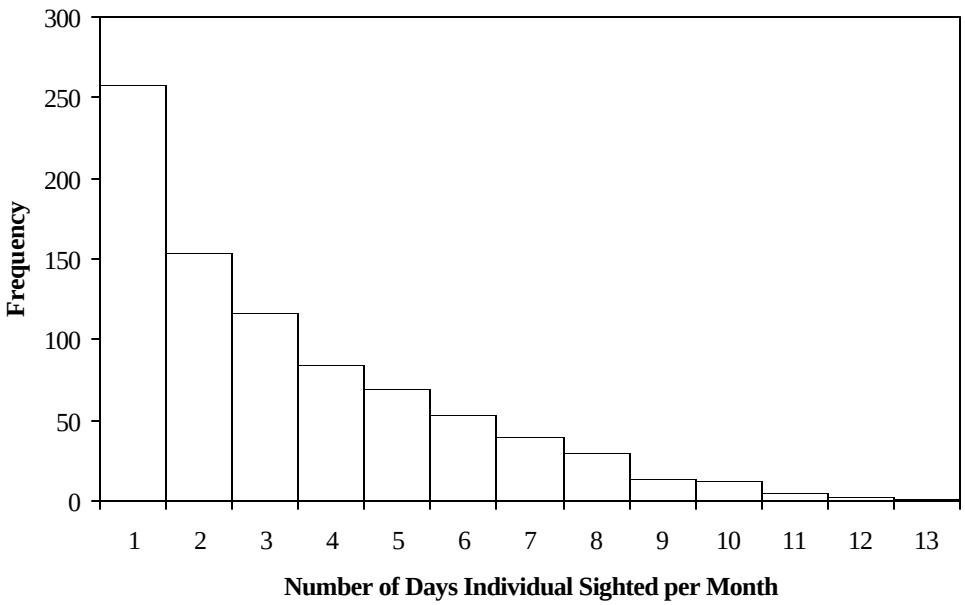

Figure 2.1. Histogram of the number of days an individual was sighted in a month (*n*=841 occurrences of individuals seen 1-13 days in a month) pooled over all *secondary* sampling periods. Note that individual whales are represented in as many months as the individual was seen, and that monthly variation in survey effort is not reflected.

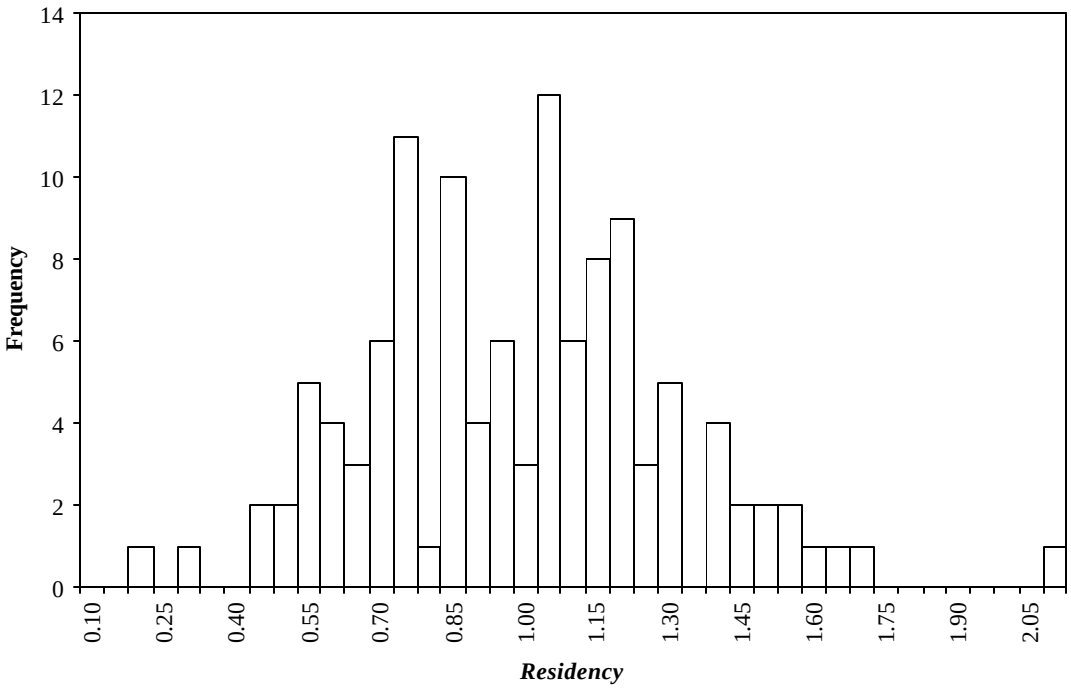

Figure 2.2. Histogram of the individual *residency* covariates (*n*=116) used in models of capture probability.

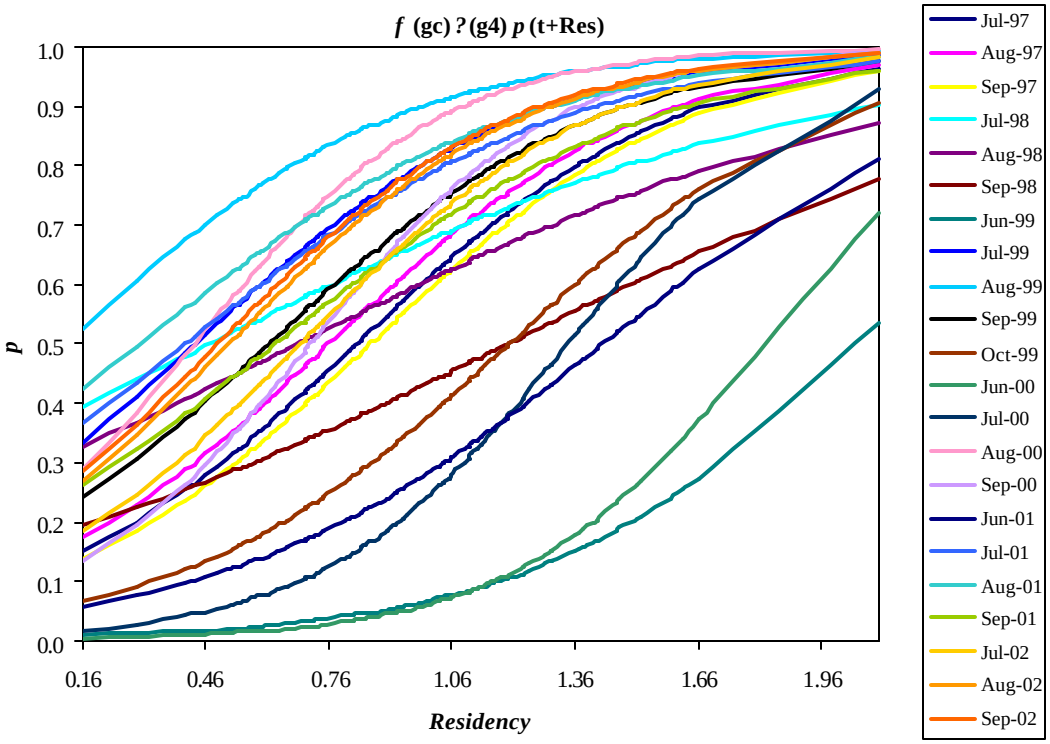

Figure 2.3. Capture probability (*p*) vs. *residency* for each *secondary* sampling period (*n*=22) according to the highest AICc weighted model.

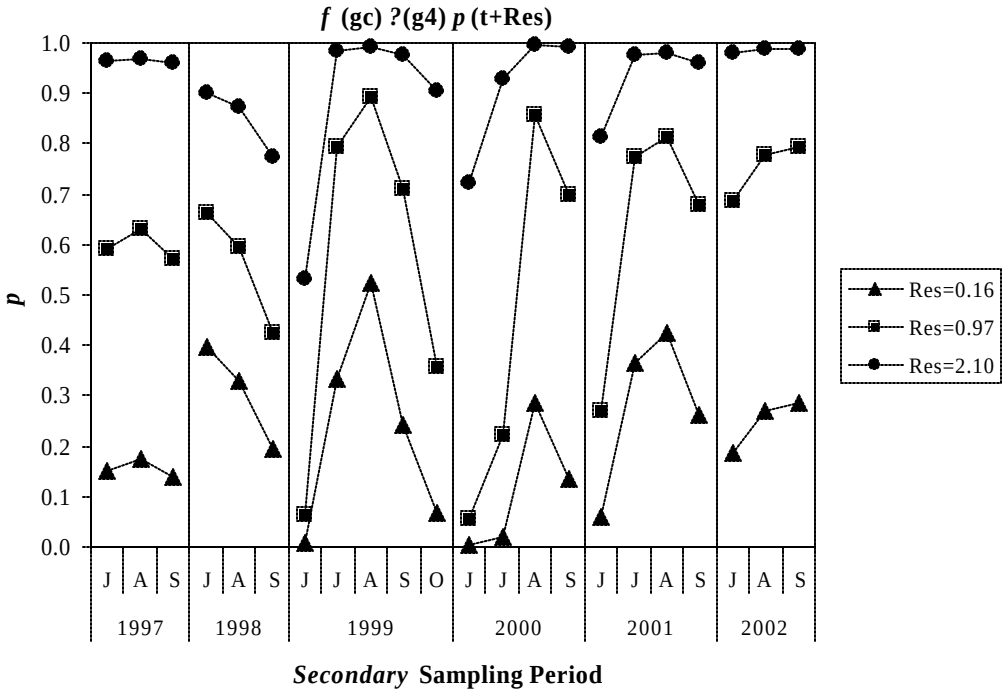

Figure 2.4. Capture probability (*p*) as a function of *secondary* sampling period (*n*=22) for the whale with the highest (Res=2.10), lowest (Res=0.16), and average (Res=0.97) residency time according to the highest weighted AICc model.

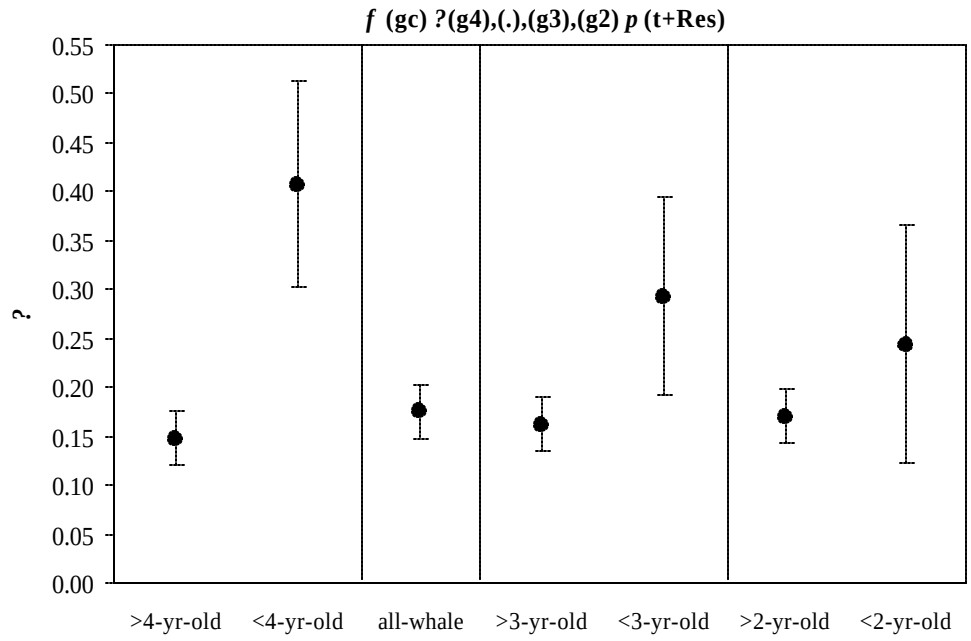

Figure 2.5. Estimates of >4-yr-old, <4-yr-old, all-whale, >3-yr-old, <3-yr-old, >2-yr-old, and <2-yr-old temporary emigration (*?*) resulting from four models of temporary emigration in combination with the highest AICc weighted capture probability model. Estimates are presented in the order that their associated model was selected. Circle = the point estimate. Bars = the standard error.

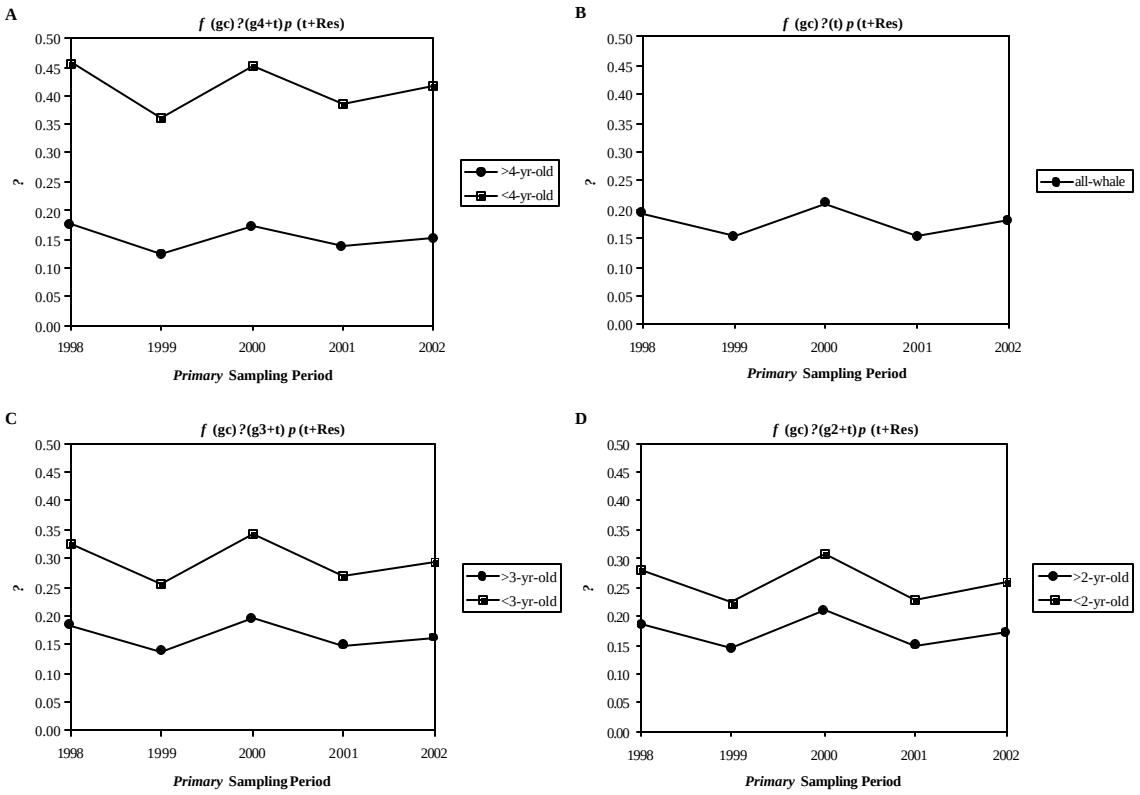

Figure 2.6. Temporary emigration (*?*) as a function of *primary* sampling period (*n*=6) for models considering whales >4-yr-old and <4-yr-old (A), all whales (B), whales >3-yr-old and <3-yr-old (C), and whales >2-yr-old and <2-yr-old (D), according to the highest AICc weighted capture probability model. Note that a temporary emigration probability for the first *primary* sampling period cannot be estimated, as there are no marked individuals outside the study area at that time. Estimates are presented in the order that their associated model was selected.

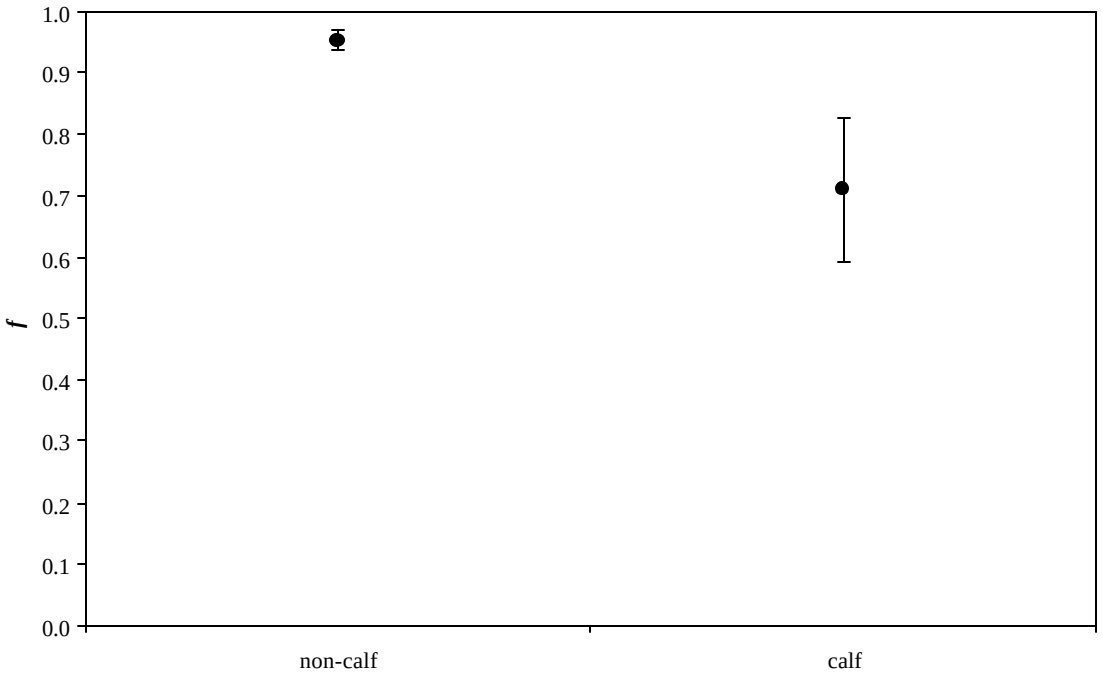

Figure 2.7. Western gray whale non-calf and calf survival (*f*) estimates. Circle = the weighted average point estimate. Bars = the unconditional standard error.

CHAPTER 3

CURRENT POPULATION GROWTH RATE AND TWENTIETH CENTURY POPULATION DYNAMICS OF WESTERN GRAY WHALES

INTRODUCTION

Similar to other populations of wildlife, determining the status of a whale population requires comparing the current population size with an accepted reference level, usually the current carrying capacity (i.e., equilibrium population size under conditions of no harvest). For whale populations that are presently depleted as a result of historical whaling, current carrying capacity is often unknown and must be estimated. Commonly, historical population levels are used as estimates of current carrying capacity (Fowler and Siniff, 1992), given that the historical population was at equilibrium and that the environment has not changed significantly since that time (Gerrodette and DeMaster, 1990). However, selecting a point in a population's history to reflect carrying capacity can be difficult (e.g., Reilly, 1992). For whale populations with long histories of aboriginal harvests prior to commercial exploitation, the task is confounded by a lack of information on aboriginal harvest levels and by the inherent ambiguity in the definition of carrying capacity (see Hartvigsen, 2001 for a recent overview of the carrying capacity concept). For example, Fowler and Siniff (1992) present carrying capacity as "…the mean naturally occurring population (i.e., in the absence of perturbations by other than aboriginal human activities) level." If aboriginal activity levels varied historically, or if they contrast with present aboriginal use of the population, which historical equilibrium population size, if any, should be regarded as current carrying capacity?

A primary method for estimating carrying capacity of exploited populations is referred to as back calculation (see Gerrodette and DeMaster, 1990 for an overview). Back calculation fits a population dynamics model to a current abundance estimate (or a series of estimates) and historical catch data, back to a point in time before commercial exploitation. That pre-exploitation population size is considered carrying capacity if it meets the aforementioned assumptions described in Gerrodette and DeMaster (1990).

The population dynamics model used in the back calculation can vary, but the model must include the specification of a density-dependent function (Gerrodette and DeMaster, 1990). General forms of commonly used age-independent and age-structured models are referred to as the generalized logistic equation (e.g., Pella and Tomlinson, 1969) and the Leslie matrix (Leslie, 1945, 1948), respectively, although the Leslie matrix should be combined with a density dependent function. Both model forms have been applied to back calculations performed on cetacean populations. Smith (1983) employed the generalized logistic equation to calculate carrying capacity for three dolphin populations in the eastern tropical Pacific. Breiwick *et al.* (1984) used a density-dependent Leslie-type matrix in a back calculation for western Arctic bowhead whales.

In addition to uncertainty involved in the modeling process (e.g., reliability of input parameters; Smith and Polacheck, 1979), problems can arise when interpreting the selected historical reference level (i.e., pre-exploitation population size) as carrying capacity. Most early attempts to back calculate the eastern gray whale population failed to reconcile the available catch records with the degree of observed late 19th century depletion, the current increase in abundance, and standard density-dependent population

models (Ohsumi, 1976; Reilly, 1981; Cooke, 1986; Lankester and Beddington, 1986). Punt and Butterworth (2002) more recently confirmed these results. Population projections in these efforts all begin prior to 1846, the onset of commercial eastern gray whaling (Scammon, 1874), when the population was harvested only by aborigines (Mitchell, 1979) and assumed to be at a pre-exploitation equilibrium. Butterworth *et al*. (2002) found that carrying capacity estimates producing reasonable trajectories through the current abundance estimates involved making untestable assumptions regarding the temporal consistency of carrying capacity or about the levels of aboriginal or early commercial catches. In order to avoid these problems, Wade (1997, 2002) relied on the richness of the current abundance data and assessed the population using projections beginning in 1900 and 1967, respectively. These analyses did not make any assumptions about where the starting population levels of the projections were relative to carrying capacity.

Estimating carrying capacity in an assessment of western gray whale status could prove equally, if not more, problematic than attempts for the eastern population. Fewer abundance and vital rate data exist, and a reference population level is not as easily determined. Modern commercial western gray whaling began in 1891 (Kato and Kasuya, 2002), but not all previous harvests were aboriginal (Table 1.1). Further, records of takes prior to the modern commercial whaling period are insufficient. For example, the 200-year history of Japanese net whaling is poorly known (Omura, 1984). Even if adequate records did exist, Gerrodette and DeMaster (1990) caution that back calculation is less useful if the pre-exploitation population level is very far back in time, as the carrying

capacity estimate then becomes heavily dependent on the input vital rates. Thus, a variation of the back calculation, such as the method used by Wade (1997) for eastern gray whales, is a more suitable alternative. In that analysis, the initial year of population projections (1900) was after the onset of commercial exploitation, but still far enough back in time to reflect the contrast (i.e., periods of high and low abundance) in the population's history.

The year 1900 is also a suitable year to begin a back calculation of the western gray whale population. The time series of modern whaling catch records begins in this year (Figure 1.1; Appendix A). Moreover, population projections will encompass the concerted Japanese modern whaling operation off the Korean peninsula (Kasahara, 1950; Kato and Kasuya, 2002). Western gray whale population size *circa* 1900 and an apparent estimate of carrying capacity do exist in the scientific literature. Berzin and Vladimirov (1981) suggested that the western gray whale population numbered 1,000-1,500 individuals by 1910, although details of the estimation process were not provided. Yablokov and Bogoslovskaya (1984) speculated that the population might have numbered between 1,500-10,000 whales prior to the onset of the 'whaling industry.' How this range was determined, and to what specific time period it applies, is unclear.

Increased international protection, conservation, and management planning for western gray whales are needed to facilitate the potential recovery of this population. In several predominant national and international contexts, marine mammal conservation currently functions by protecting populations based on the degree to which they are reduced (e.g., Fowler and Siniff, 1992; IWC, 1995; Wade, 1998). Thus, a back

calculation adhering to the previously outlined framework was performed to quantitatively demonstrate the degree to which the western gray whale population was depleted during the 20th century, and possibly historically. Along with 20th century catch data (Figure 1.1; Appendix A), mark-recapture estimates of the number of western gray whales associated with the Piltun feeding ground (Figure 1.2; Wade *et al*., 2003) were available for fitting of the population dynamics model. However, as the increase in these estimates only verifies an increase in the number of whales using the Piltun study area, the trend in these values is regarded as an overestimate of the present population growth rate (Wade *et al*., 2003). Thus, fitting the population dynamics model to these estimates would have lead to a biased estimation of model parameters. Therefore, an alternative population characteristic was needed, such as the current population growth rate. Given the survival estimates presented in Chapter 2 and some basic life history information (see below), the current western gray whale population growth rate was estimated accounting for uncertainty in these data. The population dynamics model was then fitted to the calculated growth rate. Results of the growth rate estimation and the ensuing analysis of 20th century western gray whale population dynamics are presented here.

METHODS

Growth Rate Estimation

Population Dynamics Model

According to Lotka's equation of unity (Lotka, 1907; Cole, 1954), any given set of age-specific survival and reproductive parameters can be characterized by a unique

population growth rate. The form of the Lotka equation allowing for a discrete time (in this case, annual) life history representation (e.g., Goodman, 1982) was used to estimate the population growth rate of western gray whales from 1997 to 2002:

$$1 = \sum_{x=1}^{w} \lambda^{-x} l_x m_x \qquad \text{(Equation 3.1)}$$

where x = age class
w = maximum age class
λ = finite population growth rate
l_x = survival to age class x
m_x = fecundity of age class x.

When implementing the Lotka equation, the first age class (i.e., age class 1) generally relates to young of the year at the time of birthing (i.e., age 0 individuals), such that l_1=1. As the western gray whale growth rate estimation is based predominantly on information gleaned from the Piltun feeding ground (i.e., between birthing seasons), age class 1 actually corresponds to young of the year (i.e., calves) that are approximately 6-8 months of age (see Weller *et al*., 1999 for a discussion of likely ages of calves in the Piltun study area relative to eastern gray whale estimates summarized by Rice and Wolman (1971)). The fact that l_1 is technically unknown in this case is offset by the incorporation of apparent fecundity into the growth rate estimate. That is, the measure of fecundity is also based on observations made during the feeding season. Therefore, fecundity estimates will reflect any loss of calves between the breeding and feeding grounds, making l_1=1 an appropriate assumption for the present analysis. The specific life history parameters used in the western gray whale growth rate estimation are detailed below.

The average longevity of western gray whales is unknown, and can only be speculated for eastern gray whales (Rice and Wolman, 1971). However, the maximum age class (*w*) incorporated into the Lotka equation does not necessarily characterize the longevity of individuals in the population, and can in fact be much larger. When average survival probabilities representing an unknown demographic are used to calculate the l_x schedule, *w* should be fixed at a value large enough to allow l_w to approach zero. As an average non-calf survival probability was utilized in the western gray whale growth rate estimation (see below and Chapter 2), the maximum age class was set at 150. To illustrate the principle of this concept, summing the Lotka equation to *w*=1,000 would not have changed the results of the growth rate estimation. Further, in the older scientific literature (e.g., Cole, 1954), *w* was often alternatively represented by ∞.

The intrinsic growth rate of a population (*r*) is another measure of population increase often represented in population dynamics modeling. In discrete forms of population dynamics models, the finite population growth rate (*?*) estimated by the Lotka equation corresponds to *r* according to the relationship:

$$l = 1 + r \qquad \text{(Equation 3.2)}$$

As a form of *r* was a parameter in the back calculation population dynamics model (see below), consistency and comparability of reported growth rates were needed. Therefore, results of the growth rate estimation are described in terms of $l - 1$ when associated with the Lotka equation, and by the *r* nomenclature when incorporated into the back calculation.

Life History Parameters

Four life history parameters were required for the western gray whale growth rate estimation: 1) calf survival; 2) non-calf survival; 3) calving interval (i.e., time in years between births of consecutive calves); and 4) age at sexual maturity (ASM). The mark-recapture calf and non-calf survival estimates (f) presented in Chapter 2 were utilized to construct the l_x schedule of the Lotka equation for age class 2 (recall that l_1=1) to age class *w*, where:

$$l_x = f_{x-1} l_{x-1} \qquad \text{(Equation 3.3)}$$

Thus, the calf survival estimate became f_1, and the non-calf estimate $f_{2 \to w-1}$. Calf and non-calf survival values were selected from a beta distribution (i.e., between 0 and 1) with a mean of 0.709 (SE=0.1178) and 0.952 (SE=0.0151), respectively (Chapter 2).

Fecundity (m_x) is the average rate at which female young are produced each year by females, and can be calculated as:

$$m_x = \frac{1}{CI} SR f_x \qquad \text{(Equation 3.4)}$$

where CI = calving interval
SR = population sex ratio (assumed to be 0.5).

The western gray whale calving interval was determined from photo-identification records of females with calves on the Piltun feeding ground (Table 3.1; Brownell and Weller, 2002; Weller *et al*., 2003b), following the estimation method of Jones (1990) for eastern gray whales. As in Jones (1990), only females with one or more observed calving intervals contributed to the estimation. In addition to photographic sightings collected by

TAMU, NMFS, and KIENM between 1997 and 2002, photo-identification records from the 1995 pilot study (Brownell *et al*., 1997) were included in the calculation, as these data added one observed calving interval each to the encounter histories of two females (Table 3.1).

Averaging the 10 observed calving intervals (3-year *CI*: *n*=7; 4-year *CI*: *n*=2; 2-year *CI*: *n*=1) highlighted in Table 3.1 would lead to a measure of apparent fecundity. However, this measure could potentially be confounded by the capture probability of one or more of the represented females. That is, a female who might have been associated with a calf during any given feeding season could have been sighted only after her calf was weaned, or potentially not observed at all, such that an observed calving interval might actually represent two separate intervals. In general, such a scenario was assumed atypical given the marked seasonal site fidelity to the study area exhibited by females and their calves (Weller *et al*., 1999, 2000, 2001, 2003a, 2003b; Würsig *et al*. 1999, 2000), and the infrequency of first sighting calves during a field season after weaning has occurred (*n*=4 of 22 calves identified between 1997 and 2002; Brownell and Weller, 2002; Weller *et al*., 2003b). Further, suggesting that the observed calving interval represents two intervals would have introduced one-year calving intervals in eight of the 10 cases, and annual breeding is considered rare for this species (Jones, 1990).

The remaining two cases are the observed four-year calving intervals of whales No. 005 and No. 015 (Table 3.1). These females both had calves in 1998 and 2002, but it is biologically plausible that one or both of them produced a calf in 2000 that survived until the feeding season. Although whales No. 005 and No. 015 were sighted in 2000,

they were first observed on 12 August and 30 July, respectively (Weller *et al*., 2001). Both dates are within the range of known weaning times for western gray whales (Weller *et al*., 1999, 2000, 2001, 2003a, 2003b; Würsig *et al*. 1999, 2000). Further, one of the three calves identified in 2000 was first sighted post-weaning (Weller *et al*., 2001), so its mother was unaccounted for (although planned genetic testing could clarify this issue; Brownell and Weller, 2002). Therefore, suggesting that the observed four-year calving intervals could represent two two-year intervals is not an unreasonable assumption.

The goal of calculating the average western gray whale calving interval is to estimate apparent fecundity, and subsequently the current growth rate. While averaging the 10 observed intervals might underestimate apparent fecundity because of a possible capture probability influence, assuming that the observed four-year calving intervals represent two two-year intervals could overestimate apparent fecundity. That is, if whale No. 005 or whale No. 015 produced a calf in 2000 that did not survive until the feeding season, an overestimate of apparent fecundity (and the violation of the aforementioned l_1=1 assumption) would result. Therefore, the preferred approach was to bracket a likely range of fecundity values, and thus growth rate estimates. Consequently, a low, medium, and high estimate of calving interval was incorporated into a separate fecundity and growth rate estimation. The low calving interval estimate was the average of the 10 observed intervals; the high estimate was the average with both of the observed four-year intervals representing two two-year intervals (n=12). The medium calving interval estimate attributed two two-year calving intervals to either whale No. 005 or whale No. 015 (n=11). The low, medium, and high calving interval values were selected from a

normal distribution with a mean of 3.1 (SE=0.18), 2.8 (SE=0.18), and 2.6 (SE=0.15), respectively.

The ASM indicates the first age class with non-zero fecundity in the m_x schedule. As the first age class in the Lotka equation is usually composed of age 0 individuals, m_{ASM+1} is generally the first non-zero value. However, given the previously described 6-8 month offset in the age classes, the first non-zero fecundity value was set at age class ASM. The ASM of western gray whales is unknown, but a median value of 6 years (range 5-9 years) has been estimated for eastern gray whales (see Reilly, 1992 for a summary of eastern gray whale biological parameters). Assuming that eastern and western gray whales share similar reproductive capabilities, values for western gray whale ASM were selected from a discrete uniform distribution of 5-9 years.

According the Equation 3.4, non-zero values of m_x are conditional on the survival of mature females. Given that the f_x used to calculate these values was a non-calf estimate (i.e., based on observations of juvenile and adult whales), and that juvenile survival rates are likely lower than those of adults (Caughley, 1966), there was an inherent negative bias in the fecundity estimates that could not be avoided given the available data. However, population growth rates of long-lived animals are least sensitive to changes in fecundity rates (Goodman, 1981; Taylor and DeMaster, 1993). Hence, the impact of the negatively biased fecundity values on the resulting growth rate estimates was presumed to be minimal.

Statistical Methods

In order to account for the uncertainty of the input life history parameters, the 1997-2002 western gray whale population growth rate was estimated using a Monte Carlo simulation method (e.g., Cox and Baybutt, 1981). Values of the life history parameters were randomly selected from their associated distributions and incorporated into the Lotka equation, and a growth rate specific to that set of parameters was determined. This process was conducted a large number of times (n=10,000), producing a growth rate estimate in the form of a distribution. The simulation routine was performed employing the low, medium, and high estimates of calving interval, generating a *conservative*, *intermediate*, and *liberal* growth rate estimate, respectively. Pseudocode for the growth rate estimation procedure is provided in Appendix C.

Back Calculation

Population Dynamics Model

Complex models with more parameters usually provide better fits to data than simpler models. However, simpler models often offer more insight into the modeled system than accurate numerical fits (Hilborn and Mangel, 1997). Thus, the population dynamics model used in the first quantitative western gray whale back calculation was the age-independent generalized logistic equation (e.g., Pella and Tomlinson, 1969), altered for discrete (in this case, year-to-year) growth:

$$N_{t+1} = N_t + N_t r_{MAX}\left[1-\left(\frac{N_t}{K}\right)^z\right] - C_t \qquad \text{(Equation 3.5)}$$

where t = time in integer years from 1900 to 2002

N_{t+1} = population size at time t+1
N_t = population size at time t
r_{MAX} = maximum net recruitment rate
K = carrying capacity
z = shape parameter
C_t = catch at time t.

The shape parameter (z) controls the amount of non-linearity in the density-dependent function, which sets the maximum net productivity level (MNPL) (Taylor and DeMaster, 1993; Wade, 1998), according to the relationship (e.g., Smith, 1983):

$$MNPL = \frac{K}{(1+z)^{1/z}} \qquad \text{(Equation 3.6)}$$

Marine mammal populations are thought to exhibit concave non-linear density dependence, such that MNPL>0.5K making z>1.0 (Eberhardt and Siniff, 1977; Taylor and DeMaster, 1993; Fowler, 1994). However, available data make it difficult to estimate MNPL for any marine mammal population. Allowing MNPL>0.5K for marine mammals is viewed by Eberhardt and Siniff (1977) as a conservative management policy. Therefore, MNPL was assumed to occur at 0.6K (i.e., z=2.39) in the present analysis.

As the projection began in 1900, N_{1900} became an additional parameter in the model. Thus, the set of parameters (q) specified by the model were r_{MAX}, K, and N_{1900}. Two status indices ($\hat{N}_{2002}/K$ and $\hat{N}_{2002}/N_{1900}$) were also calculated using a model output ($\hat{N}_{2002}$) and two model parameters (N_{1900} and K). Assumptions of the generalized logistic equation are: 1) growth of the population is dependent on population size (i.e., density dependence); 2) the population was initially at a stable age distribution; 3) K is constant; 4) catch values are known, and 5) catch rates are proportional to the size of each

age class. Information is sparse regarding both the age-specific selectivity of whalers before and after 1900 and the general uncertainty (e.g., under-reporting and whales struck, but lost) in the post-1900 catch data. Consequently, assumptions 2, 4, and 5 were possibly violated by using this model to characterize western gray whale population dynamics. Examining the validity of model assumptions was not an objective of the present analysis, but should be considered in future assessments.

Realistically, the main status determination objective of the back calculation was to estimate N_{1900}. Although K was technically an estimated parameter, the lack of contrasting observed growth rate estimates (i.e., from periods of both low and high abundance) was expected to provide little information about this parameter. Hilborn and Mangel (1997) illustrate a case where the generalized logistic model was fitted to a series of abundance estimates for Serengeti wildebeest (*Conochaetes taurinus*). Although there was excellent agreement between the model predictions and the observed data, the abundance estimates were uninformative in determining carrying capacity (i.e., K was completely undefined). The abundance estimates merely indicated that K could be any value large enough to account for the increasing population size observed during the study period.

Statistical Methods

A Bayesian statistical method (e.g., Press, 1989; Gelman *et al*., 1995) was used to estimate the model parameters and the status indices. The likelihood function for the parameters calculated the likelihood of the model predicted 1997-2002 growth rate

($r^{\text{model}}_{1997-2002}$) given the observed estimate of 1997-2002 growth rate from the life history data ($r^{\text{LH data}}_{1997-2002}$), where:

$$r^{\text{model}}_{1997\text{-}2002} = \frac{\sum_{t=1997}^{2001}\left(\frac{N_{t+1}}{N_t} - 1\right)}{5} \qquad \text{(Equation 3.7)}$$

Assuming the observed 1997-2002 growth rate estimate was normally distributed with standard deviation (s_r), the likelihood function was:

$$L(q \mid r^{\text{LH data}}_{1997\text{-}2002}, s_r) = \frac{1}{\sqrt{2p}\, s_r} e^{-\frac{1}{2}\left(\frac{r^{\text{LH data}}_{1997\text{-}2002} - r^{\text{model}}_{1997\text{-}2002}}{s_r}\right)^2} \qquad \text{(Equation 3.8)}$$

In order to integrate the product of the prior distributions of the parameters and the likelihood function, the Sample-Importance-Resample (SIR) algorithm (Rubin, 1988; Smith and Gelfand, 1992) was used. SIR requires randomly selecting values of the parameters from their joint prior distributions to form a sample set q_i, of which the associated likelihood is calculated and stored. The process is repeated until an initial sample of n_1 q_is and likelihoods is generated. The n_1 q_is are then resampled with replacement n_2 times, with probability equal to weight q_i, where:

$$q_i = \frac{L(q_i \mid r^{\text{LH data}}_{1997-2002}, s_r)}{\sum_{j=1}^{n_1} L(q_j \mid r^{\text{LH data}}_{1997-2002}, s_r)} \qquad \text{(Equation 3.9)}$$

The resample serves as a random sample of size n_2 from the joint posterior distributions of the parameters (Rubin, 1988).

In the present analysis, a large value of n_1 was established (n_1=2,000,000) to ensure convergence of the integration by avoiding potentially overly influencing the resample with repetitive values. However, to confirm that the initial sample was large enough, the maximum number of times a single q_i appeared in the resample and the number of unique q_is in the resample were enumerated. The value of n_2 was set to 5,000 in order to yield sufficiently smooth posterior distributions. The entire back calculation was repeated three times, fitting the population dynamics model to the *conservative*, *intermediate*, and *liberal* 1997-2002 growth rate estimate, respectively. Pseudocode for the back calculation routine is shown in Appendix D.

Prior Distributions

The prior distribution for r_{MAX} was a uniform distribution (U) from 0.00 to 0.10, which was more restrictive than the prior distribution of U(0.01, 0.13) used in the population assessment of eastern gray whales by Wade (2002). However, given the small present population size, the posterior distribution of r_{MAX} was expected to closely approximate the distribution of the specified $r_{1997-2002}^{\text{LH data}}$ and associated standard deviation. The 95th percentiles of the three 1997-2002 growth rate estimates were all well below 0.10 (Table 3.2). Although the 5th percentiles of the *conservative* and *intermediate* 1997-2002 growth rate estimates were both less than 0.00 (Table 3.2), a maximum net recruitment rate below zero was considered biologically implausible.

The prior distribution for K was U(1,500, 20,000). While Yablokov and Bogoslovskaya (1984) hypothesized that the western gray whale population might have

previously numbered between 1,500-10,000 whales, there is no quantitative basis for this estimate. Yet, given the over 400-year history of western gray whaling, a value of *K* less than 1,500 whales was considered highly improbable. Previous speculation (Yablokov and Bogoslovskaya, 1984) and genetic inference (LeDuc *et al.*, 2002) suggest that the western gray whale population was never as large as that of the eastern population. Recent point estimates of eastern gray whale carrying capacity range from approximately 25,000 to 32,000 whales (Wade, 2002). Thus, a range of upper bounds for the prior distribution of *K* between 10,000 and 40,000 was explored for use in the western gray whale back calculation. These preliminary analyses demonstrated that any value within this range could be utilized as an upper prior bound without influencing the general results of the back calculation. Therefore, to avoid potentially increasing the number of initial samples and resamples (which would require more computation time), an upper bound for *K* of 20,000 was established, with the recognition that this value is somewhat arbitrary. However, to demonstrate the minimal effect a different upper bound for *K* within the aforementioned range would have on the back calculation results, an additional back calculation was performed. This analysis duplicated the back calculation incorporating the *intermediate* estimate of $r_{1997-2002}^{\text{LH data}}$, with the exception of a prior distribution for *K* of U(1,500, 10,000).

The prior distribution for N_{1900} was initially set as U(500, 20,000). Given that the population sustained a harvest of at least 1,100 whales between 1900 and 1915 (Figure 1.1; Appendix A), a value of N_{1900} less than 500 whales was regarded as unlikely. For

each draw of N_{1900}, the upper bound of the prior was constrained to be less than the value of *K* selected in that sample. However, preliminary analyses revealed that forward projections from most N_{1900} values selected from the upper portion of the prior distribution could not produce a depleted population in 2002. Given that the likelihood function was based on the observed 1997-2002 growth rate, a mechanism to penalize such trajectories was not in place. Thus, the *backwards* method described by Butterworth and Punt (1995) was implemented. In this approach, a current estimate of absolute abundance is treated as a model input along with the other model parameters, with the exception of the projection starting population size parameter. For each sample, these model inputs are selected from their prior distributions, and then used to calculate the initial population level corresponding to those values. That is, the population is projected *backwards* from the current abundance estimate to the starting population level. Therefore, the prior for initial population size is implicitly determined by the priors for the other parameters (Butterworth and Punt, 1995).

The mark-recapture estimate of the number of western gray whales associated with the Piltun study area in 2002, which is considered to closely approximate current population size (Figure 1.2; Wade *et al*., 2003), was utilized as a model input (N_{2002}) in the western gray whale back calculation. The prior distribution for N_{2002} was normally distributed with mean 98 and standard error 5 (Figure 1.2; Wade *et al*., 2003). During each initial sample, the randomly selected values from the priors for r_{MAX}, *K*, and N_{2002} were used to calculate a corresponding N_{1900} within the aforementioned prior distribution

for this parameter. Specifically, this process was accomplished by using a bisection approach to find the value of N_{1900} between 500 and *K*, given the prior draws of r_{MAX}, *K*, and N_{2002}, that would minimize the difference (i.e., residual) between $\hat{N}_{2002}$ and N_{2002}. That is, N_{1900} was initialized at a value halfway between 500 and *K*, only to become the new upper or lower bound of possible N_{1900} values if the $\hat{N}_{2002}$ and N_{2002} residual was positive or negative, respectively. A value of N_{1900} halfway between the boundaries of the redefined interval was examined, and the bisection routine continued until $\hat{N}_{2002}$ was very close to (arbitrarily defined to mean within five whales of) N_{2002}. At that point, the exact value of N_{1900} was solved for that would minimize the squared residual of $\hat{N}_{2002}$ and N_{2002}, which finally completed the q_i for that initial sample. Thus, although the resultant N_{1900} was always within the initially designated prior distribution, the actual prior for N_{1900} was a non-uniform distribution dictated by r_{MAX}, *K*, and N_{2002}.

Preliminary analyses revealed that not all combinations of r_{MAX} and *K* (particularly with high values of r_{MAX}) could produce an estimate of $\hat{N}_{2002}$ that closely approximated N_{2002}, regardless of the value of N_{1900} (i.e., the bisection routine could not find an N_{1900} 'solution'). Since the likelihood function was based solely on the observed and predicted 1997-2002 growth rate estimates, a diagnostic was implemented to identify and penalize such parameter sets. That is, before the bisection procedure was initiated with the selected q_i, N_{1900} was set at both 500 and *K*. If the resulting trajectories did not bracket

N_{2002} (i.e., the $\hat{N}_{2002}$ and N_{2002} residuals were either both positive or both negative), then that q_i was assigned a likelihood of zero.

As the $r_{1997-2002}^{\text{LH data}}$ utilized in the likelihood function had some basis in the mark-recapture analyses of the western gray whale photographic dataset (i.e., through the survival estimates), concern may be expressed about the lack of independence between $r_{1997-2002}^{\text{LH data}}$ and the mark-recapture estimate used to generate N_{2002}. However, the only data that are shared between these two estimates are the monthly sightings used to estimate capture probability in 2002. Further, a lack of covariance was found between capture probability in 2002 and the non-calf and calf survival estimates. Therefore, the estimates of $r_{1997-2002}^{\text{LH data}}$ and N_{2002} were treated as independent values.

RESULTS

Growth Rate Estimation

Estimates of the *conservative*, *intermediate*, and *liberal* 1997-2002 population growth rates are displayed in Table 3.2. As expected, the sequence of these estimates reflects the incorporation of the low, medium, and high fecundity values, respectively, with higher fecundity estimates resulting in increased growth rates. The growth rate estimates suggest that the western gray whale population was increasing during the observation period (Table 3.2, Figure 3.1). However, in each case, the left tails of the distribution indicate that some combinations of the life history parameters produced a negative growth rate (Figure 3.1).

Back Calculation

The maximum number of times a single q_i appeared in the resample of each of the three back calculations was two, and the number of unique q_is in each of the three resamples was greater than 4,950. Given the small number and reduced extent of repetitive parameter sets in the resample of each version of the back calculations, the size of each initial sample (n_1=2,000,000) was considered adequate for integration convergence. A summary of the back calculation model parameters and status indices according to the *conservative*, *intermediate*, and *liberal* 1997-2002 population growth rate scenarios is shown in Table 3.3.

As expected, the point estimate and posterior distribution for r_{MAX} in each of the three back calculations closely resembled the value and distribution for $r_{1997-2002}^{\text{LH data}}$ used in model fitting (Tables 3.2-3.3, Figures 3.1-3.2). That is, given the model of population dynamics and the small present population size, the western gray whale population is essentially currently growing at its maximum net recruitment rate. However, the left tails of each r_{MAX} posterior distribution (Figure 3.2) and corresponding $r_{1997-2002}^{\text{LH data}}$ distribution (Figure 3.1) differed, as the prior distribution for r_{MAX} prevented negative values of this parameter.

As anticipated, the point estimate and posterior distribution for *K* in each of the three back calculations reproduced the prior distribution for this parameter (Table 3.3, Figure 3.3). That is, any value of *K* within the prior distribution could support likely combinations of the other parameters. In other words, the carrying capacity of western

gray whales is undefined. The same situation resulted in the additional *intermediate* $r_{1997-2002}^{\text{LH data}}$ scenario back calculation utilizing the prior distribution of U(1,500, 10,000) for *K* (Figure 3.4A). The posterior distributions and point estimates for the other model parameters and status indices in this analysis duplicated those resulting from the initial *intermediate* back calculation (Table 3.3), with the exception of $\hat{N}_{2002} / K$ (see below).

The point estimate and posterior distribution for N_{1900} in each of the three back calculations indicate that only values within the lower range of the investigated prior distribution were able to produce a depleted population in 2002 using the *backwards* method and the likelihood function (Table 3.3, Figure 3.5). The resulting N_{1900} posterior distributions were negatively correlated with the observed 1997-2002 population growth rate estimates incorporated in the back calculations (Figure 3.5). That is, as the value of $r_{1997-2002}^{\text{LH data}}$ increased, the value of N_{1900} that was required to minimize the residual between $\hat{N}_{2002}$ and N_{2002} decreased.

The point estimate and posterior distribution for the status index $\hat{N}_{2002} / K$ were essentially the same between each version of the back calculation (Table 3.3, Figure 3.6), reflecting the similarity between each posterior distribution for *K* (Figure 3.3). Although the back calculation procedure did not define a value of western gray whale carrying capacity, the resulting $\hat{N}_{2002} / K$ suggests that the population is currently less than one percent of its original size (Figure 3.6). However, the posterior distribution for $\hat{N}_{2002} / K$ is the one model output dictated by the selected upper bound of the prior distribution for

K. That is, the $\hat{N}_{2002}/K$ distribution would shift to the left or right if the upper bound was increased or decreased, respectively. A slight rightward shift is evident in the posterior distribution for $\hat{N}_{2002}/K$ resulting from the back calculation using the *intermediate* 1997-2002 growth rate estimate and the prior distribution of U(1,500, 10,000) for *K* (Figure 3.4B; Median=0.017, 5th-95th Percentiles=0.010-0.049).

Yet, the posterior distribution for $\hat{N}_{2002}/K$ would never shift farther to the right than the posterior distribution for the status index $\hat{N}_{2002}/N_{1900}$, as N_{1900} can only be less than or equal to *K* in the back calculation (although the over 300-year history of western gray whaling prior to 1900 implies that the population size was already reduced by that year; Omura, 1984). Thus, the resulting $\hat{N}_{2002}/N_{1900}$ values can be interpreted as a maximum estimate of current population size relative to *K*. The three back calculation point estimates and posterior distributions for $\hat{N}_{2002}/N_{1900}$ suggest that the western gray whale population is currently *at most* between 8-9% of its original size (Table 3.3, Figure 3.7). The $\hat{N}_{2002}/N_{1900}$ posterior distributions were positively correlated with the value of $r_{1997-2002}^{\text{LH data}}$ used in model fitting (Figure 3.7). That is, values of $\hat{N}_{2002}/N_{1900}$ were smaller for the lower estimates of $r_{1997-2002}^{\text{LH data}}$, meaning that the population is most depleted according to the *conservative* back calculation scenario.

Results of the three back calculations reveal that the western gray whale population is presently highly depleted (Figure 3.7). Interestingly, findings from each of the three back calculations also indicate that the population has been highly depleted (i.e.,

less than 10% of its size in 1900) for over 70 years (Figure 3.8). In other words, the western gray whale population spent over half of the 20th century at extremely low population densities.

DISCUSSION

Growth Rate Estimation

Although variations have been documented, biological and observational data collected when eastern gray whales were recovering have indicated that the population has predominantly adhered to a two-year calving interval (e.g., Rice and Wolman, 1971; Blokhin, 1984; Jones, 1990). Evidence exists that, at least during the late 1980's, pregnancy rates of eastern gray whales have declined (Reilly, 1992). Density dependent mechanisms would suggest that lower pregnancy rates (i.e., increased calving intervals) would be attributed to the population reaching higher densities (e.g., Fowler, 1981). If the reproductive potentials of eastern and western gray whales are comparable, then a maximized reproductive output based on a two-year calving interval would be expected for the low-density western gray whale population. However, the low, medium, and high western gray whale fecundity values used in the growth rate estimation were all based primarily on three-year calving intervals (see Brownell and Weller, 2002 for a potential explanation of the three-year calving interval phenomenon).

Despite the estimates of longer calving interval and reduced calf survival (Chapter 2), the 1997-2002 population growth rate estimates imply that the population was increasing during that time (Table 3.2, Figure 3.1). However, the calculated growth rates

are relatively low compared to estimates from other depleted populations of baleen whales. Best (1993) summarized the growth rates of 10 severely depleted baleen whale populations (i.e., estimated to be less than 10% of their original population size at one time), including one bowhead, four right, one gray (eastern), one blue, and three humpback whale populations. These growth rate estimates ranged from 0.031 to 0.144, but were not necessarily measured when the populations were at their lowest levels. Depletion levels were known for five of the 10 populations, and demonstrated that higher growth rates corresponded to more depleted populations (Best, 1993). Yet, the 1997-2002 growth rates calculated for the severely depleted western gray whale population (i.e., at most between 8-9% of its original size; Figures 3.6-3.7) are markedly lower than the growth rate estimates of the three most depleted populations (i.e., ~3-20% of their initial population level during the observation period) discussed in Best (1993). However, drawing conclusions from this contrast is imprudent, as the growth rate values of these three populations (i.e., one right and two humpback whale populations) have large (or unknown) associated errors (Best, 1993).

A potentially more meaningful comparison can be made between the two gray whale populations. The trajectory of abundance estimates for eastern gray whales showed an annual rate of increase of 0.032 (SE=0.0055) during the period when the population doubled from about 10,000 to 20,000 whales, while maintaining an aboriginal harvest averaging approximately 175 whales per year (Reilly, 1992). Thus, estimates of their maximum net recruitment have ranged from 0.05-0.08 in stock assessments (e.g., Wade, 2002; Wade and Perryman, 2002). The small size of the western gray whale

population implies that they are likely currently growing at their maximum net recruitment rate. Results of the back calculation support this suggestion (Figure 3.2). Yet, the current western gray whale population growth rate estimates (Figure 3.1) are essentially half in value of the range of maximum net recruitment rates attributed to eastern gray whales. This difference in estimated maximum growth rates between the two populations is likely due to varying natural and anthropogenic influences (e.g., prey availability and human-caused mortality, respectively) on individual life history parameters, although the specific causes are unclear. However, given that the 1997-2002 western gray whale population growth rate estimates do include the effect of possible human-caused mortality (e.g., direct catching, entanglement in fishing gear), these values (and thus estimates of r_{MAX}) may be lower than the actual biological maximum growth rate of the population.

Interestingly, genetic evidence predicted that the rate of population increase of western gray whales could be comparatively low. LeDuc *et al*. (2002) detected the presence of 10 haplotypes in biopsy samples of western gray whales, which was higher than expected. In contrast, only five haplotypes have been identified for western North Atlantic right whales, a population estimated to consist of approximately 300 individuals (Malik *et al*., 2000). A possible explanation for the high retention of haplotypes in western gray whales is that the depleted population has grown much more slowly since 1966 (the last year of reported modern commercial western gray whaling; Brownell and Chun, 1977; Kato and Kasuya, 2002) than recovering eastern gray whales (LeDuc *et al*., 2002). If the population growth rate of western gray whales had been higher than the

eastern gray whale rate of 0.032, then the western gray whale populations would have been too low in 1996 to have included enough females to maintain 10 haplotypes (LeDuc *et al*., 2002).

Accounting for uncertainty in the western gray whale life history parameters revealed that some combinations of these values resulted in a negative growth rate (Figure 3.1). A population exhibiting a negative population growth rate is doomed to extinction, unless anthropogenic factors contributing to the population decline (e.g., human-caused mortality, habitat degradation) can be identified and mitigated. Thus, conservation plans for western gray whales should reflect not only the depleted status of the population, but also the possibility that the population is currently declining. Future monitoring will allow for the refined estimation of the life history parameters, which is needed to further investigate the possibility that the population growth rate is not at a replacement level.

Back Calculation

The posterior distributions for r_{MAX} and K resulting from the three western gray whale back calculations were not surprising. As aforementioned, the small population size in conjunction with the model of population dynamics employed was expected to produce a distribution of r_{MAX} similar to the distribution of $r_{1997-2002}^{\text{LH data}}$ used in the likelihood function of each back calculation scenario (Figures 3.1-3.2). Carrying capacity was expected to be undefined, as the data (i.e., $r_{1997-2002}^{\text{LH data}}$) used to fit the population dynamics model were measured only when the population was at low densities. Data characterizing the western gray whale population at higher densities are necessary to

make inferences about its carrying capacity. Alternatively, a back calculation in which the initial population size of the projection was assumed to be at a pre-exploitation equilibrium could be attempted. However, for reasons discussed above (e.g., the lack of required historical catch records), this task would currently be unfeasible without making numerous untestable assumptions.

Preliminary analyses exploring the full range of the initial prior distribution for N_{1900} demonstrated that forward projections from higher values could not generate a depleted population in 2002. Increasing the size of the initial samples to ensure that enough reasonable trajectories existed for integration convergence might have mitigated this problem, except that the $r_{1997-2002}$-based likelihood would not have penalized the unrealistic trajectories. Thus, these trajectories could have still appeared in the resample. Instead, allowing r_{MAX}, K, and N_{2002} to implicitly determine the prior distribution of N_{1900} via the *backwards* method (Butterworth and Punt, 1995) was a more appropriate and successful solution. An examination of the posterior distributions for N_{1900} illustrates the utility of the *backwards* method. That is, only a small range of values within the lower portion of the original N_{1900} prior distribution were able to produce a depleted 2002 population in conjunction with the incorporated values of $r_{1997-2002}^{\text{LH data}}$ (Figure 3.5).

The posterior distributions for N_{1900} indicate that the western gray whale population likely numbered around 1,000-1,200 individuals in 1900, when intensive modern commercial whaling for gray whales began (Kasahara, 1950; Kato and Kasuya, 2002). Omura (1984) proposed that the population at this time was already substantially

reduced from its original size after sustaining centuries of pre-modern whaling harvests. However, as previously indicated, findings from the back calculations are not able to clarify the degree to which the population in 1900 was depleted from its pre-exploitation level. The estimates of N_{1900} are still important in determining the current status of western gray whales, as associated values of $\hat{N}_{2002} / N_{1900}$ can be regarded as a maximum estimate of current population size relative to *K*. The posterior distributions for $\hat{N}_{2002} / N_{1900}$ imply that the western gray whale is presently *at most* between 8-9% of its initial population size (Figure 3.7). Note that if the 20th century catches were actually higher than the minimum numbers used in the western gray whale back calculations, then a higher and lower value of N_{1900} and $\hat{N}_{2002} / N_{1900}$, respectively, would have been estimated by the analysis. Additionally, the possibility that the population is even further depleted, potentially down to a size below 1% of its original level, should not be disregarded (Figures3.4B and 3.6).

Significance

Perhaps the most significant result of the western gray whale back calculation analysis is the implication that the population spent a majority of the 20th century at extremely low population densities (Figure 3.8). The long-term depleted status of western gray whales raises concerns about the negative effects of the population remaining at low densities. Populations at low densities are subject to increased risk of extinction by threatening factors, such as environmental and anthropogenic catastrophes (Gilpin, 1987).

This extinction risk can be compounded by depensation (i.e., the Allee effect; Allee *et al*., 1949; Dennis, 1989). In depensation, the population growth rate decreases with decreasing population density (see Fowler and Baker, 1991 for a review of population dynamics at low densities). Severe depensation implies the existence of a critical population density, below which the population will go extinct (Courchamp *et al*., 1999). Factors such as inbreeding depression, demographic stochasticity (e.g., sex-ratio fluctuations), and reduced cooperative interactions (e.g., reproduction, resulting from the inability to find a mate) can lead to depensation (Fowler and Baker, 1991; Courchamp *et al*., 1999).

Although empirical evidence supports the occurrence of such negative factors associated with low population densities (see Petersen and Levitan, 2001 for a recent review), little evidence of actual depensation exists in the scientific literature. Further, the role of depensation, if any, in the population dynamics of whales is unknown. However, issues relating to depensation should not be ignored, as the associated low-density effects could be enough to slow the recovery of a population, making it more vulnerable to extinction risk (Petersen and Levitan, 2001). Current threats to western gray whales could also inhibit the recovery of the population, increasing its susceptibility to all of the aforementioned low-density population effects (see Chapter 2 and Weller *et al*., 2002c for discussions of current threats). Disturbances associated with the intensive multinational oil and gas development off the northeastern shelf of Sakhalin Island are of particular concern (Würsig *et al*., 1999, 2000; Weller *et al*., 2002c, 2002d).

Using findings of the back calculations to suggest a magnitude to which the recovery of western gray whales is threatened by current threats and low-density factors would be premature. However, the western gray whale back calculation population dynamics model and resulting parameter estimates could provide a framework for a population viability analysis (PVA) (Gilpin and Soulé, 1986), which could be used to compare estimates of the probability of western gray whale extinction. Results of a PVA could be interpreted through the use of a decision analysis, where probabilities of extinction would be presented relative to both alternative states of nature (e.g., r_{MAX}) and alternative anthropogenic actions (e.g., human-caused mortality).

In conclusion, the western gray whale population is small, highly depleted, and has a low population growth rate. Western gray whales are at risk from factors threatening low-density populations, and current threats could compound these risks. These points highlight the timely need for the increased protection, conservation, and management planning of this critically endangered population.

Table 3.1. Annual records of known reproductive western gray whale females photographically identified in the Piltun study area between 1995 and 2002 (no data were collected in 1996). 1 = photographically identified. XX = photographically identified with a calf. 0 = not photographically identified. *n* = the number of calving intervals (highlighted) observed for each female. Records compiled from Brownell and Weller (2002) and Weller *et al*. (2003b).

Whale ID	1995	1996	1997	1998	1999	2000	2001	2002	*n*
005	0	-	1	XX	1	1	1	XX	1*
007	1	-	1	1	1	1	XX	0	0
009	1	-	1	XX	1	1	XX	1	1
011	0	-	1	1	1	1	1	XX	0
015	0	-	1	XX	1	1	1	XX	1*
018	XX	-	1	XX	1	1	XX	0	2
019	XX	-	XX	1	1	XX	1	1	2
026	0	-	1	1	0	0	0	XX	0
031	0	-	XX	0	0	0	0	0	0
036	0	-	1	XX	1	1	XX	1	1
038	1	-	1	1	XX	0	1	1	0
040	0	-	1	1	XX	0	0	XX	1
043	1	-	0	0	1	1	1	XX	0
055	0	-	0	XX	1	1	XX	1	1
063	0	-	1	XX	0	1	1	1	0
087	0	-	0	0	1	XX	1	0	0
092	0	-	0	0	0	1	XX	1	0

*n =2 when observed interval was assumed to represent two intervals.

Table 3.2. Summary of 1997-2002 western gray whale population growth rates (*?*-1) resulting from a Monte Carlo simulation of 10,000 trials sampling from associated distributions for life history parameters, including a low (*conservative*), medium (*intermediate*), and high (*liberal*) estimate of calving interval (*CI*).

CI	*?*-1	Median	Standard Deviation	5th-95th Percentiles
3.1 (SE=0.18)	*conservative*	0.026	0.0190	-0.008-0.054
2.8 (SE=0.18)	*intermediate*	0.031	0.0194	-0.003-0.061
2.6 (SE=0.15)	*liberal*	0.036	0.0198	0.001-0.066

Table 3.3. Summary of model parameters (r_{MAX}, K, and N_{1900}) and status indices ($\hat{N}_{2002}/K$ and $\hat{N}_{2002}/N_{1900}$) resulting from Bayesian back calculations of western gray whales using the SIR algorithm (n_1=2,000,000; n_2=5,000), incorporating the *conservative, intermediate,* and *liberal* estimates of 1997-2002 population growth rate ($r_{1997-2002}^{\text{LH data}}$) into the likelihood function.

$r_{1997-2002}^{\text{LH data}}$	Scenario	Parameter	Posterior Median	5th-95th Percentiles
0.026 (SD=0.0190)	*conservative*	r_{MAX}	0.028	0.005-0.058
		K	10,789	2,548-19,093
		N_{1900}	1,216	799-1,769
		$\hat{N}_{2002}/K$	0.009	0.005-0.038
		$\hat{N}_{2002}/N_{1900}$	0.080	0.054-0.123
0.031 (SD=0.0194)	*intermediate*	r_{MAX}	0.033	0.006-0.064
		K	10,919	2,487-19,089
		N_{1900}	1,137	744-1,739
		$\hat{N}_{2002}/K$	0.009	0.005-0.039
		$\hat{N}_{2002}/N_{1900}$	0.086	0.056-0.133
0.036 (SD=0.0198)	*liberal*	r_{MAX}	0.037	0.009-0.069
		K	10,953	2,541-19,031
		N_{1900}	1,071	693-1,666
		$\hat{N}_{2002}/K$	0.009	0.005-0.039
		$\hat{N}_{2002}/N_{1900}$	0.091	0.058-0.142

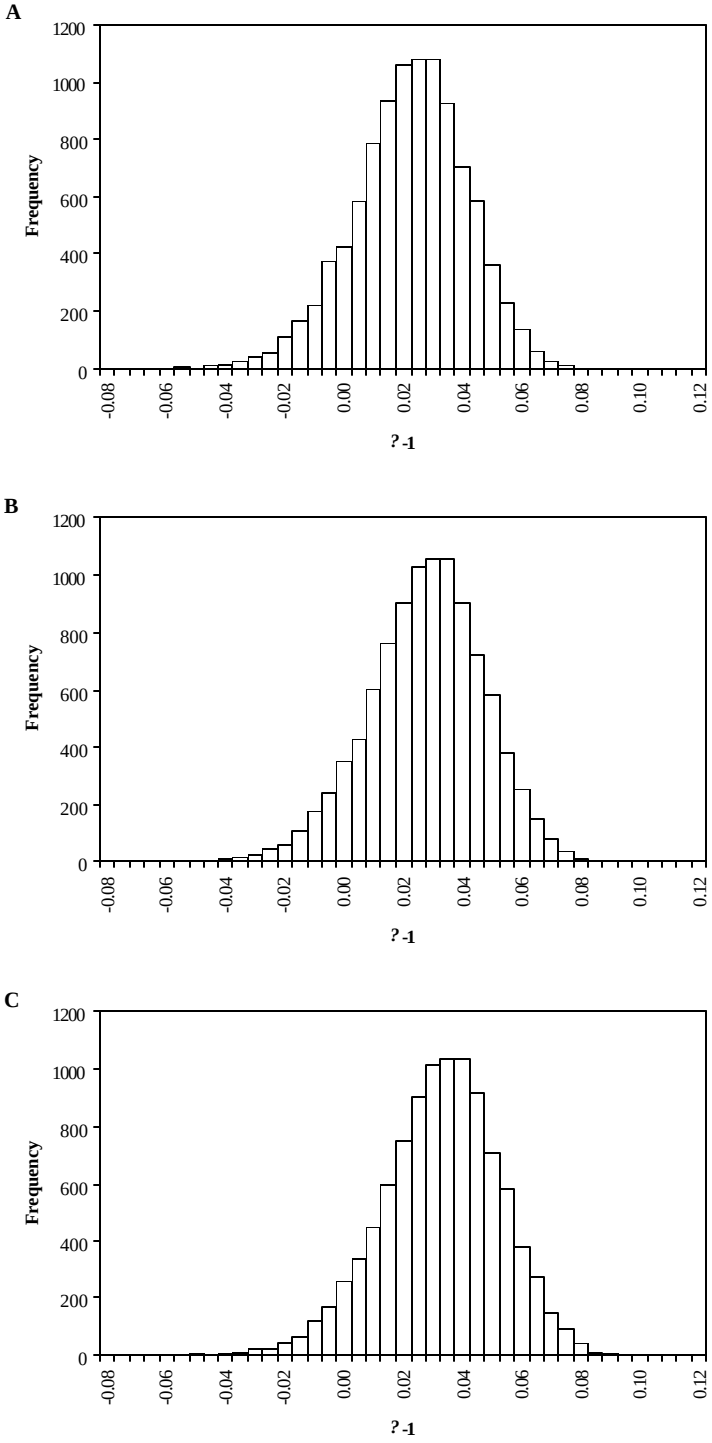

Figure 3.1. Histogram of values for the *conservative* (A), *intermediate* (B), and *liberal* (C) estimates of 1997-2002 population growth rate (*?*-1).

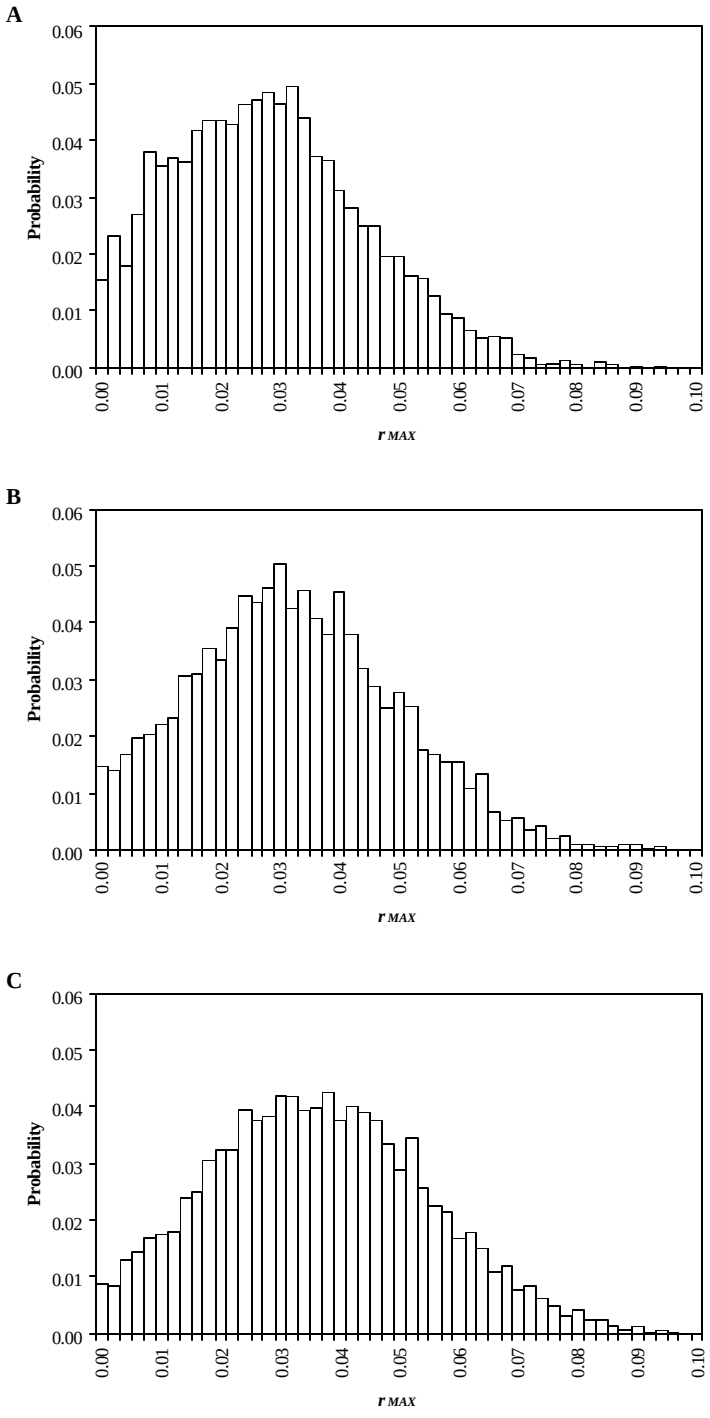

Figure 3.2. Posterior probability distributions for maximum net recruitment rate (r_{MAX}) resulting from back calculations using the *conservative* (A), *intermediate* (B), and *liberal* (C) estimates of 1997-2002 population growth rate.

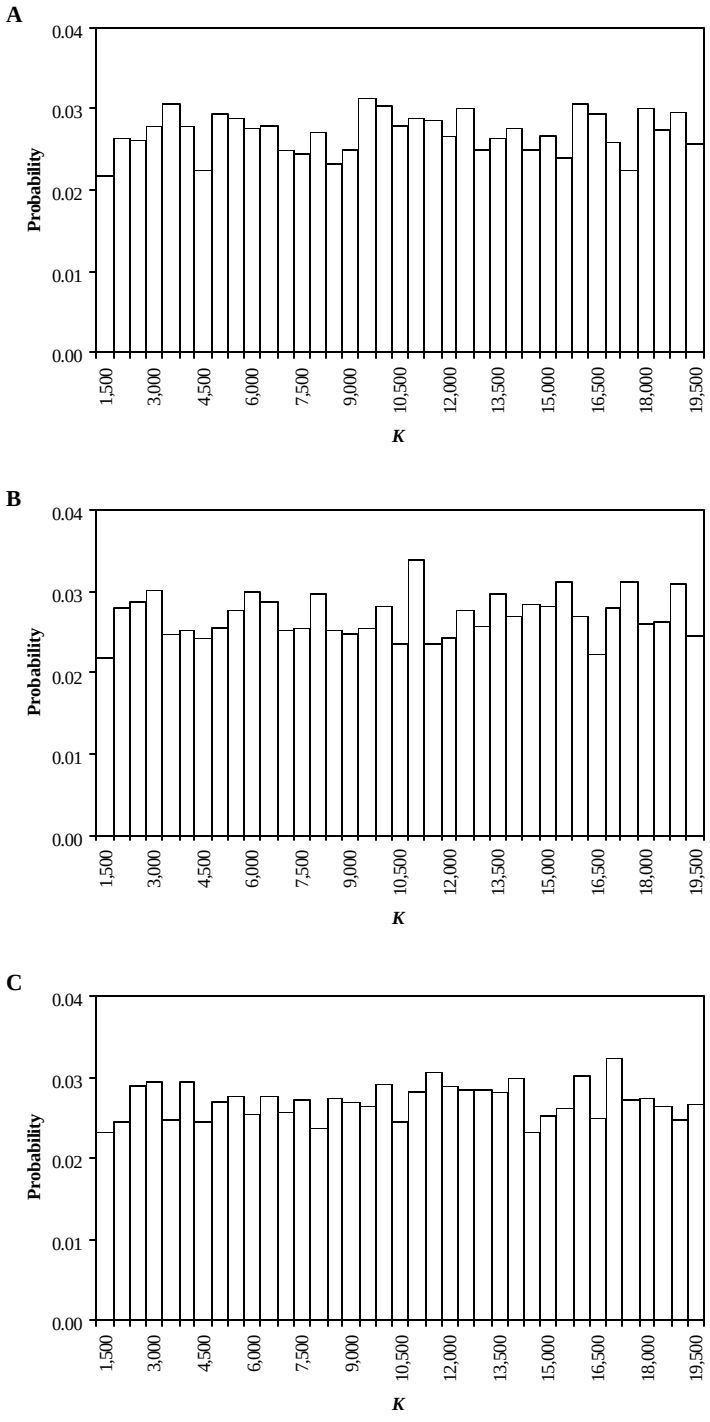

Figure 3.3. Posterior probability distributions for carrying capacity (*K*) resulting from back calculations using the *conservative* (A), *intermediate* (B), and *liberal* (C) estimates of 1997-2002 population growth rate.

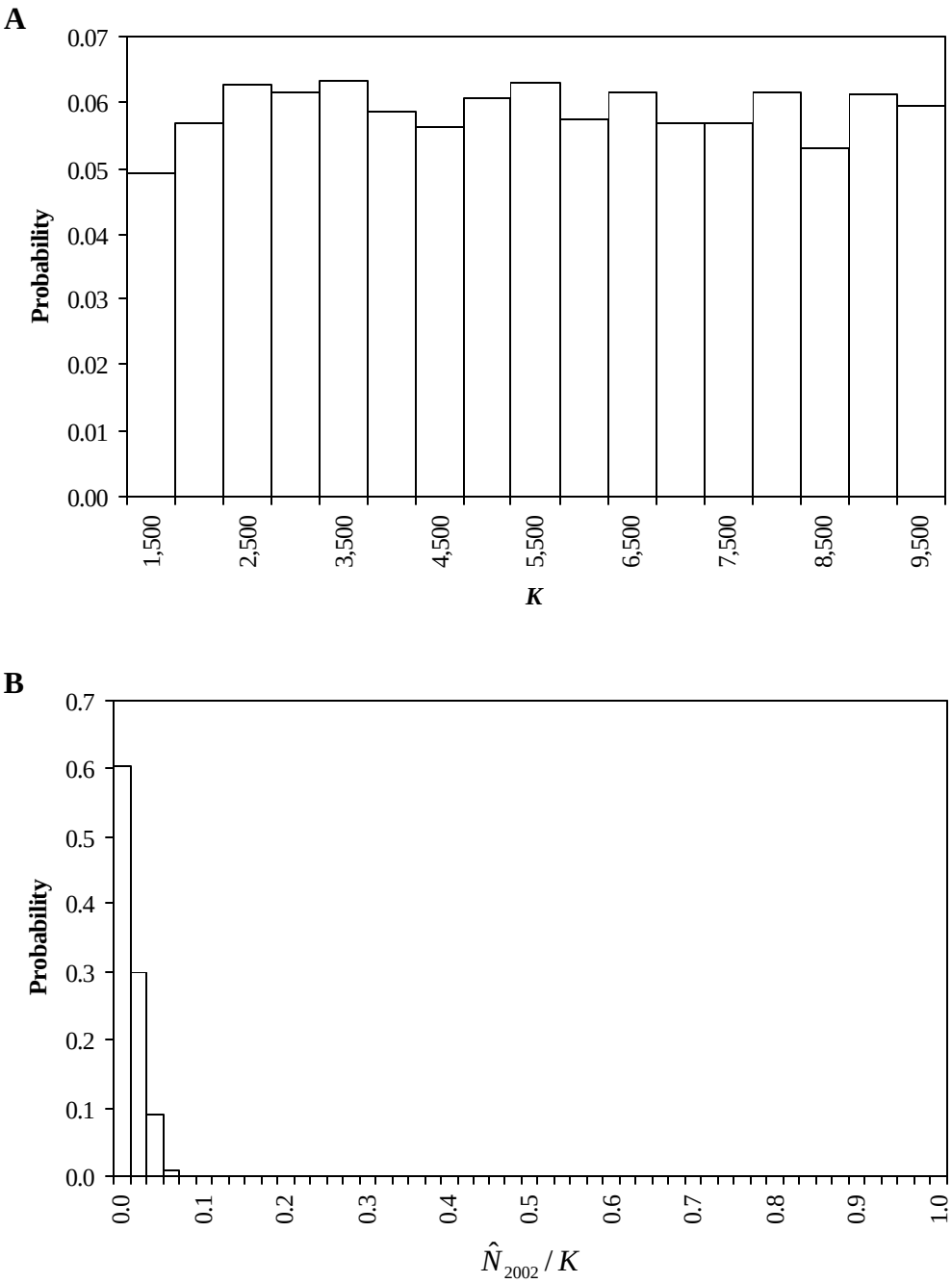

Figure 3.4. Posterior probability distributions for carrying capacity (*K*) (A) and a status index ($\hat{N}_{2002} / K$) (B) resulting from a back calculation using a prior distribution for *K* of U(1,500, 10,000) and the *intermediate* estimate of 1997-2002 population growth rate.

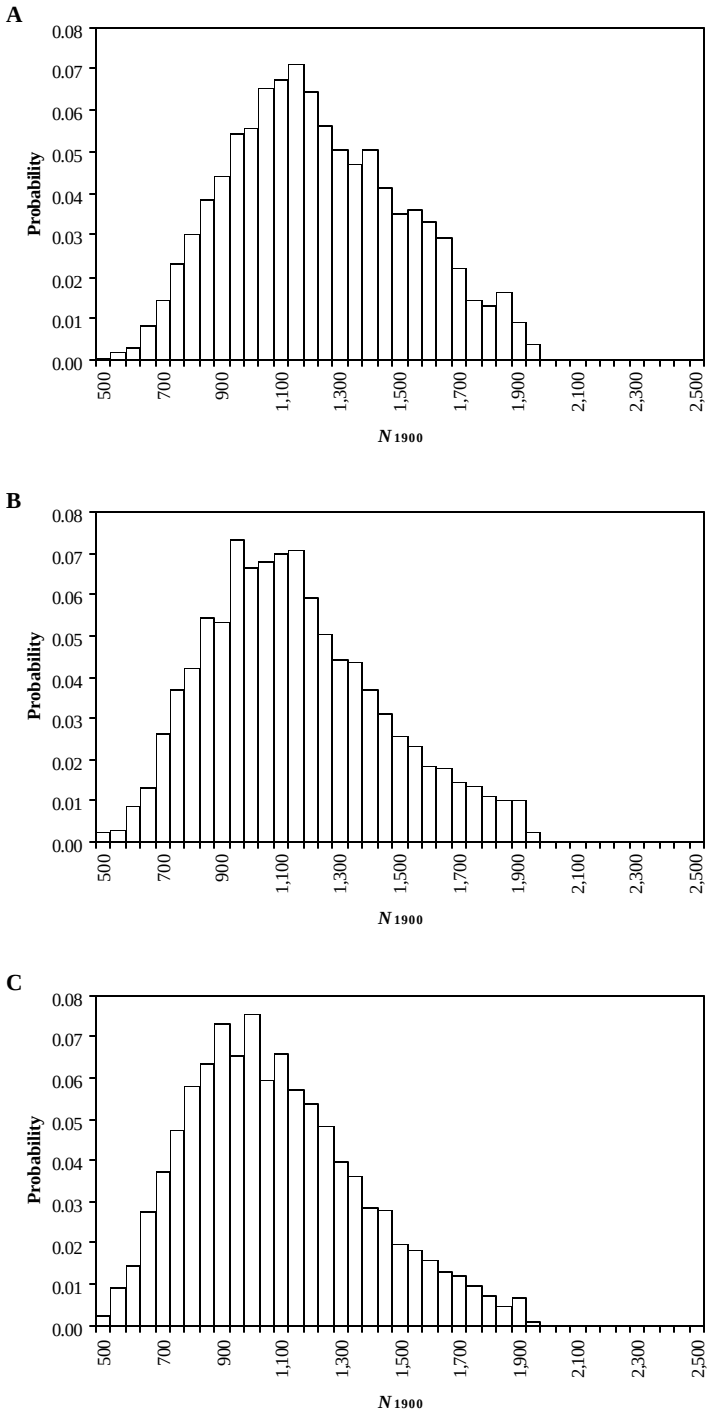

Figure 3.5. Posterior probability distributions for population size in 1900 (N_{1900}) resulting from back calculations using the *conservative* (A), *intermediate* (B), and *liberal* (C) estimates of 1997-2002 population growth rate.

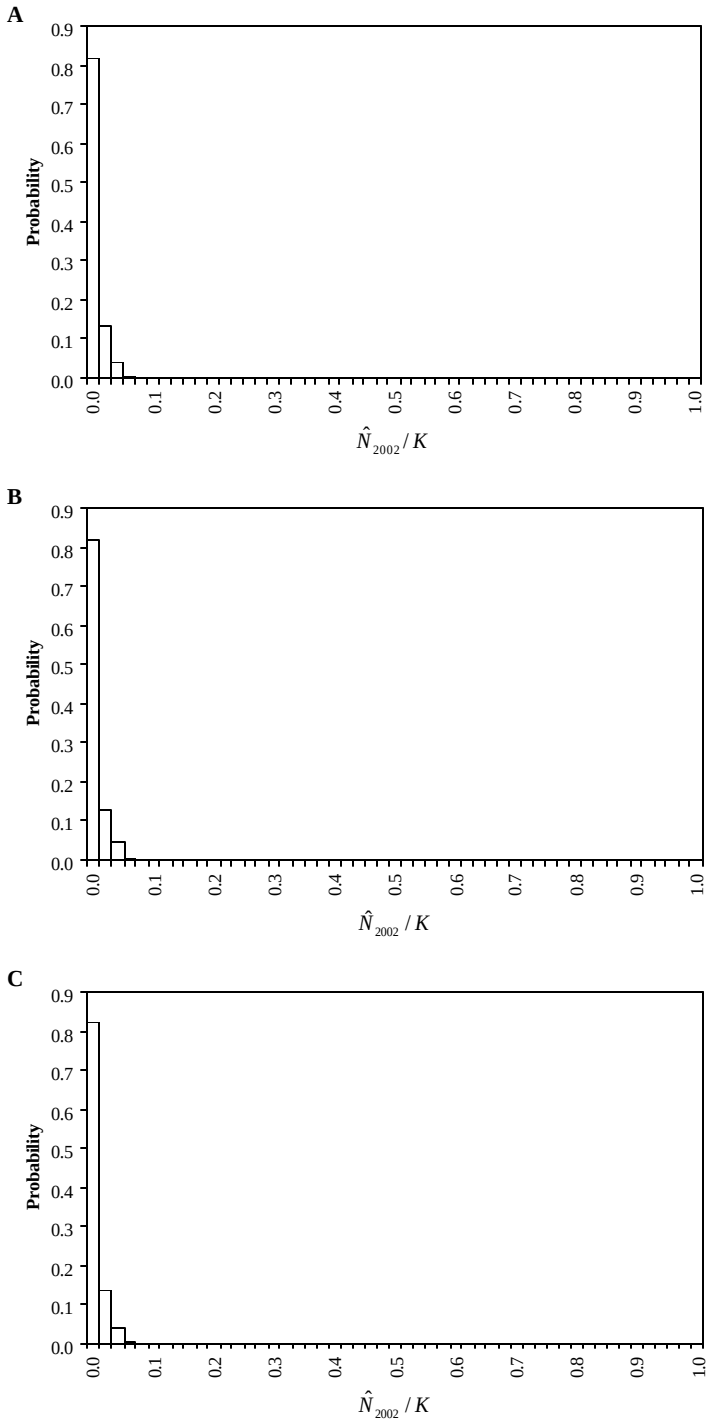

Figure 3.6. Posterior probability distributions for a status index ($\hat{N}_{2002} / K$) resulting from back calculations using the *conservative* (A), *intermediate* (B), and *liberal* (C) estimates of 1997-2002 population growth rate.

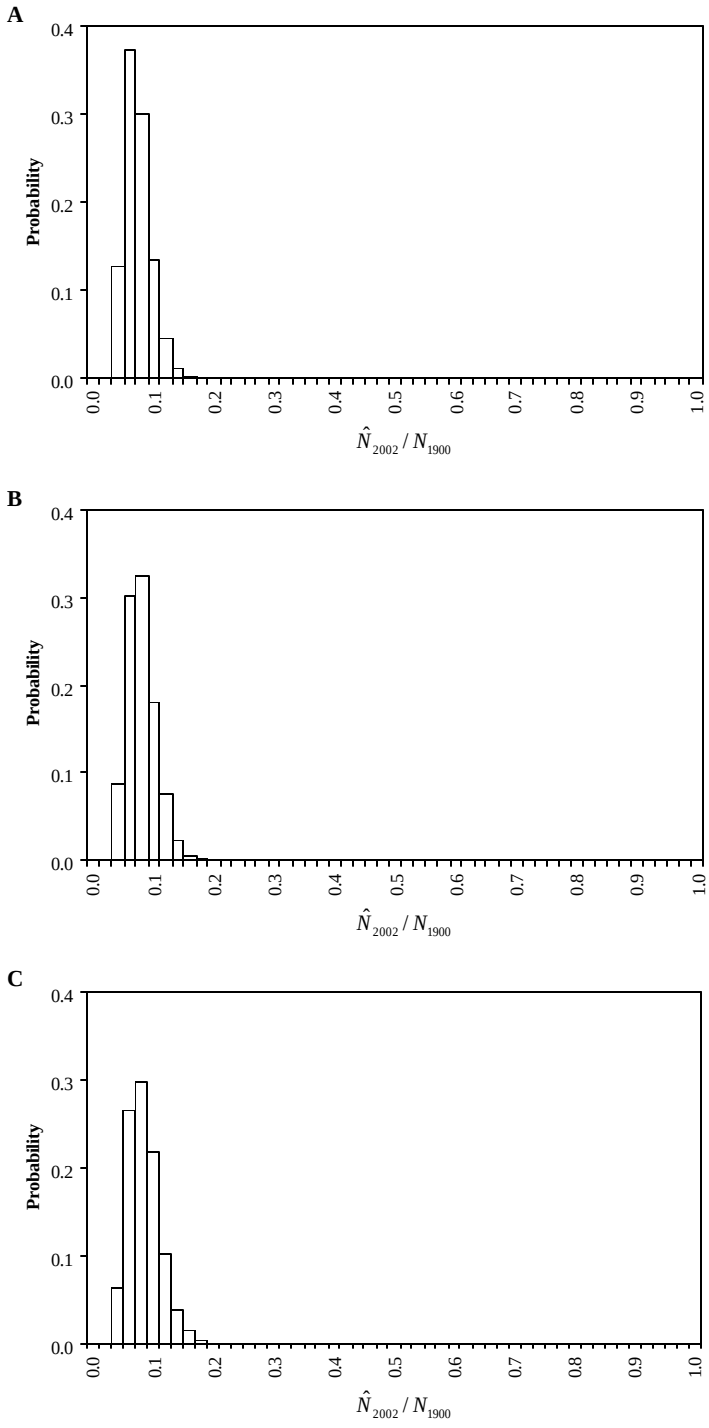

Figure 3.7. Posterior probability distributions for a status index ($\hat{N}_{2002} / N_{1900}$) resulting from back calculations using the *conservative* (A), *intermediate* (B), and *liberal* (C) estimates of 1997-2002 population growth rate.

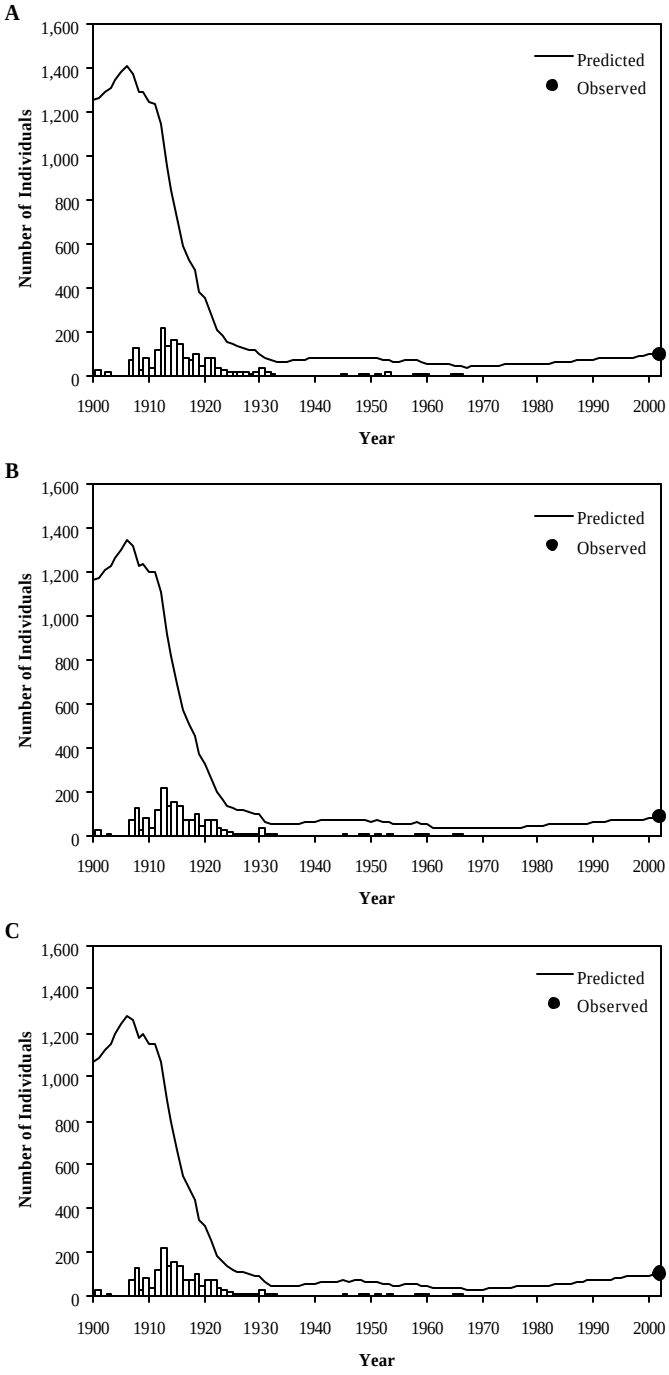

Figure 3.8. Twentieth century population projections resulting from back calculations using the *conservative* (A), *intermediate* (B), and *liberal* (C) estimates of 1997-2002 population growth rate. Predicted = the population dynamics model trajectory with the highest likelihood in the resample. Observed = the 2002 population size used in the *backwards* method. Bars = the minimum numbers of whales caught during the 20th century.

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Appendix A. Minimum numbers and associated details of western gray whales caught during the 20th century. Years are displayed continuously until 1966, the reported end of modern whaling for western gray whales. Highlighted rows represent total yearly minimum catches.

Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1900	?	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	23	Kato and Kasuya (2002) from Park (1987)
1900	?	Kawajiri, Yamaguchi	Sea of Japan	Japan	Japanese	?	2	Omura (1984) from Tada (1978)
1900							25	
1901							?	Kato and Kasuya (2002) from Park (1987)
1902	?	Jangjeon	Sea of Japan	Korea	Russian	Modern	9	Kato and Kasuya (2002) from Park (1987)
1902	?	Unknown	Unknown	Unknown	Unknown	Modern	5	Kato and Kasuya (2002) from Park (1987)
1902							14	
1903							?	Kato and Kasuya (2002)
1904							?	Kato and Kasuya (2002)
1905							?	Kato and Kasuya (2002)
1906	Nov-Mar	Ulsan	Sea of Japan	Korea	Japanese?	Modern	59	Kato and Kasuya (2002) from Park (1987)
1906	?	Unknown	Unknown	Unknown	Unknown	Modern	11	Kato and Kasuya (2002) from Park (1987)
1906							70	
1907	Nov-Mar	Ulsan	Sea of Japan	Korea	Japanese?	Modern	125	Kato and Kasuya (2002) from Park (1987)
1907							125	
1908	Nov-Mar	Ulsan	Sea of Japan	Korea	Japanese?	Modern	26	Kato and Kasuya (2002) from Park (1987)
1908							26	
1909	Dec	Ulsan	Sea of Japan	Korea	Japanese	Modern	65	Andrews (1914)
1909	Dec	Chan Chien Dogo	Sea of Japan	Korea	Japanese	Modern	18	Andrews (1914)
1909	Dec	Hidokatsu	Sea of Japan?	Korea?	Japanese	Modern	1	Andrews (1914)
1909							84	
1910	Jan	Ulsan	Sea of Japan	Korea	Japanese	Modern	32	Andrews (1914)
1910	Feb	Ulsan	Sea of Japan	Korea	Japanese	Modern	3	Andrews (1914)
1910	Mar	Ulsan	Sea of Japan	Korea	Japanese	Modern	1	Andrews (1914)
1910	Feb	Oshima, Nagasaki	Tsushima Strait	Japan	Japanese	Modern	1	Andrews (1914)
1910	Mar	Chan Chien Dogo	Sea of Japan	Korea	Japanese	Modern	1	Andrews (1914)
1910							38	
1911	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	106	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1911	Nov-Apr	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	13	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1911	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	2	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1911							121	
1912	Mar	Chan Chien Dogo	Sea of Japan	Korea	Capt. Melsom	Modern	2	Andrews (1914), Mizue (1951)

Appendix A. Continued.

Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1912	Jan	Ulsan	Sea of Japan	Korea	Japanese	Modern	23	Andrews (1914)
1912	?	Unknown	Unknown	Unknown	Unknown	Modern	193	Kato and Kasuya (2002), Omura (1988) from Kasahara (1950)
1912							218	
1913	?	Unknown	Unknown	Unknown	Unknown	Modern	131	Kato and Kasuya (2002), Omura (1988) from Kasahara (1950)
1913							131	
1914	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	109	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1914	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	30	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1914	Oct?	Ayukawa, Miyagi	Pacific	Japan	Japanese?	Modern	3	Mizue (1951), Brownell and Chun (1977)
1914	Jul?	Nemuro, Hokkaido	Pacific	Japan	Japanese?	Modern	1	Kasahara (1950), Mizue (1951), Brownell and Chun (1977), Kato and Kasuya (2002)
1914	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	15	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1914							158	
1915	?	Area XII-XIV	Unknown	Unknown	Japanese?	Modern	130	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1915	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	9	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1915							139	
1916	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	36	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1916	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	41	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1916	?	Area II, III, or IV	Unknown	Japan	Unknown	Modern	1	Kasahara (1950)
1916							78	
1917	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	53	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1917	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	13	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1917	?	Area XIV	Yellow Sea	Korea?	Japanese?	Modern	2	Kasahara (1950), Wang (1984), Omura (1988), Kato and Kasuya (2002)
1917							68	
1918	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	91	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1918	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	10	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1918	?	Area XIV	Yellow Sea	Korea?	Japanese?	Modern	2	Kasahara (1950), Wang (1984), Omura (1988), Kato and Kasuya (2002)
1918	?	"Other"	Unknown	Unknown	Unknown	Modern	1	Kato and Kasuya (2002) from Kasahara (1950)
1918							104	
1919	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	35	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1919	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	11	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1919							46	
1920	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	51	Kasahara (1950), Kato and Kasuya (2002)
1920	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	14	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)

Appendix A. Continued.

Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1920	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	10	Kasahara (1950), Kato and Kasuya (2002)
1920							75	
1921	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	23	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1921	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	53	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1921	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	2	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1921							78	
1922	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	19	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1922	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	19	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1922	May?	Area XIV	Yellow Sea	Korea?	Japanese?	Modern	2	Kasahara (1950), Mizue (1951), Wang (1984), Omura (1988), Kato and Kasuya (2002)
1922							40	
1923	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	4	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1923	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	23	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1923							27	
1924	?	Ulsan	Sea of Japan	Korea	Japanese?	Modern	1	Kato and Kasuya (2002) from Emoto Log
1924	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	13	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1924	?	Unknown	Unknown	Unknown	Unknown	Modern	4	Kato and Kasuya (2002) from Kasahara (1950)
1924							18	
1925	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	10	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1925							10	
1926	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	9	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1926	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	1	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1926	May?	Sakhalin	Sea of Okhotsk	Russia	Unknown	Modern	1	Kasahara (1950), Mizue (1951), Kato and Kasuya (2002)
1926							11	
1927	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	6	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1927	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	3	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1927	?	Area III	Sea of Okhotsk	Unknown	Unknown	Modern	1	Kasahara (1950), Kato and Kasuya (2002)
1927							10	
1928	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	9	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1928							9	
1929	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	11	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1929	?	Area XIV	Yellow Sea	Unknown	Japanese?	Modern	1	Kasahara (1950), Wang (1984), Omura (1988), Kato and Kasuya (2002)

Appendix A. Continued.

Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1929							12	
1930	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	30	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1930							30	
1931	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	10	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1931							10	
1932	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	7	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1932							7	
1933	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	modern	1	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1933							1	
1934							?	Kato and Kasuya (2002) from Kasahara (1950)
1935							?	Kato and Kasuya (2002) from Kasahara (1950)
1936							?	Kato and Kasuya (2002) from Kasahara (1950)
1937							?	Kato and Kasuya (2002) from Kasahara (1950)
1938							?	Kato and Kasuya (2002) from Kasahara (1950)
1939							?	Kato and Kasuya (2002) from Kasahara (1950)
1940							?	Kato and Kasuya (2002) from Kasahara (1950)
1941							?	Kato and Kasuya (2002) from Kasahara (1950)
1942	?	Ulsan	Sea of Japan	Korea	Japanese?	Modern	1	Kato and Kasuya (2002) from Emoto Log
1942	?	Otomae, Kurils	Unknown	Russia	Japanese?	Modern	1	Kasahara (1950), Mizue (1951), Brownell and Chun (1977), Kato and Kasuya (2002)
1942							2	
1943	?	Ulsan	Sea of Japan	Korea	Japanese?	Modern	1	Kato and Kasuya (2002) from Emoto Log
1943							1	Kato and Kasuya (2002) from Emoto Log
1944							?	Kasahara (1950), Kato and Kasuya (2002)
1945	Jan	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	3	Kato and Kasuya (2002) from Emoto Log
1945	May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	2	Kato and Kasuya (2002) from Emoto Log
1945							5	
1946							?	Brownell and Chun (1977), Kato and Kasuya (2002)
1947							?	Brownell and Chun (1977), Kato and Kasuya (2002)
1948	Jan?	Ulsan	Sea of Japan	Korea	Korean?	Modern	9	Brownell and Chun (1977), Kato and Kasuya (2002) from Park (1987)
1948							9	
1949	?	Ulsan	Sea of Japan	Korea	Korean?	Modern	4	Brownell and Chun (1977), Kato and Kasuya (2002)
1949	Sep	Area XIV	Yellow Sea	China?	Chinese	Modern	1	Kato and Kasuya (2002) from Wang (1978)
1949							5	

Appendix A. Continued.

Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1950							?	Brownell and Chun (1977), Kato and Kasuya (2002)
1951	?	Ulsan	Sea of Japan	Korea	Korean?	Modern	7	Brownell and Chun (1977), Kato and Kasuya (2002)
1951							7	
1952	?	Ulsan	Sea of Japan	Korea	Korean?	Modern	1	Brownell and Chun (1977), Kato and Kasuya (2002)
1952							1	
1953	?	Ulsan	Sea of Japan	Korea	Korean?	Modern	7	Brownell and Chun (1977), Kato and Kasuya (2002)
1953	Mar-Jun	Wailuo Harbor, Lui Zhou Peninsula	South China Sea?	China	Chinese?	?	4	Wang (1984)
1953							11	
1954							?	Brownell and Chun (1977), Kato and Kasuya (2002)
1955							?	Brownell and Chun (1977), Kato and Kasuya (2002)
1956							?	Brownell and Chun (1977), Kato and Kasuya (2002)
1957							?	Brownell and Chun (1977), Kato and Kasuya (2002)
1958	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	7	Brownell and Chun (1977), Kato and Kasuya (2002)
1958	Jun	Yantai, Shandong	Yellow Sea	China	Chinese	Modern	1	Kato and Kasuya (2002) from Wang (1978)
1958							8	
1959	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	7	Brownell and Chun (1977), Kato and Kasuya (2002)
1959	Jun	Southeast Honshu	Pacific	Japan	Japanese	Modern	1	Nishiwaki and Kasuya (1970), Brownell and Chun (1977)
1959							8	
1960	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	8	Brownell and Chun (1977), Kato and Kasuya (2002)
1960	Apr	Area XIV	Yellow Sea	China?	Chinese	Modern	1	Kato and Kasuya (2002) from Wang (1978)
1960							9	
1961	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	3	Brownell and Chun (1977), Kato and Kasuya (2002)
1961							3	
1962							?	Brownell and Chun (1977), Kato and Kasuya (2002)
1963	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	2	Brownell and Chun (1977), Kato and Kasuya (2002)
1963							2	
1964	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	3	Brownell and Chun (1977), Kato and Kasuya (2002)
1964							3	
1965	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	4	Brownell and Chun (1977), Kato and Kasuya (2002)
1965							4	
1966	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	5	Brownell and Chun (1977), Kato and Kasuya (2002)
1966							5	

Appendix A. Continued.

Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1968	Feb	Shingu, Wakayama	Seto Inland Sea?	Japan	Japanese	?	1	Nishiwaki and Kasuya (1970), Omura (1984), Brownell and Chun (1977), Kato and Kasuya (2002)
1996	May	Suttu, Hokkaido	Sea of Japan	Japan	Japanese	Hand Harpoon	1	Brownell and Kasuya (1999), Kato and Kasuya (2002)

Appendix B. Monthly encounter histories of western gray whales photographically identified from 1997 to 2002 off Piltun Lagoon, Sakhalin Island, Russia. 1 = photographically identified. 0 = not photographically identified. Whale identification (ID) numbers of whales first identified as calves are italicized. *n* = the number of monthly photo-identification surveys. Encounter histories compiled from Weller *et al*. (1999, 2000, 2001, 2003a, 2003b) and Würsig *et al*. (1999, 2000).

Whale ID number	Jul 97 (*n* =10)	Aug 97 (*n* =8)	Sep 97 (*n* =4)	Jul 98 (*n* =13)	Aug 98 (*n* =9)	Sep 98 (*n* =13)	Jun 99 (*n* =1)	Jul 99 (*n* =18)	Aug 99 (*n* =14)	Sep 99 (*n* =14)	Oct 99 (*n* =9)	Jun 00 (*n* =2)	Jul 00 (*n* =5)	Aug 00 (*n* =22)	Sep 00 (*n* =11)	Jun 01 (*n* =3)	Jul 01 (*n* =14)	Aug 01 (*n* =15)	Sep 01 (*n* =16)	Jul 02 (*n* =12)	Aug 02 (*n* =13)	Sep 02 (*n* =11)
001	1	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
002	1	1	0	0	0	0	0	1	1	0	0	1	1	1	0	0	1	1	0	0	0	0
003	1	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
004	1	1	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
005	1	0	0	1	1	0	0	1	1	0	0	0	0	1	1	1	1	0	0	1	1	1
006	1	1	1	1	0	0	0	1	1	1	0	0	0	1	1	0	1	0	0	0	0	0
007	1	1	0	1	0	0	0	0	1	1	1	0	0	1	1	0	1	1	1	0	0	0
008	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
009	1	1	1	1	1	0	0	1	1	1	1	0	0	1	1	0	1	1	1	1	1	1
010	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	0	1	1	0	1	0	1
011	1	1	1	1	1	1	0	1	1	1	0	1	0	1	0	1	1	0	0	1	1	0
012	0	1	1	0	0	0	0	1	1	0	0	0	0	1	1	1	0	0	0	0	1	0
013	1	1	0	0	1	1	0	1	1	1	0	0	0	1	1	1	1	1	1	0	1	1
014	1	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	1	0	0
015	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	1	1
016	1	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	1	0	0	1	0	0
017	1	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
018	1	0	1	1	1	1	0	1	1	1	1	0	0	1	0	0	1	1	0	0	0	0
019	1	1	0	1	0	0	0	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1
020	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
021	0	1	0	0	1	0	0	1	1	0	0	0	0	0	0	1	1	0	0	1	0	0
022	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
023	0	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0
024	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	0	1	1	1	1	1	0
025	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1
026	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
027	0	1	0	0	0	1	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0
028	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	1	1	1	1	0	0	0
029	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	0
030	0	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0

Appendix B. Continued.

Whale ID number	Jul 97 (*n* =10)	Aug 97 (*n* =8)	Sep 97 (*n* =4)	Jul 98 (*n* =13)	Aug 98 (*n* =9)	Sep 98 (*n* =13)	Jun 99 (*n* =1)	Jul 99 (*n* =18)	Aug 99 (*n* =14)	Sep 99 (*n* =14)	Oct 99 (*n* =9)	Jun 00 (*n* =2)	Jul 00 (*n* =5)	Aug 00 (*n* =22)	Sep 00 (*n* =11)	Jun 01 (*n* =3)	Jul 01 (*n* =14)	Aug 01 (*n* =15)	Sep 01 (*n* =16)	Jul 02 (*n* =12)	Aug 02 (*n* =13)	Sep 02 (*n* =11)
031	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
032	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
033	1	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1
034	1	0	0	0	1	1	0	1	1	1	0	0	0	1	0	0	1	1	1	1	0	1
035	1	0	0	1	0	0	0	1	1	1	0	0	0	1	1	0	1	1	1	1	1	1
036	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1
037	0	1	1	0	0	0	0	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1
038	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	1
039	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
040	0	0	1	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1
041	0	0	1	0	0	0	0	1	1	1	0	0	0	1	1	1	1	1	1	0	0	0
042	0	0	1	0	0	1	0	1	1	1	1	0	0	1	1	0	0	0	0	0	0	0
043	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0	1	1	1	1	1
044	1	0	0	1	0	0	0	1	1	0	0	0	1	1	0	0	1	1	1	0	0	0
045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
047	0	0	0	1	0	0	0	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0
048	1	0	0	0	1	0	0	1	0	0	0	0	0	1	0	1	1	1	1	1	1	1
049	0	0	0	0	1	0	0	1	1	1	0	0	0	1	0	0	0	1	1	1	1	1
050	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
051	0	0	0	1	1	0	0	1	1	1	0	0	1	1	1	0	0	1	1	0	0	1
052	0	0	0	1	1	0	0	1	1	1	0	0	1	1	1	0	0	1	1	1	1	1
053	0	0	0	1	0	0	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0
054	0	0	0	1	0	1	0	0	1	1	0	0	0	1	1	0	1	1	1	0	0	0
055	0	0	0	1	1	1	0	1	1	1	1	0	0	1	1	0	1	1	1	1	1	1
056	0	0	0	1	1	0	0	1	1	1	1	0	0	1	1	0	1	1	1	1	1	1
057	0	0	0	1	1	1	0	0	1	0	1	0	0	1	1	0	1	1	1	1	1	1
058	0	0	0	1	1	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0
059	0	0	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
060	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
061	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
062	0	0	0	1	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
063	0	0	1	0	1	0	0	0	0	0	0	0	0	1	1	0	1	1	1	0	1	1
064	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
065	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B. Continued.

Whale ID number	Jul 97 (*n* =10)	Aug 97 (*n* =8)	Sep 97 (*n* =4)	Jul 98 (*n* =13)	Aug 98 (*n* =9)	Sep 98 (*n* =13)	Jun 99 (*n* =1)	Jul 99 (*n* =18)	Aug 99 (*n* =14)	Sep 99 (*n* =14)	Oct 99 (*n* =9)	Jun 00 (*n* =2)	Jul 00 (*n* =5)	Aug 00 (*n* =22)	Sep 00 (*n* =11)	Jun 01 (*n* =3)	Jul 01 (*n* =14)	Aug 01 (*n* =15)	Sep 01 (*n* =16)	Jul 02 (*n* =12)	Aug 02 (*n* =13)	Sep 02 (*n* =11)
066	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
067	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0
068	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
069	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	0
070	1	0	0	0	1	0	0	1	1	1	0	0	0	0	1	0	0	1	1	1	1	1
071	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
072	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1
073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
074	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
075	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	1
076	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	1	1	0
077	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
078	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
079	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	1	1	1
080	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
081	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1
082	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1
083	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	0	1	1	1	0	1	0
084	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1
085	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0
086	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
087	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0	0	0	0	0
088	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1
089	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1
090	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	1
091	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
092	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	1	1	0
093	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	1	1
094	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
095	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
096	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
097	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
098	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1
099	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1

Appendix B. Continued.

Whale ID number	Jul 97 (*n* =10)	Aug 97 (*n* =8)	Sep 97 (*n* =4)	Jul 98 (*n* =13)	Aug 98 (*n* =9)	Sep 98 (*n* =13)	Jun 99 (*n* =1)	Jul 99 (*n* =18)	Aug 99 (*n* =14)	Sep 99 (*n* =14)	Oct 99 (*n* =9)	Jun 00 (*n* =2)	Jul 00 (*n* =5)	Aug 00 (*n* =22)	Sep 00 (*n* =11)	Jun 01 (*n* =3)	Jul 01 (*n* =14)	Aug 01 (*n* =15)	Sep 01 (*n* =16)	Jul 02 (*n* =12)	Aug 02 (*n* =13)	Sep 02 (*n* =11)
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1
101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Appendix C. Pseudocode outlining the Monte Carlo simulation procedure used for the western gray whale 1997-2002 population growth rate estimation.

1) Specify the distributions for the life history parameters (f_{calf}, $f_{non-calf}$, *CI*, and ASM), the maximum age class (*w*), and the number of samples in the simulation (*n*).

2) Draw values of f_{calf} and $f_{non-calf}$ from their distributions, and determine the l_x schedule (Equation 3.3).

3) Select values from the distribution of *CI* and ASM, and compute the m_x schedule (Equation 3.4).

4) Use Equation 3.1 to find the population growth rate (?) that characterizes the selected life history parameters.

5) Store the set of life history parameters and the resulting growth rate estimate.

6) Repeat Steps 2-5 until a sample size of *n* is generated.

Appendix D. Pseudocode outlining the Bayesian statistical method used for the 20th century western gray whale back calculation.

1) Specify the data ($r_{1997-2002}^{\text{LH data}}$), the prior distributions for the model parameters (r_{MAX}, K, and N_{1900}) and the 2002 abundance estimate (N_{2002}), and the number of initial samples (n_1) and resamples (n_2).

2) Draw a value of r_{MAX}, K, and, N_{2002} from their joint prior distributions.

3) Given these parameters, determine if a value of N_{1900} exists within its prior distribution that would produce a reasonable $\hat{N}_{2002}$. If so, implement the *backwards* method by using a bisection approach to find the value of N_{1900} such that $\hat{N}_{2002}$ is as close as possible to N_{2002}. If not, penalize the parameter set and proceed to the next sample (Step 2).

4) Use Equation 3.5 to project the population from 1900 to 2002 according to the selected parameters.

5) Estimate $r_{1997-2002}^{\text{model}}$ (Equation 3.7) and the two status indices ($\hat{N}_{2002}/K$ and $\hat{N}_{2002}/N_{1900}$).

6) Calculate the likelihood of the parameters using the likelihood function (Equation 3.8).

7) Store the set of parameters, status indices, and associated likelihood.

8) Repeat Steps 2-7 until an initial sample of size n_1 is generated.

9) With probability equal to weight q_i, resample the initial sample with replacement n_2 times, thus approximating the joint posterior distributions of the parameters and status indices.

previously suspected. This species may then be expected to be found (at least in canyon bottoms) at 1770 m and above throughout the entire area of the Animas Mountains but further collecting will be necessary to demonstrate validity of this expectation. It is further suggested that *T. umbrinus* may occur in New Mexico above 1770 m (5800 ft) south of San Luis Pass in the San Luis Mountains, and from there south into the state of Chihuahua, Mexico.

We are grateful to the New Mexico Department of Game and Fish for granting us permission to collect *Thomomys umbrinus* (permit no. 1055S); to Mr. Robert Burris, Manager of the Gray Ranch, for granting us permission to enter the Animas Mountains; to Mr. Wes Bonsell, U. S. Fish & Wildlife Service for assisting us in obtaining permission to enter this area; and to Mr. Bret Thaeler for field assistance. The Department of Biology, New Mexico State University, provided support for this work.

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LANDIS L. HINESLEY AND CHARLES S. THAELER, JR., *Department of Biology, New Mexico State University, Las Cruces, New Mexico 88003.* *Submitted 19 October 1976. Accepted 23 November 1976.*

PROBABLE EXISTENCE OF THE KOREAN STOCK OF THE GRAY WHALE (*ESCHRICHTIUS ROBUSTUS*)

Two geographically isolated populations of gray whales, *Eschrichtius robustus*, are known in the North Pacific—the eastern Pacific or California stock, and the western Pacific or Korean stock (Rice and Wolman, 1971; Tomilin, 1967). The range of the Korean stock is from the Sea of Okhotsk to the southern shores of the Republic of Korea (Tomilin, 1967; Andrews, 1914). Rice and Wolman (1971) reviewed the history of commercial exploitation of the Korean stock. Mizue (1951) reported that the last catch from this stock was a single whale taken in 1933 off the eastern coast of Korea, and concluded that the stock was extinct. Bowen (1974) summarized his recent negative findings and also concluded that the stock was probably extinct. The purpose of this note is to review and report recent catches and observations on western Pacific gray whales.

Chun examined six gray whales landed at Ulsan, Korea in 1948. The date of capture, size, and sex of these were as follows: 1 January, 37 feet (ft) (11.3 meters, m), female; 3 January, 33 ft (10.1 m), female, and 42 ft (12.8 m), male; 5 January, 40 ft (12.2 m), male; 8 January, 42 ft (12.8 m), male; and 11 January, 40 ft (12.2 m), male.

Gray whales landed at Ulsan and reported to Chun were the following: 1945–1947, 0; 1948, 9; 1949, 4; 1950, 0; 1951, 7; 1952, 1; 1953, 7; 1954–1957, ?; 1958, 7; 1959, 7; 1960, 8; 1961, 3; 1962, 0; 1963, 2; 1964, 3; 1965, 4; 1966, 5; 1967–1975, 0. Between 1948 and 1966 at least 67 gray whales were taken in South Korean waters. However, the absence of catch reports between 1967 and 1975 does not necessarily indicate that no gray whales were taken.

The last sighting of this species in Korean waters was a female with a calf near Yokji Island (34°40′N, 128°15′E) in May 1968. This observation was reported to Chun by a Korean whaler. During recent research cruises in the Sea of Okhotsk, four gray whales were observed in Tugursk Gulf in June 1967 (Berzin, 1974), but in August 1974 only a single gray whale was observed (Berzin and Kuz'min, 1975; Kuz'min and Berzin, 1975).

Bowen (1974) considered that three gray whales recorded in the western Pacific should be regarded as strays from the California stock and not survivors of the Korean stock. These records are as follows: one taken off Otomae (Shiashkotan Island) in the northern Kuril Islands in 1942 (Mizue, 1951); the other two off the southeast coast of Honshu, Japan at 33°29′N, 135°55′E and 33°43′N, 136°02′E in 1959 and 1968, respectively (Nishiwaki and Kasuya, 1970). Nishiwaki and Kasuya (1970) reported that their 1968 specimen had nasal bones that were fused and similar in shape to a skull from California illustrated by Andrews (1914). However, nothing is known about individual variation in either stock and they noted that more specimens need to be examined before any conclusion can be reached.

A consideration of older Japanese records suggests that the whales noted by Bowen (1974) were not outside the normal migratory path and thus probably belong to the Korean stock. Mizue (1951) reported that four gray whales were killed in 1914 along the northern Pacific coast of Japan, one off Nemuro, eastern Hokkaido, and three off Ayukawa, Miyagi Prefecture, Honshu. Omura (1974) has summarized records from the coasts of Wakayama, Kochi (Shikoku), Yamaguchi, and Kyushu, and hypothesized that the Seto Inland Sea was a calving ground for the Japanese substock of western Pacific gray whales. The migration route to and from the Seto Inland Sea was probably along the east coast of Japan from the Kuril Islands (Nishiwaki and Kasuya, 1970; Omura, 1974). Japanese gray whales were nearly exterminated by the end of the 19th century (Nishiwaki and Kasuya, 1970) and/or driven out of the Seto Inland Sea because of increased industrial development and ship traffic (Omura, 1974).

We believe, because of the above reports and observations, there is no reason to think that any of the recent gray whales from the western Pacific should be regarded as vagrants from the California stock. The Korean stock of gray whales probably still exists in small numbers. Whether this stock is below its "critical population size" is unknown, but the continued small catches during this century have probably prevented any recovery. The western Pacific stock is not accorded complete protection by the regulations of the International Whaling Commission because several nations which may exploit it (People's Republic of China, Democratic People's Republic of Korea, and the Republic of Korea) are not signatories to the International Convention for the Regulation of Whaling, 1946. Even under the Convention the taking of gray whales is permitted by aborigines of the Contracting Governments when the meat and products of such whales are to be used exclusively for local consumption. Therefore, we believe the western Pacific stock of gray whales will become extinct in the near future unless meaningful international protection is achieved.

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ROBERT L. BROWNELL, JR., AND CHAN-IL CHUN, *Department of Vertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560, and National Fisheries University of Busan (Busan Fisheries College), Busan, Korea, 601-01.* *Submitted 6 July 1976. Accepted 12 November 1976.*

BURROWING IN WILD AND DOMESTIC NORWAY RATS

The burrowing behavior of the wild Norway rat has been studied by Pisano and Storer (J. Mamm., 29:374–383, 1948) and Calhoun (Ecology and Sociology of the Norway Rat, pp. 15–54, 1962). This behavior is of obvious importance to animals living in nature but of little consequence to Norway rats maintained in captivity. The following study tests the hypothesis that the propensity of the Norway rat to burrow has been significantly reduced during the process of domestication.

A total of 35 wild and 26 domestic Norway rats were used in the present study. Ten male and 16 female wild rats were born and reared in captivity by 21 pairs of field-trapped parents. In addition, nine adult males trapped in two different locations in the Syracuse, New York, area were tested after being in captivity a minimum of 24 days (range = 24–163 days). Ten male and 13 female domestic subjects were of Long Evans hooded stock representing the offspring of 10 breeding pairs. The remaining three females were Sprague-Dawley albino subjects. All subjects (except for field-trapped rats) were reared and maintained in 35.6 by 35.6 by 17.8 centimeter (cm) wire-bottom cages prior to testing, precluding early digging experience. All animals were fed "Charles River Rat and Mouse Diet" and water *ad libitum*. Ages and weights of the subjects at the start of testing are presented in Table 1.

Subjects were individually placed in burrowing chambers with 91.4 by 76.2 by 0.64 cm plate glass sides held 21.6 cm apart by plywood ends and base. Chambers were filled with commercial ("Sunshine"), fumigated organic topsoil to a depth of about 50 cm. A wire mesh lid prevented the animals from escaping and removable black polyethylene plastic sheets covered the plate glass sides. Food and water were provided *ad libitum*. Temperature in the experimental room varied from 20 to 22°C and an artificial light:dark cycle of 14:10 was maintained. Burrowing chambers were checked daily for 4 consecutive days between 1500 and 1700 hours. Because rats usually tunneled along the plate glass wall, removal of the black plastic sheets revealed the nature of the burrows constructed. Side and top views of the burrow system were recorded daily using a grid painted on the glass as a reference. Existing tunnels were destroyed only after the 4-day test period was terminated. The topsoil in each apparatus was changed after every third animal had been tested.

Significantly more wild rats dug burrows than domestic rats (Table 1) during the 4-day test period ($\chi^2 = 10.5$, df = 1, $P < .001$). Although wild females exhibited more burrowing activity than domestic females ($\chi^2 = 6.12$, df = 1, $P < .02$) laboratory-reared wild males did not differ significantly from their domestic male counterparts (Fisher Exact Probability Test; Siegel, Non-Parametric Statistics, pp. 96–104, 1956). However, because field-trapped males tended to burrow more than laboratory-reared wild males and domestic males did not burrow at all, a Chi-square test including all three male groups proved significant ($\chi^2 = 9.8$, df = 2, $P < .01$).

Laboratory-reared female wild rats dug more burrows than their lab-reared male counterparts (Fisher Exact Probability Test, $P < .05$) but male and female domestic stocks did not differ significantly (F.E.P. Test) even though females were the only domestic rats to burrow.

The western gray whale population is distinct: a response to SC/61/BRG22

Brownell, R.L., Jr.[1], Lang, A.R.[1], Burdin, A.M.[2,3], Bradford, A.B.[4] and Weller, D.W.[1]

[1] NOAA Fisheries, Southwest Fisheries Science Center, La Jolla, California, USA
[2] Kamchatka Branch of Pacific Institute of Geography, Far East Branch - Russian Academy of Sciences, Petropavlovsk, Kamchatka, RUSSIA
[3] Alaska Sealife Center, Seward, Alaska, USA
[4] School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington, USA

The western gray whale population was depleted to such low levels by commercial whaling that some considered it extinct (Mizue, 1951; Bowen, 1974). As such, gray whales sighted in the western Pacific after the 1930s were, for a period of time, considered to be strays or vagrants from the eastern stock (Nishiwaki and Kasuya, 1970). The publication of reports of catches off the coast of Korea through the first half of the 1960s (Brownell and Chun, 1977), as well as an increased number of sightings off Russia and Japan after that time (Nishiwaki and Kasuya, 1970; Berzin, 1974), eventually caused this hypothesis to be re-evaluated and replaced by the suggestion that a small remnant population of western gray whales remained throughout the 20th century.

Most of what is known today about western gray whales comes from ongoing studies since 1995 of feeding animals off the northeastern shelf of Sakhalin Island, Russia. These studies show that whales photographically identified off Sakhalin have strong site fidelity and return annually to this area; this is particularly true of females with calves (Weller *et al*., 1999). In addition, information gained via biopsy sampling of individuals off Sakhalin has shown them to be genetically distinct from the eastern population (Lang *et al*., 2008a). More recent observations of western gray whales in regions potentially visited by animals from both the eastern and western North Pacific (e.g. the waters off eastern Kamchatka), however, have once again raised questions about the degree to which Sakhalin gray whales are from those in the eastern Pacific as illustrated by paper SC/61/BRG22.

SC/61/BRG22 suggests that the current population of western gray whales is derived from eastern gray whales. It is disappointing that the author of this paper does not offer any data or references to support the conclusions drawn nor does the paper take into account the rather substantial body of work comparing eastern and western gray whales using both mtDNA and microsatellite makers (LeDuc *et al*., 2002; Lang *et al*., 2008a, 2008b). Similarly, the extensive discussions regarding this topic, as reported in numerous reports of the IWC SC and IUCN have also been ignored.

That being said, the idea that the western gray whale population is derived from the eastern population is not a new idea. Nishiwaki and Kasuya (1970) suggested that a specimen from Japan killed by local fishermen had some similar characteristics to eastern gray whales. Here we provide a partial review of information gained from sightings and genetic data which addresses the question of gray whale population differentiation:

1. The observation offered in SC/61/BRG22 that sightings of gray whales off Sakhalin became more common during a time when the eastern gray whale population was increasing is used to suggest that the feeding ground off Sakhalin was established in part as a result of range expansion of the eastern population.
    a. The last known catches off Korea continued through the 1960s confirming the existence of the population (Brownell and Chun, 1977). Some records of gray whales off Russia, Japan, and Korea exist for the 1960s and 1970s (reviewed in Brownell and Weller 2008). A few sightings of western gray whales were reported from the western Okhotsk Sea in the 1960s but these observations are not well known because they were reported only in Russian (e.g. Berzin, 1974).

Aerial observations of a small number of whales off the northeastern coast of Sakhalin began in the early 1980s (Blokhin et al. 1985, Berzin et al. 1990); concerted boat-based studies in that area starting in 1995 have documented continued use of the northeastern Sakhalin area by western gray whales (see Weller *et al*., 2008a). An increase in the number of reported sightings, strandings, and entanglements of gray whales off Japan also started in the 1980s, and records have become more frequent since then (reviewed in Koya *et al*., 2008). It therefore seems most likely that sightings of gray whales in the western Pacific during the 1960s and 1970s were representative of a small number of animals that survived extirpation from commercial whaling and that this population has been increasing slowly.

b. Both mtDNA and bi-parentally inherited microsatellite markers (n=14) have now been used to measure differentiation between eastern and western gray whale populations as well as to compare levels of nuclear genetic diversity retained in each (LeDuc *et al*., 2002; Lang *et al*., 2008b). Mean levels of genetic diversity were similar between the eastern and western populations, suggesting that significant amounts of nuclear genetic diversity have not yet been lost in the small western population. Comparison of microsatellite allele frequencies confirmed that eastern and western populations are genetically distinct ($p<0.001$).

c. The whale entrapped in a set net in Yoshihama Bay, Japan in 2007 was photographically matched to an animal first identified as a calf off Sakhalin in 2006, providing a confirmed link between the Sakhalin feeding ground and a migratory corridor off Japan (Weller *et al*., 2008b). A genetic sample was collected from this whale during the 2006 field season off Sakhalin. Although this whale has a haplotype that is common in both eastern and western sample sets, genetic assignment tests group her (and her mother) with the western cluster of animals. As well, paternity testing assigns this whale a putative father that has been repeatedly identified off Sakhalin; this male is also the putative father of two other calves first identified off Sakhalin. By establishing a connection between the entrapped whale and other whales utilizing Sakhalin, this genetic information adds further support for the link between the feeding ground off Sakhalin and the migratory corridor off the eastern side (Pacific) of Japan.

2. Recent sightings of Sakhalin gray whales in areas potentially utilized by animals from the eastern population (eastern Kamchatka) are used in SC/61/BRG22 to suggest that animals feeding off Sakhalin are part of the eastern population.

   a. The lack of sighting and photo-identification effort off Kamchatka until recent years makes it difficult to assess whether use of this area by Sakhalin gray whales is a new phenomenon or simply was previously undiscovered. If the appearance of Sakhalin whales off eastern Kamchatka represents a recent range expansion of western gray whales (potentially recolonization of areas previously used) it would be consistent with similar shifts in the distribution of feeding eastern gray whales and may be driven by ecological factors. Alternatively, it is also possible that sources of anthropogenic disturbance from oil and gas development activities on or near the Sakhalin feeding ground have displaced whales from, or worse yet, indicates abandonment of what has traditionally been a critical feeding habitat (especially for mother-calf pairs) for the population (Weller *et al*., 2008a).

   b. The sample set used in the genetics studies by Lang *et al*. (2008b) includes 12 samples from gray whales taken in the hunt off Chukotka in 1994. The mtDNA haplotypes of these animals are all haplotypes either found only among the eastern samples or found in higher frequencies in the eastern sample set. Assignment tests group all of these animals with the eastern cluster (although one animal's assignment is somewhat equivocal), suggesting that the gray whales using this region are primarily eastern animals.

c. A genetic sample was collected from a gray whale in August 2004 on the eastern side of the Kamchatka peninsula. This animal was identified as a female and her genotype did not match that of any other sampled animals. The genotype of this sample had a higher probability of belonging to the western population than to the eastern population, supporting photo-identification studies that have shown that some western gray whales use this area during summer months.

d. Although understanding movements of animals between feeding grounds has important implications for management and conservation, genetic "isolation" is dependent on a lack of interbreeding between groups of animals. As such, even if substantial mixing of eastern and western gray whales occurs in feeding areas, isolation could still be maintained if those animals were returning to different areas to breed (Lang *et al*., 2008b).

Recommendations for future work to address these issues are:

Satellite tagging – a major gap in our understanding of the western gray whale population and the threats it faces lies in our lack of knowledge about migratory routes and wintering grounds. Satellite tagging may help to address that lack of knowledge and may provide further information on the discreteness of the western gray whale population. The lack of recent sightings in areas south of Japan further supports this need. On this point we agree with SC/61/BRG22.

Photo-identification comparisons of the western gray whale catalogue with those maintained for eastern gray whales might provide an additional line of evidence to further address questions about the isolation of the western population.

Genetic sampling of animals feeding in areas potentially used by both eastern and western animals would be valuable in assessing the stock identity of those individuals.

Genetic analysis of samples obtained from animals entrapped, stranded, or sighted in other areas of the western gray whale's range other than Sakhalin and Kamchatka (e.g. Japan) would provide useful information to determine the relationship of such animals to those identified off Sakhalin. Similarly, if any historic bone or baleen samples from western gray whales exist, genetic analysis could be used to compare genetic diversity between historic and current western gray whales.

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Author for correspondence:
Anna Brüniche-Olsen
e-mail: abruenic@purdue.edu

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Population genetics

Genetic data reveal mixed-stock aggregations of gray whales in the North Pacific Ocean

Anna Brüniche-Olsen[1], R. Jorge Urban[2], Vladimir V. Vertyankin[3], Céline A. J. Godard-Codding[4], John W. Bickham[5] and J. Andrew DeWoody[1,6]

[1]Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47905, USA
[2]Departamento Académico de Ciencias Marinas y Costeras, Universidad Autónoma de Baja California Sur, Km 5.5 Carretera al Sur, Mezquitito, La Paz, BCS 23080, México
[3]Kronotsky State Nature Biosphere Reserve, Elizovo, Kamchatka 684100, Russia
[4]Institute of Environmental and Human Health, Texas Tech University (TTU) and TTU Health Sciences Center, Lubbock, TX 79409, USA
[5]Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77845, USA
[6]Department of Biological Sciences, Purdue University, West Lafayette, IN 47905, USA

AB-O, 0000-0002-3364-2064

Gray whales (*Eschrichtius robustus*) in the Western Pacific are critically endangered, whereas in the Eastern Pacific, they are relatively common. Holocene environmental changes and commercial whaling reduced their numbers, but gray whales in the Eastern Pacific now outnumber their Western counterparts by more than 100-fold. Herein, we investigate the genetic diversity and population structure within the species using a panel of genic single nucleotide polymorphisms. Results indicate the gray whale gene pool is differentiated into two substocks containing similar levels of genetic diversity, and that both our Eastern and Western geographical samples represent mixed-stock aggregations. Ongoing or future gene flow between the stocks may conserve genetic diversity overall, but admixture has implications for conservation of the critically endangered Western gray whale.

1. Background

The gray whale (*Eschrichtius robustus*) is considered to consist of two stocks defined by the location of feeding and breeding grounds [1]. Western gray whales exist along the Asian Pacific coast and the Eastern gray whales populate the North American coastline, each presumably migrating to separate breeding and feeding areas [2]. The Western stock is now listed as *critically endangered*, whereas the Eastern stock is of *least concern* [3]. Both experienced population decline during the mid-Holocene [4] and were extensively harvested during commercial whaling [5,6]. The Eastern stock now numbers approximately 27 000 individuals [6], but the Western stock is approximately 200 individuals [7]. Satellite tagging and photo identification have revealed long-distance movements between the Western and Eastern Pacific [7,8], suggesting that stock structure may be more complex than a simple east–west divide [7,8]. Presumptively neutral genetic markers have shown low differentiation between eastern and western sampling locales [9,10], and given the critically endangered status of the Western stock, such movements and associated gene flow could prove extremely beneficial by counteracting genetic erosion [11].

We genotyped a panel of 95 single nucleotide polymorphisms (SNPs) using skin biopsies of gray whales from the Eastern and Western Pacific to assess genetic diversity and population structure (figure 1). We were particularly

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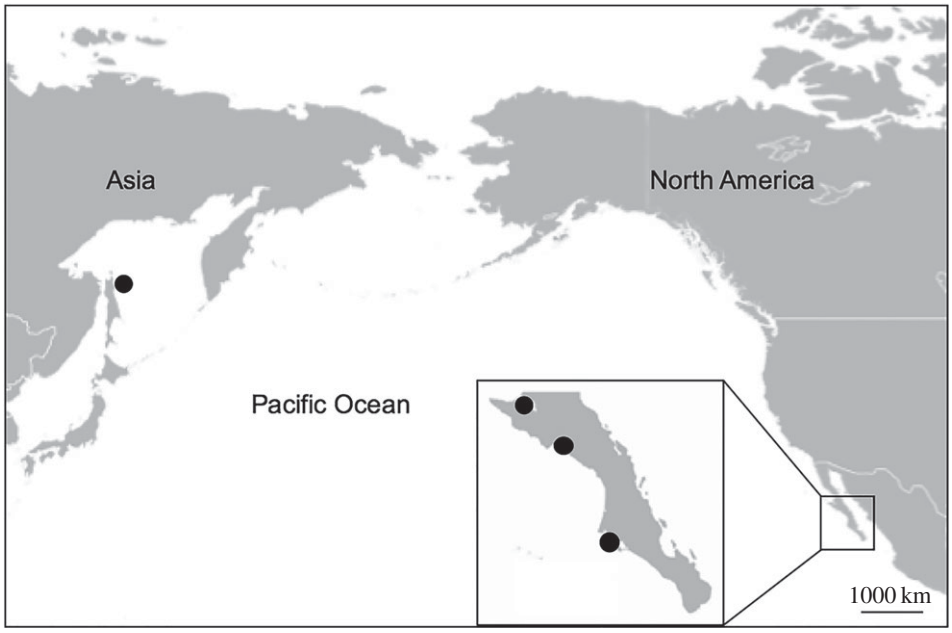

Figure 1. Sampling locations for the gray whales obtained near Sakhalin Island, Russia, and off the coast of Baja, Mexico.

interested in whether the gene pool was geographically partitioned and if there was evidence of admixture. Our results indicate that: (i) two substocks with similar levels of functional genetic diversity exist; (ii) the pronounced differentiation within the gray whale gene pool is not predicted by simple geography; and (iii) genetic signatures indicate that some individuals were admixed.

2. Material and methods

(a) Genetic diversity

Tissue biopsy samples were collected between 2011 and 2016 using a 150 lb draw weight compound crossbow (Barnett RC-150) with 40 mm by 7 mm internal diameter tips arrows [12]; 77 were sampled near Sakhalin Island (Russia) summer feeding grounds and 135 near the Mexican winter breeding grounds (figure 1) [2]. Following DNA extraction, we genotyped samples using SNPs in or near genes of functional importance, including osmoregulation, thermoregulation and oxygen delivery [13]. We removed samples with more than 20% missing data and loci with more than 25% missing data before using Allelematch v. 2.5 [14] to identify potential replicate samples [15].

Observed (H_O) and expected (H_E) heterozygosity and the inbreeding coefficient (F) were quantified in Genodive v. 2.0b [16]. Statistical departures from equilibrium were assessed using 10^3 bootstraps. We used Demerelate [17] to calculate Blouin's genetic similarity measure (M_{xy}) [18], which is independent of population size. Differences in mean M_{xy} were assessed with a Welch two-sample t-test and Fisher's exact test was used to test for heterozygote excess or deficiency.

(b) Population structure

We used four complementary approaches to characterize genetic structure: F_{ST} [19], Jost's D [20], discriminant analysis of principal components (DAPC) [21] and admixture analysis [22,23]. Significant differentiation for the F-statistics was assessed using a log-likelihood ratio test (G) [24]. DAPC was performed in adegenet v. 2.1.0 [24] by transforming SNP data to principal components followed by discriminant analysis. Admixture analysis was conducted with LEA v. 1.6.0 [25] and Structure v. 2.3.4 [23]; they yielded qualitatively similar results, so only the Lea results are reported. We did not purge putative siblings to avoid bias [26]. We evaluated clusters (K) from 1 to 6 and used the Bayesian information criterion and tested the robustness of our population structure inference by subsampling data (electronic supplementary material, S1) [27]. To assess the potential of hierarchical structure, we also ran the admixture analyses for sampling locations separately.

To infer recent migration rates between the two sampling locations, we used BayesAss v. 3.0 [28]. Migrants and their recent descendants were identified based on transient disequilibrium at individual multi-locus genotypes. A Monte Carlo Markov Chain (MCMC) of length 5×10^6 with sampling every 2×10^3 iteration was used, with the first 10% removed as burn-in. Delta values, which describe the maximum amount that the parameters can change in each iteration, were adjusted for allele frequencies ($a = 0.4$), migration rates ($m = 0.1$) and inbreeding values ($F = 0.7$) to assure an acceptance rate of 20–60% of the total iterations for each parameter. Two different seed values were used, and the MCMCs were checked for mixing and convergence in Tracer v. 1.6.0 (http://tree.bio.ed.ac.uk/software/tracer/). We estimated effective population sizes (N_e) based on linkage disequilibrium [29] using NeEstimator v. 2.01 [30].

3. Results

Of the 91 autosomal loci, 84 loci passed our quality-control criteria and Allelematch identified 166 unique genotypes (electronic supplementary material, S2) [15]. On average, each sample was genotyped at 82 loci, and the overall proportion of missing data was low (less than 0.03). Putative duplicate samples were always from the same location (e.g. east/east and west/west); thus, there were no replicate genotypes between the two sampling sites. The overall H_O was 0.30 and we detected no global deviations from equilibrium using the exact test, but H_O was significantly lower ($t = 10.0$; d.f. = 164; $p = 0.0001$) in the Eastern Pacific ($H_O = 0.28$) compared to the Western Pacific ($H_O = 0.32$). There were minor departures from random mating at both sampling sites (electronic supplementary material, S3).

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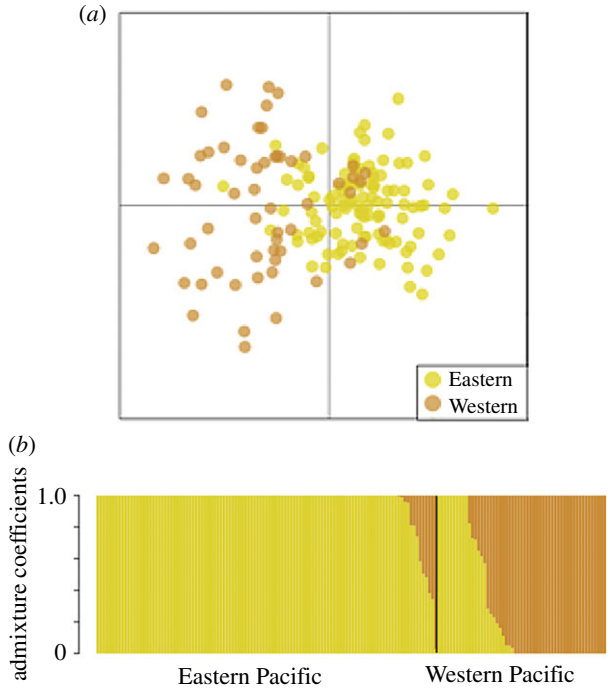

Figure 2. Genetic structure and geographical affiliations of sampled gray whales: (*a*) DAPC for the two ($K = 2$) geographical clusters; and (*b*) LEA admixture coefficients for each individual are represented by coloured vertical bars that illustrate proportional genomic ancestry for each individual in two ($K = 2$) geographical clusters. Both analyses suggest that each geographical site harbours mixed-stock aggregations of gray whales. (Online version in colour.)

The degree of genetic differentiation between the two primary geographical sites was small ($F_{ST} = 0.039$; $D = 0.017$) but significant ($p = 0.001$). Discriminant analysis showed that gray whales from the two sites could generally be separated, but there was some overlap in principal components (figure 2*a*). Similarly, the Lea admixture results divided the gray whales into two clusters (figure 2*b*; electronic supplementary material, S4); this result was confirmed by subsampling (electronic supplementary material, S5). No substructure was found within either cluster (electronic supplementary material, S6). There were putatively admixed individuals sampled from each primary geographical site, but a larger proportion was sampled from the Western Pacific (figure 2*b*). The Western Pacific samples had significantly ($p = 2 \times 10^{16}$) lower genetic similarity index ($M_{xy} = 0.72$; s.d. $\pm$ 0.070) than the Eastern Pacific samples ($M_{xy} = 0.75$; s.d. $\pm$ 0.039), which indicates that the mixed-stock aggregation in the Western Pacific consists of a more uniform proportion of both substocks (electronic supplementary material, S7 and S8). The Eastern samples had an eightfold larger contemporary N_e (mean = 164; 122–237, 95% confidence interval (CI)) than the Western samples ($N_e = 22$ and 95% CI = 19–25)). BayesAss identified an approximately 65-fold difference in absolute migration rates ($m_{w \leftarrow e} = 0.327 \pm 0.006$; $m_{e \leftarrow w} = 0.0051 \pm 0.042$), which mirrors the large difference in estimated census numbers of Eastern versus Western gray whales.

4. Discussion

Gray whales that summer in the Western Pacific are of major conservation concern [2]. Previous studies [4,9] have revealed modest genetic differences between Eastern and Western gray whales, but no obvious structure within a sampling locale. Our SNP data provide additional resolution showing that each substock is found in both the Eastern and Western Pacific (figure 2*a*,*b*), but we identified no further substocks. Despite the 100-fold population size difference, whales sampled from the Eastern Pacific were more homogeneous than those from the Western Pacific (figure 2*a*,*b*; electronic supplementary material, S7 and S8). This likely reflects that admixed individuals in the Western Pacific inflate the similarity index more so than in the Eastern Pacific owing to their relative frequencies (i.e. overall population sizes).

Our analyses identified admixed individuals (figure 2*b*) and some overlap between the two substocks (figure 2*a*), patterns likely driven by introgression [7,8,31]. Migration was most pronounced into the Western Pacific, where the two substocks were found in a ratio of 2 : 1. The high degree of gene flow ($N_e m \gg 1$) into the Western Pacific stock could be sufficient to prevent loss of genetic diversity but might eventually homogenize the gene pool. The whales from the Eastern Pacific had marginally lower heterozygosities and nominally higher inbreeding than those sampled in the Western Pacific (electronic supplementary material, S2), but these minor statistical deviations may reflect a modest ascertainment bias rather than true biological differences, given that the markers were originally developed from Western Pacific samples [13].

Our SNP data show that despite mid-Holocene population declines [4], commercial whaling [5,6] and a prolonged bottleneck, the critically endangered Western gray whale is still genetically diverse at functionally important loci. These results confirm earlier microsatellite and mitochondrial DNA studies of a few presumptively neutral markers [9,10], but extend those data using genic SNPs that identify admixed individuals and mixed-stock aggregations on both sides of the Pacific. Overall, these data indicate that current population structure is not determined by simple geography and may be in flux owing to migratory dynamics [7,8]. Our findings have conservation implications (e.g. how future IUCN designations are formulated), but also provide a contemporary snapshot into the evolutionary phenomenon of divergence with gene flow that appears to be an integral part of rorqual evolution [31].

Ethics. Russian and Mexican field research was approved by the Ethics Committee of the National Scientific Center of Marine Biology of the Far East Branch of the Russian Academy of Science and by the Subsecretaria de Gestion Para La Protection Ambiental of the Mexican Direcion General de Vida Silvestre, respectively. US research on marine mammal samples collected abroad by foreign colleagues falls under the authority of NOAA and requires a US MMPA permit as well as the proper CITES permits for import and export of the samples. Russian and Mexican collaborators obtained proper research permits, which covered ethical considerations for the collection of samples. Thus, all relevant US and international permits were secured for this research. National Marine Fisheries Service Office of Protected Resources' Marine Mammal Health and Stranding Response Program permit 93-1905-MA-009526. CITES permit 13US082589/9, 13RU00580, MX89451 and MX71396.

Data accessibility. SNP genotypes have been uploaded to the Dryad Digital Repository: http://dx.doi.org/10.5061/dryad.954ht26 [15].

Authors' contributions. A.B.-O. and J.A.D. conceived the work and planned the research design. J.U.R., V.V.V., C.A.J.G.-C. and J.W.B. initiated the study, conducted/supervised fieldwork and secured permits. A.B.-O. genotyped samples and performed all analyses. All authors wrote the manuscript, critically revised it, approved the final version and agree to be held accountable for the content herein.

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Competing interests. The authors declare that they have no competing interests.

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BMC Evolutionary Biology

RESEARCH ARTICLE Open Access

The inference of gray whale (Eschrichtius robustus) historical population attributes from whole-genome sequences

Anna Brüniche-Olsen[1*], Rick Westerman[2], Zuzanna Kazmierczyk[3], Vladimir V. Vertyankin[4], Celine Godard-Codding[5], John W. Bickham[6] and J. Andrew DeWoody[1]

Abstract

Background: Commercial whaling caused extensive demographic declines in many great whale species, including gray whales that were extirpated from the Atlantic Ocean and dramatically reduced in the Pacific Ocean. The Eastern Pacific gray whale has recovered since the 1982 ban on commercial whaling, but the Western Pacific gray whale—once considered possibly extinct—consists of only about 200 individuals and is considered critically endangered by some international authorities. Herein, we use whole-genome sequencing to investigate the demographic history of gray whales from the Pacific and use environmental niche modelling to make predictions about future gene flow.

Results: Our sequencing efforts and habitat niche modelling indicate that: i) western gray whale effective population sizes have declined since the last glacial maximum; ii) contemporary gray whale genomes, both eastern and western, harbor less autosomal nucleotide diversity than most other marine mammals and megafauna; iii) the extent of inbreeding, as measured by autozygosity, is greater in the Western Pacific than in the Eastern Pacific populations; and iv) future climate change is expected to open new migratory routes for gray whales.

Conclusion: Our results indicate that gray whale genomes contain low nucleotide diversity and have been subject to both historical and recent inbreeding. Population sizes over the last million years likely peaked about 25,000 years before present and have declined since then. Our niche modelling suggests that novel migratory routes may develop within the next century and if so this could help retain overall genetic diversity, which is essential for adaption and successful recovery in light of global environmental change and past exploitation.

Keywords: Admixture, Relatedness, Runs-of-homozygosity, Cetacean, Demographic history

Background

Widespread commercial whaling during the last two centuries unsustainably harvested many whale populations [1]. Whale products such as oil, meat, blubber, and ambergris were commercially important and overharvesting greatly diminished many whale populations [2–5]. In 1982 the International Whaling Commission (IWC) instituted a moratorium on commercial whaling (https://iwc.int/commercial), and although some whale populations have since recovered to near their pre-whaling abundance, others remain compromised. Recent, anthropogenic bottlenecks due to commercial whaling can be contrasted with more ancient, natural bottlenecks often associated with climate and/or ecological change [3].

Great whales are important for marine ecosystems, as they facilitate nutrient transfer in the water column and stabilize ecosystems by increasing biodiversity [6]. Whales are associated with areas of high primary productivity, and their sensitivity to environmental changes make them prime indicators of ecological perturbations [7]. The marine ecosystem is rapidly changing due to anthropogenic impacts [8–10], most of which have unknown

* Correspondence: abruenic@purdue.edu
[1]Department of Forestry & Natural Resources, Purdue University, West Lafayette, IN 47905, USA
Full list of author information is available at the end of the article

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consequences for the future of marine environments and marine mammals [11, 12]. Scientists are just beginning to understand how large marine mammals have responded to past climatic cycles [13–15], and models predict that range and distribution patterns will shift towards the poles in the face of global warming [16].

One species severely affected by commercial whaling is the gray whale (Eschrichtius robustus). Gray whales were once common in the Northern hemisphere, but were extirpated from the Atlantic ocean by the early eighteenth century [17], potentially due to environmental change and/or by commercial whaling [2, 18]. Today, gray whales are found in the Eastern Pacific near the coast of North America and the Western Pacific near the coast of Asia (Fig. 1). There is evidence of gene flow between the two "stocks", but there is also statistically detectable genetic differentiation between them [2, 19]. The eastern gray whale (EGW) population has been extensively studied, and post-whaling estimates based on genetic and ecological data indicate there are ~ 27,000 individuals [19–21]. In contrast, data on the western population is limited [22, 23]. Commercial whaling lasted considerably longer in the western Pacific [24], and today the western gray whale (WGW) is thought to be comprised of < 200 individuals and is listed as 'critically endangered' by the International Union for Conservation of Nature (IUCN) [25, 26].

During the late Pleistocene and Holocene (i.e., within the last ~ 100,000 years), the Northern hemisphere experienced massive changes to its marine ecosystems [27]. Glacial periods led to ice cap oscillations that repeatedly opened and closed migration corridors [28–30], and fluctuations in water temperature and sea levels likely forced changes to habitats and feeding modes [2, 3]. Gray whale carrying capacities have been modelled based on shifts in feeding habitat during the last 120,000 years, and those data suggest that multiple demographic bottlenecks may have occurred [3]. In addition to the trophic data, DNA sequences suggest that the EGW population has been subject to a genetic bottleneck during the last century [20]. Although population fluctuations have not been investigated in the WGW, microsatellite and mitochondrial data suggest that the two populations have similar levels of neutral

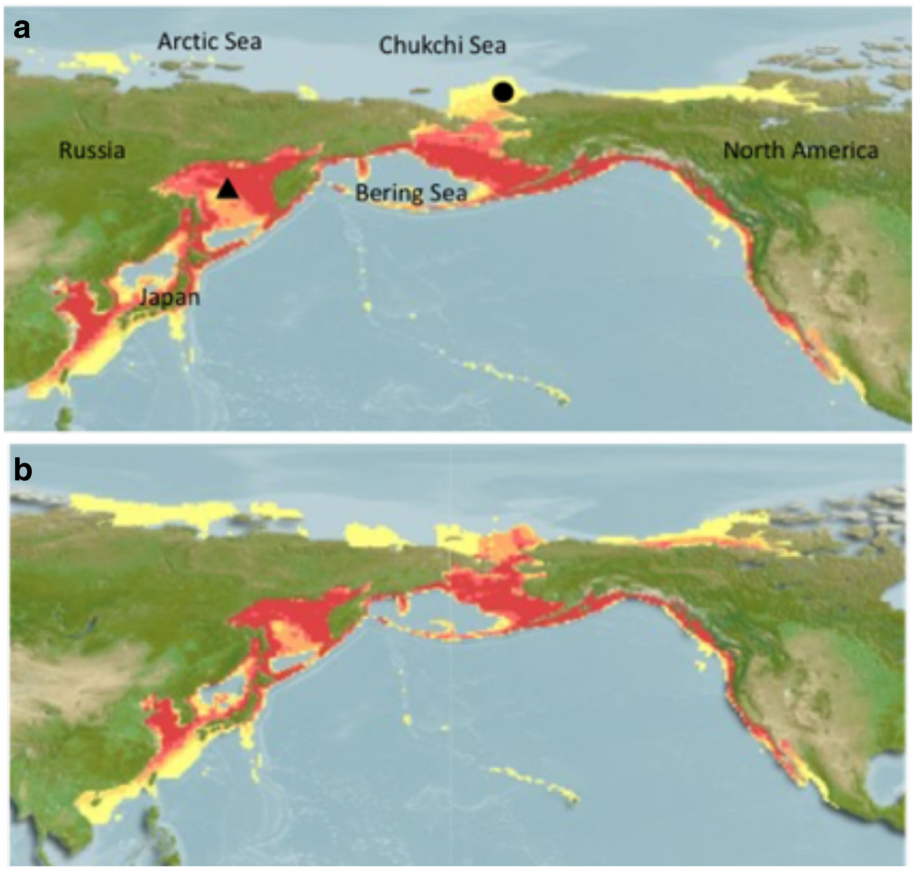

Fig. 1 Environmental niche modelling of (**a**) current and (**b**) future (year 2100) suitable habitat for gray whales in the Pacific Ocean. Colours depict the habitat suitability ranging from low (yellow) to high (red). Shapes represent sampling locations for the putative western grey whales (triangle) and eastern grey whales (circle). Feeding grounds are located at higher latitudes, whereas breeding grounds are at lower latitudes

genetic diversity and thus may have similar long-term demographic histories [2, 19].

The ongoing reductions in the extent of sea ice provide gray whales with new potential migration routes and they may be shifting their range farther north in the Arctic [31]. Gray whales have responded to climate changes by shifting the timing of their southbound migration [32]. Because they annually migrate thousands of kilometres from their summer feeding grounds at high latitudes to their winter calving waters at lower latitudes, there may be opportunities for contemporary (i.e., within the last few dozen generations) gene flow between eastern and western Pacific populations (Fig. 1). There are indications of historical (referring to the Pleistocene and early Holocene) gene flow between Atlantic and Pacific gray whales [2], and—more recently—a satellite-tagged WGW has been tracked to an EGW wintering area near the Mexican coast [22]. Furthermore, photographic identification has documented individual gray whales moving between the western Pacific (near Sakhalin Island, Russia) and the eastern Pacific [26]. Collectively, these data suggest that the currently recognized WGW and EGW "populations" of this highly vagile species are not completely independent (i.e., gene flow is possible). Fortunately, population attributes such as historical demography, admixture (i.e., interbreeding between populations that have previously been isolated), and genetic diversity can now be addressed using whole genome sequences [33–35]. The ability to make population inferences from one or a few samples is especially important for rare species, where sampling efforts are often difficult, expensive, and should be minimized because of conservation concerns.

Herein, we employ genomic and computational techniques to infer population attributes of gray whales. The distribution of gray whales is largely disjunct today, but these geographic isolates were demographically and genetically connected in the past (as evidenced by the fact that they are recognized as a single species). Given the recent growth of the EGW population and ongoing climate change, there is reason to suspect that increased gene flow between EGW and WGW may occur in the future. We are interested in the long-term demographic trajectory of gray whales, both from a historical and a future perspective. Given the critically endangered status of the WGW, we were interested in comparing genomes of the WGW and the EGW to investigate levels of genetic diversity as a key component of adaptive potential. We used coalescent-based approaches to retrospectively gauge ancient admixture in gray whale genomes during the Pleistocene, and measures of autozygosity to directly assess inbreeding and search for signals of contemporary differentiation. Our habitat prediction models suggest that novel migratory routes may develop within the next century, which could influence the overall retention of genetic diversity in the species. This study presents the first genomic comparison of gray whales, and extends our insights into the molecular diversity and demographic history of this enigmatic species while contributing to our understanding of how our ocean's great whales have responded to historical climate change.

Methods

Sampling, sequencing and SNP calling

We used previously published whole genome DNA sequences from DeWoody et al. [36]. These sequences were derived from two gray whales sampled near Sakhalin Island, Russia, designated WGW1 (female) and WGW2 (male), and from one putative Eastern gray whale female (EGW) that was beached near Barrow, Alaska (Fig. 1). There is some uncertainty as to true population affinities of these individual gray whales. For example, WGW1 was biopsied near Sakhalin Island in the western Pacific but the same whale has been photographically identified in the eastern Pacific (Laguna San Ignacio; M. Scott, unpublished data). Nevertheless, we assigned geographical names to whales based on sampling locations in order to be comparable with previous genetic work on gray whales [2, 19, 37]. The data utilized herein consisted of 2x100bp paired-end (PE) libraries from each whale (~ 1 billion reads per individual; ~ 700 million high-quality reads per individual after quality-control; Additional file 1: Table S1). For detailed sampling and genome sequencing methodology see DeWoody et al. [36]. For a summary of number of reads per individual and quality control effects, see Additional file 1: Table S1.

We used FASTQC v0.11.2 (www.bioinformatics.babraham.ac.uk/projects/fastqc) to generate summary statistics for the sequencing reads. TRIMMOMATIC v0.32 [38] was used to remove adaptor sequences and trim low quality bases (< 20 Phred scores) from both the 5′ and 3′ end of each read. BWA v0.7.12 [39] was used to map the PE reads to the published genome of the common minke whale (*B. acutorostrata*) (GenBank accession: SAMN02192642, [40]) using the 'bwtsw' function that indexes whole genomes, and the 'mem' function for mapping. PICARD-TOOLS v2.0.1 (http://broadinstitute.github.io/picard/.) was employed to mark duplicate reads. SAMTOOLS v1.3 [41] was used for alignment manipulation. Local realignment, duplicate removal, and SNP variant calling were carried out with GATK v3.5 [42] following 'Best Practices protocol' [43, 44]. Genotypes were called across all three samples together using the 'gvcf' option. We used a minimum base quality score of 20 (which corresponds to a base calling error rate of ~ 1% [45]) with a minimum mapping quality score of 20. In the downstream analyses, we only used SNPs with minimum 20× coverage, which should help minimize

the number of heterozygotes falsely scored as homozygotes [46, 47]. Eight minke whale scaffolds are X-linked [48], and we removed gray whale reads that mapped to these scaffolds so they would not bias our downstream analyses. None of our gray whale reads mapped to Y-linked scaffolds because [48] reported none in their minke genome assembly.

Genetic diversity

Nucleotide diversity can be used to assess ancient admixture as well as contemporary differentiation [34, 49, 50]. We estimated observed heterozygosity for each individual, θ_{genome}, based on the number of heterozygous sites / total number of sites where only sites with minimum 20× coverage were considered. We used θ values associated with each individual to independently estimate equilibrium effective population sizes (N_e) following $\theta = 4N_e\mu$ [51]. To quantify differences in N_e we compared θ among individuals, assuming that substitution rates do not vary appreciably across samples.

We directly quantified inbreeding levels by identifying the number and lengths of autosomal runs-of-homozygosity (ROHs) in each individual. A ROH is a genomic region that contains far less nucleotide variation than expected based on the genome–wide average for an individual [52]. Under random mating, the length of ROH regions is expected to decrease with increasing number of generations to the 'most recent common ancestor' (MRCA) due to recombination and de novo mutations. In contrast, with inbreeding—as is often the case for critically endangered species—autozygosity is expected to increase over time, thus increasing the number and length of ROHs in the genome each generation. Analysis of ROH abundance and extent thus provides information on a population's demographic history and on the genetic relationships among individuals [53].

We estimated four different ROH parameters: i) number of ROHs in each genome (N_{ROH}); ii) the mean length of ROHs (L_{ROH}); iii) the heterozygosity outside ROHs (θ_{noROH}); and iv) the inbreeding coefficient F_{ROH}, the overall proportion of the genome contained in ROHs. We estimated θ_{noROH} as the number of heterozygous SNPs / (total number of SNPs – SNPs in ROHs). When F_{ROH} is compared to θ_{genome}, it quantifies the effect of inbreeding on overall levels of genomic variation. To compare our results directly to patterns of ROHs found in other species [54], we used PLINK v1.90b3.36 [55] and defined ROHs as portions of the genome that spanned at least 20 homozygous sites allowing for a single heterozygous SNP (e.g., due to de novo mutation) and 1 missing SNP (e.g., a site with missing data) following Howrigan et al. [56]. We searched the genomes for ROHs in consecutive 20 SNP sliding windows and, to facilitate detecting both short and long ROHs, we set the lower bound for ROHs to 1 kb. We used a Welch two-sample t-test to test for pairwise differences in L_{ROH} among individuals whereas pairwise ROH frequency distributions were compared among all three gray whales using a two-sample Kolmogorov–Smirnov test. All statistical tests were conducted in R [57].

Relatedness and population structure

We used PLINK to measure relatedness among individuals. Pairwise identical-by-state (IBS) comparisons were estimated based on the ratio of probabilities between a heterozygote–heterozygote site, $p(\text{HetHet}) = 4p^2q^2$, to the probability of a homozygote–homozygote site, $p(\text{HomHom}) = p^2q^2$. For each pair of individuals, the number of variable sites where they share no alleles (IBS = 0; e.g., discordant homozygotes AA/BB and BB/AA) are counted along with the number of sites where they share two alleles (IBS = 2) (e.g., heterozygotes AB/AB, BA/BA). On average, we expect this probability ratio to be 1:2 if the pair comes from a randomly mating population [55, 58]. A 'HetHet': HomHom' ratio > 2 suggests that the individuals are more related than expected by chance, and a HetHet': HomHom' ratio < 2 suggests that the individuals have recent ancestry from different random mating populations. We used the 'pairwise population concordance' (PPC) test to evaluate if this probability ratio significantly deviated from the expected ratio under random mating, applying a significance level of 0.05, a minor allele frequency (MAF) of 0.01, and a minimum distance of 500 k base pairs between informative SNPs to limit the effects of linkage disequilibrium (LD).

Ancient admixture

To test for ancient admixture, we used the ABBA–BABA *D*-statistic test implemented in ANGSD v0.912 [34, 59]. The *D*-statistic tests for admixture between four individuals: two conspecific individuals (P1 and P2), a potential introgressor (P3), and an outgroup (O). At each polymorphic site in the genome the relationship among these four individuals and the topology of the species tree is compared. Sites that are inconsistent with the species tree are the sites where P2 shares a derived allele with P3 but not P1 (ABBA sites) or P1 shares derived sites with P3 but not P2 (BABA sites). An excess of either ABBA or BABA sites, compared to the sites supporting the species tree (i.e., AABB), is an indication of admixture between P2 and P3 or between P1 and P3, respectively. In the absence of ancient population structure, incomplete lineage sorting is the only process other than admixture that produces inconsistency with the species tree topology, but incomplete lineage sorting is expected to produce ABBA and BABA sites in an equal ratio [49, 50]. The *D*–test statistic evaluates the number (n) of ABBA and BABA sites ($D = (n\text{ABBA} - n\text{BABA})$ /

(nABBA + nBABA)) and $D < 0$ means that P1 is more closely related to P3 than to P2, whereas $D > 0$ indicates that P2 is more closely related to P3 than P1. The significance of the D test was evaluated with a Z-score, where $|Z\text{-scores}| > 3$ was used as the critical value for a significant test [50]. As an outgroup, we used the common minke whale. The phylogenetic relationships among baleen whales are not completely resolved [60, 61], but the common minke whale is the closest relative with a published genome sequence [62]. We used an LD block size of 10 Mb; increasing the block size (e.g., 20 Mb, 30 Mb) did not change the outcome of the ABBA-BABA test. We tested all scaffolds > 10 Mb in length in order to obtain a reliable Z-score. Admixture D-statistics were considered significant for $|Z\text{-scores}| > 3$.

Inference of demographic history

We used the PSMC' mode implemented in MSMC [33, 63] to infer ancient demographic histories. Eleven scaffolds larger than 30 Mb in length, corresponding to a total of ~ 400 Mb, were used to improve the accuracy of inferring past recombination events [33, 64]. We ran the MSMC analysis for each individual separately using default settings; 20 iterations and averaging over 30 time segments. To quantify the variance in N_e we bootstrapped using the same MSMC settings. For each individual, 20 bootstrapped datasets were generated by randomly sampling 5 Mb sequences from each of the 11 scaffolds used to trace the mean N_e. Substitution rates—for both mitochondria and nuclear loci—are reportedly 8–10 fold slower in baleen whales than in other mammals [65, 66]. In order to convert θ to N_e over time, we applied an autosomal substitution rate of 4.8×10^{-10} bp^{-1} year^{-1} (credibility interval (CI): $1.5 \times 10^{-10} - 10 \times 10^{-10}$) [67], and a generation time of 18.9 years which corresponds to the midpoint of estimated generation times which range between 15.5 and 22.3 years [68, 69]. MSMC runs were assessed for convergence using the R package CODA [70].

Prediction of suitable habitat

We used AQUAMAPS [71] to predict the relative probability of the future gray whale distribution across the Northern Hemisphere based on contemporary local conditions. Suitable habitat was based on occurrence records available via Ocean Biogeographic Information System (http://www.iobis.org) using the contemporary environmental envelope settings suggested by Alter et al. [2] (Additional file 1: Table S2), and future (year 2100) envelope settings from AQUAMAPS [72]. We assumed that current environmental conditions are representative of the Holocene, as the Holocene climate has experienced relatively little variation compared to interglacial cycles [73].

Results

Genetic diversity

We mapped, from each individual, high-quality PE reads from one eastern and two western gray whales to the minke whale genome. The mean depth of coverage per individual ranged from 27× to 30× (Additional file 1: Table S1), and this relatively deep coverage allowed us to assess nucleotide diversity with confidence. The level of genetic diversity represented by theta (θ) was lower in the individuals from the Western population ($\theta = 6.69 \times 10^{-4}$ and 6.64×10^{-4}) relative to the individual from the putative Eastern population $\theta = 8.00 \times 10^{-4}$ (Fig. 2). Thus, there is about a 1.2-fold difference in genetic diversity between East and West.

Inbreeding

We found ROHs ranging from 1 to 559 Kb in length; few were longer than 300Kb (Fig. 3). Estimates of θ_{genome} and θ_{noROH} were lower in both WGWs than in the EGW (Table 1). The western individuals had fewer ROHs (WGW1: $n_{ROH} = 188{,}012$ and WGW2: $n_{ROH} = 126{,}893$) than the Eastern individual ($n_{ROH} = 263{,}877$), but their mean ROH length were significantly longer (WGW1: $L_{ROH} = 11$Kb and WGW2: $L_{ROH} = 17$Kb; both $p = 2.2 \times 10^{-16}$) than in the eastern individual (EGW: $L_{ROH} = 6$Kb). ROHs covered a larger proportion of the western gray whale genomes (WGW1: $T_{ROH} = 2.1 \times 10^6$ bp; WGW2: $T_{ROH} = 2.2 \times 10^6$ bp) compared to the eastern gray whale (EGW: $T_{ROH} = 1.6 \times 10^6$ bp) (Table 1). All individuals differed significantly from one another in L_{ROH} ($p = 2.2 \times 10^{-16}$), and the Kolmogorov–Smirnov test showed that the ROH distributions were significantly different from one another (WGW1 & EGW $D = 0.186$, $p = 2.2 \times 10^{-16}$; WGW2 & EGW $D = 0.322$, $p = 2.2 \times 10^{-16}$, and WGW1 & WGW2 $D = 0.142$ $p = 2.2 \times 10^{-16}$). This suggest that there are significant differences in genealogical histories between all individuals. Estimates of F_{ROH} were 0.088 (WGW1), 0.092 (WGW2), and 0.067 (EGW) and thus on average the WGWs were ~ 1.3 times as inbred as EGW.

Relatedness and population structure

To evaluate pairwise relatedness, we used the 'HetHet' to 'HomHom' ratios (where a ratio of 2.0 is expected for individuals from the same random mating population and a ratio > 2.0 suggests that the pair is more related to each other than expected based on chance alone). All pairwise comparisons yielded a 'HetHet' to 'HomHom' ratio ≥ 2 (Table 2), and the PPC test could not reject the null hypothesis: 'HetHet': HomHom' ratio = 2 (Table 2). Thus this test is uninformative as the three individuals may or may not belong to the same gene pool.

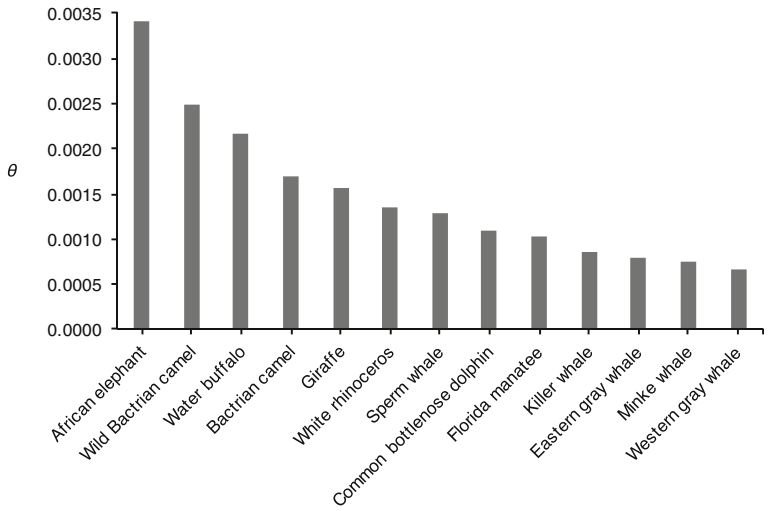

Fig. 2 Overview of nuclear genomic diversity (θ) in various cetaceans, marine mammals, and large herbivores. Data from the current study and Brüniche-Olsen et al. [54]. Mean θ is provided for the two western gray whales in this study

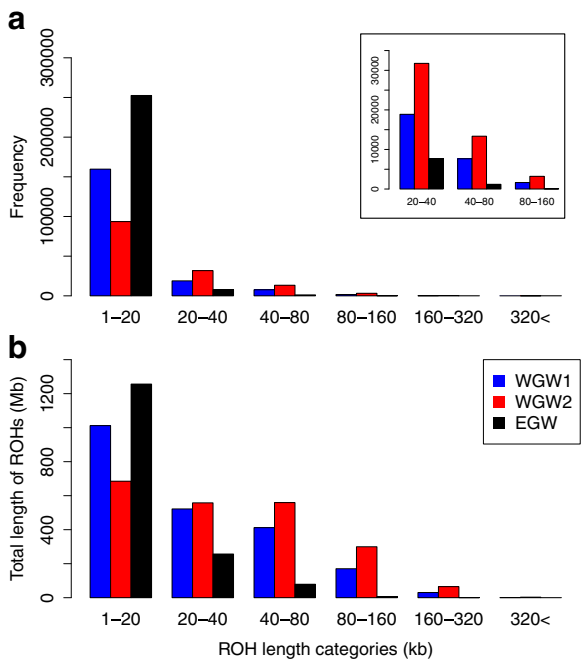

Fig. 3 Total number of runs of homozygosity (ROHs) and proportion of ROH size classes in sampled gray whale genomes. Shown for each individual is the number of ROHs in each size class (**a**), with an insert showing the 1-160Kb ROH length categories in detail) and the sum of ROH lengths (Mb) in the genome (**b**). A Kolmogorov–Smirnov test indicated that the pairwise comparisons of ROH frequency distributions between were significantly different from each other (WGW1 & EGW $D = 0.186$, $p = 2.2 \times 10^{-16}$; WGW2 & EGW $D = 0.322$, $p = 2.2 \times 10^{-16}$, and WGW1 & WGW2 $D = 0.142$ $p = 2.2 \times 10^{-16}$), suggesting that there are significant differences in genealogical histories between individuals

Ancient admixture

The ABBA–BABA test revealed no significant support for ancient admixture (e.g., historical panmixia) between the Western and Eastern gray whales (Fig. 4; Additional file 1: Table S3). If ABBA and BABA patterns are equally common, then in theory $D = 0$ and the data are consistent with the tree. Deviations where $D \neq 0$ can be due to: i) P3 exchanged genes with P1 or P2; ii) ancestral population (P1, P2 and P3's founder) structure leading to discordant gene trees; or iii) P1 or P2 could have received genes from an unsampled 'ghost' population (Pg). The test is not influenced by demographic events assuming that P1, P2 and P3's ancestral population was panmictic [49], which should be a reasonable assumption for gray whales [2].

Inference of long-term demographic history

We traced effective population size estimates over the last ~ 1,000,000 years using the PSMC' method (Fig. 5; Additional file 1: Figure S1). The three individuals exhibit very consistent trajectories, indicating a step decline in N_e from $N_e > 50{,}000$ in the interval of ~ 1,000,000 years before present (YBP) until 100,000 YBP followed by a more stable period (~ 100,000–30,000 YBP) with N_e ~ 25,000 for both EGW and WGW populations. Prior to the LGM both populations increase in size to N_e ~ 45,000; hereafter a reduction in N_e to a population size of N_e~ 20,000 is observed in all three trajectories. These consistent results among individuals suggest there is relatively little noise in this PSMC' analysis and that the trajectories themselves are likely a realistic representation of historical population dynamics. Furthermore, the most recent estimate of census population size (N_c) of the EGW is 27,000 [21]. The concordance between N_c and

Table 1 Summary statistics for the gray whales. Heterozygosity across the entire genome (θ_{genome}), heterozygosity excluding ROHs (θ_{noROH}), number of ROHs (N_{ROH}), mean ROH length (L_{ROH}), sum of ROH lengths (T_{ROH}), and inbreeding coefficient (F_{ROH}) in the gray whale autosome. All results are based on sites with depth of coverage ≥20×. A genome size of 2.4Gb was used for calculating F_{ROH}

Sample	θ_{genome}	θ_{noROH}	N_{ROH}	L_{ROH} (×10^3nt)	T_{ROH} (×10^6nt)	F_{ROH}
WGW1	6.69×10^{-4}	6.79×10^{-4}	188,012	11.4 (16.0)	2.1	0.088
WGW2	6.64×10^{-4}	6.74×10^{-4}	126,893	17.1 (22.7)	2.2	0.092
EGW	8.00×10^{-4}	8.11×10^{-4}	263,877	6.1 (6.8)	1.6	0.067

recent N_e estimates (Fig. 5) suggests that the substitution rate we used (4.8×10^{-10} bp^{-1} year^{-1}) is a reasonable approximation of the true genome-wide substitution rate.

Predictions of suitable habitat

Our environmental niche modelling suggests that current habitat suitability is relatively high from Taiwan to Kamchatka through much of the Bering Sea and along the coast of North America to the Gulf of California (Fig. 1a). Currently marginal habitat, which is expected to improve in the future due to ongoing climate change, includes the Arctic and Chukchi Seas (Fig. 1b).

Discussion

Anthropogenic factors are rapidly changing the global environment. We think that predictions regarding future biological impacts (e.g., species range shifts) are most informative when presented in a historical context. Genomic data have great potential in this regard as they can be used as a window to the past (e.g., the reconstruction of past demographic histories) and into the future (e.g., by identifying genes expected to face particular selection pressures, such as those related to thermoregulation). Using whole genome data from contemporary eastern and western gray whale populations, we quantified genetic diversity in gray whales and inferred key population attributes that bear on their evolution and conservation.

Table 2 Relatedness and population clustering. Estimates are based on PLINK genotype calls where the 'identical by state' (IBS) genotype pattern was estimated for a pair of samples and the test for population clustering was conducted using pairwise population concordance (PPC). The genotype pattern for each variable site is estimated as the sharing of two ancestral alleles, one ancestral and one derived allele, and two derived alleles between the individuals. The IBS ratios indicate that all pairs (ratios > 2.0) are more related than expected under random mating. The PPC results indicate we cannot reject the null hypothesis (ratio = 2) that all three individuals belong to the same population ($p = 0.05$)

Pair	HomHom	HetHet	Ratio	PPC
WGW1 & WGW2	1533	4377	2.9	1.00
WGW1 & EGW	1384	4513	3.3	1.00
WGW2 & EGW	1572	4252	2.7	1.00

Genetic diversity and inbreeding

The genome-wide heterozygosity in gray whales is similar to the minke whale, but lower than other marine mammals—e.g., sperm whales (*Physeter catodon*), common bottlenose dolphin (*Tursiops truncatus*), killer whales (*Orcinus orca*), and manatees (*Trichechus manatus latirostris*)—and considerably lower than terrestrial megafauna (i.e., African elephant (*Loxodonta africana*), camels (*Camelus bactrianus* and *C. ferus*), white rhinoceros (*Ceratotherium simum*)) (Fig. 2). We expect that the variation in θ may be explained in part by differences in body size; larger animals have slower mutation rates, longer generation times, and produce fewer offspring—all factors that impact θ [74, 75]. Gray whales are the largest of the mammals surveyed here, which could partly explain their low genomic diversity, but population declines over the last ~ 20,000 years (Fig. 5) may also be a significant contributing factor.

Reduced genomic diversity is a concern as it constrains adaptive potential [76]. We observed lower θ_{genome} and θ_{noROH} in western than eastern gray whales (Table 1), likely due to the smaller size of the western population compared to the eastern population. Small population sizes and reduced gene flow will lead to increased inbreeding that has the potential to reduce reproductive fitness due to homozygosity of deleterious recessive alleles and to reduced heterosis. The extent of ROHs in a genome is correlated with population size reductions and increased consanguinity [52, 53]. Our data indicate that, consistent with contemporary population sizes, ROHs significantly reduce overall nucleotide variation in the gray whale genome (Table 1). The timing and duration of bottlenecks are directly associated with the extent of ROHs; i.e., recent inbreeding leads to long ROHs whereas ancient inbreeding persists in the genome as shorter ROHs that have been disrupted by mutation and recombination [77, 78]. The eastern gray whale had more but shorter ROHs than the western gray whales (Table 1, Fig. 3). This is not surprising given that the eastern population is ~ 100× larger and has not experienced extensive recent inbreeding [20]. In contrast, the western gray whale individuals had fewer but longer ROHs and a larger proportion of their genomes in ROHs (Table 1), a pattern that can be produced by a continuous small population size or a genetic bottleneck

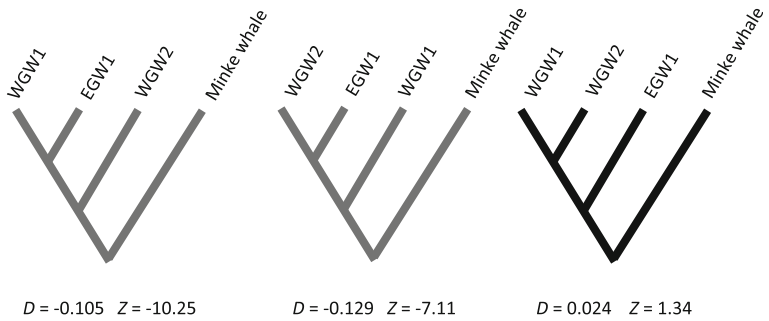

Fig. 4 Results from the ABBA-BABA tests for different possible topologies among gray whales from the eastern and western populations when using the common minke whale as the outgroup. The *D*-statistic for each topology is considered statistically significant, meaning the topology can be rejected, if the associated standard score (|*Z*|) has an absolute value > 3. The two gray topologies were both rejected (|*Z*| > 3), but the black topology could not be rejected (|*Z*| < 3). This indicates that the signal of contemporary genomic structure we detected among geographic populations is stronger than the signal of historical admixture. WGW, western gray whale. EGW, eastern gray whale

that persists for multiple generations [53]. The small size of the western population (< 200 individuals) may not only have led to loss of genetic diversity, but also the loss of adaptive potential in the face of impending environmental change [8–10].

Relatedness, gene flow and geographical isolates

Gray whales are one of the most vagile species on earth; telemetry and photographic data indicate that some individuals annually move thousands of kilometres across the Pacific [22, 26]. This contemporary movement of individuals between eastern and western populations provides opportunities for gene flow. Furthermore, our niche modelling suggests that gray whales from the east and from the west could encounter the same suitable habitat (Fig. 1b). However, despite the potential overlap in suitable habitat and the known movement of individuals between the populations, their genomes significantly differ in terms of homozygosity (Fig. 3). Thus the ROH data are consistent with previous reports of population structure between eastern and western gray whales [2, 19]. However the PPC test could not reject the null hypothesis of random mating (Table 2; $p = 1.00$) and the relatedness analysis showed that the EGW was more closely related to both of the WGWs than expected by chance. These PPC and relatedness results are consistent with an earlier relatedness analysis based on 88 gene-associated SNPs, which found the EGW was no more or less related to the WGW population than expected on the basis of chance alone [36].

During the Pleistocene, climate-dependent dispersal occurred between the Pacific and Atlantic gray whale

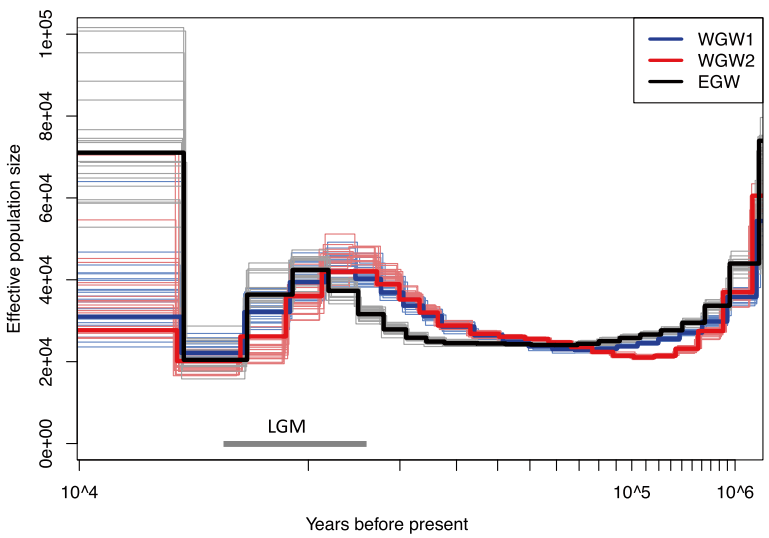

Fig. 5 Estimated historical effective population sizes (N_e) for western (red and blue) and eastern (black) gray whales. Thick lines represent the median N_e and thin light lines of the same colour represent 20 iterations of bootstrap sampling. Estimates represent averages based on 11 autosome scaffolds larger than 30 Mb. An estimated mutation rate of 4.8×10^{-10} bp^{-1} year^{-1} and a mean generation time of 18.9 years were used in these PSMC' analyses. The last glacial maximum (LGM) is indicated with a gray bar

populations; prior to the last glacial period (110,000–11,700 YBP) and after the opening of the Bering Strait, gray whales migrated between the Pacific and Atlantic oceans [2]. Analyses of mitochondrial sequences have documented haplotype sharing between the eastern and western populations, suggesting that recent maternal gene flow has occurred during the Holocene [2]. In 2010, a Pacific gray whale was observed in the Mediterranean Sea, a sighting which produced speculation that climate-induced shrinking of the Arctic Sea ice may ultimately enable gray whales to recolonize the Atlantic [79]. Thus, although gene flow between the western and eastern populations has no doubt occurred multiple times since the Pleistocene, the signal of contemporary genomic structure we detected between geographic populations is stronger than the signal of historical admixture (Fig. 4). For all *D*–test statistics we found the two WGWs to be more closely related to each other than either was to the EGW (Additional file 1: Table S3), although we could not reject the hypothesis that the individuals belong to the same randomly mating population (Table 2).

Dating and severity of population decline (s)

The dating of population size changes is inexact due to errors in the estimation of mutation rates and generation times, but genetic datasets are nevertheless often highly concordant with independent datasets (e.g., fossil evidence; [80, 81]). Demographic histories inferred from single whole genome sequences trace from the two haplotypes to their coalescence in the MRCA. This means that the most recent past is not well resolved, and if unphased haplotypes are used—as done in this study—this also affects deep (past) resolution [63]. Thus, our PSMC' analyses are unlikely to recover any Anthropocene population size changes associated with commercial whaling, as any genetic signal this may have left is much too recent for this method to detect. That said, trajectories of N_e over the last ~1,000,000 years are highly consistent with one another and suggest a similar demographic history in each lineage (Fig. 5). Pre-whaling eastern gray whale census population size (N_c) has been estimated at 96,000 (CI: 76,000–118,000) individuals based on nuclear microsatellites [67], whereas mitochondrial DNA sequences [20] yield N_c estimates of 100,670 (90% HPD: 59,940–111,550). These N_c estimates correspond to N_e of ~32,000 (CI: 25,000–39,000) for microsatellites, and N_e ~17,000 (90% HPD: 10,000–19,000) for mitochondrial DNA, which is similar to our post LGM N_e estimate ~20,000 (Fig. 5). These differences among studies may illustrate that using a subset of genomic markers does not accurately capture overall genomic diversity perhaps because of the ascertainment bias associated with the selection of highly polymorphic markers such as microsatellites [82].

Our data suggest an ancient population decline during previous ice ages and a more recent decline in the last ~25,000 years (Fig. 5). Glacial periods are often associated with population declines, and the large shifts in climate have impacted both terrestrial [83, 84] and marine mammals [85–88]. Taken together with the evidence for contemporary bottlenecks—occurring around the time of commercial whaling [20]—these results support population models which indicate multiple bottlenecks have occurred in gray whales [3]. Cumulatively, these bottlenecks may have contributed to the relative paucity of genetic diversity observed in gray whales (Fig. 2).

Western gray whales (WGWs)

We were particularly interested in tracing the demographic history and quantifying genetic diversity within the WGW because of its conservation status. We found that WGWs had increased autozygosity (higher F_{ROH}) and lower θ_{genome} (Table 2) compared to the eastern gray whale, both of which would be expected in a small inbred population [52]. However, despite having a more than 100–fold difference in census population size, the genomic differences were modest as N_e only differed 1.2 fold between the two geographic populations. The observed ROH patterns suggest that the western population has experienced population size reduction and an elevated level of inbreeding relative to the eastern individual (Fig. 3). These ROH patterns likely result from recent processes (e.g., inbreeding and drift) as opposed to a long-term small population size, which should be reflected in the Pleistocene N_e (Fig. 5). The small population size and low genetic diversity limit the potential evolutionary responses to future environmental change, and thus ongoing efforts to conserve the WGW are critical. Our samples sizes are large in terms of number of genetic loci, but small in terms of individual animals. Future studies will reveal whether the patterns we observe herein are indicative of the species as a whole.

Conclusion

Whole genome sequencing of cetaceans provides new insights into how these enigmatic animals have responded to past and ongoing changes in the marine environment. Herein, we present the first genome-scale study of gray whale demographic history. Our results show that gray whales from the eastern and western Pacific have low genetic diversity, that the past gray whale population (s) was much larger and experienced multiple declines since the Pleistocene, and that there is some evidence of geographic structuring between the populations. Ecological predictions for the year 2100 suggest the current habitat of gray whales in the Pacific Ocean is

unlikely to decrease while their former habitat in the Atlantic Ocean could expand with global warming [2]. Combined with decreasing sea ice cover in the Arctic, this expanding habitat could provide gray whales with opportunities to use alternative migration routes that could genetically bind east and west [31] but only time will tell how anthropogenic effects, genetic drift, inbreeding, and climate change will impact the population viability of gray whales over the long-term.

Additional file

Additional file 1: Table S1. Information on raw reads filtering statistics. Paired-end libraries were sequenced on an Illumina HiSeq 2500. **Table S2.** Environmental variables used in AQUAMAPS to generate maps of suitable habitat for gray whales during the Holocene. **Table S3.** The *D*–test statistic evaluates the number (*n*) of ABBA and BABA sites ($D = (n\text{ABBA} - n\text{BABA}) / (n\text{ABBA} + n\text{BABA})$) and $D < 0$ means that P1 is more closely related to P3 than to P2, whereas $D > 0$ indicates that P2 is more closely related to P3 than P1. The significance of the *D* test was evaluated with a *Z*-score, where $|Z\text{-scores}| > 3$ was used as the critical value for a significant test. **Figure S1.** Inferred effective population sizes (N_e) over time. Estimates are averages based on 11 autosomal scaffolds larger than 30 Mb. A substitution rate of a) 10×10^{-10} bp^{-1} year^{-1} and b) 1.5×10^{-10} bp^{-1} year^{-1} were used. (DOCX 446 kb)

Abbreviations

CI: credibility interval; EGW: eastern gray whale; F_{ROH}: inbreeding coefficient; IBS: identical-by-state; IUCN: International Union for Conservation of Nature; IWC: International Whaling Commission; LD: linkage disequilibrium; LGM: Last Glacial Maximum; MAF: mean length of ROHs (L_{ROH}) minor allele frequency; MRCA: most recent common ancestor; N_e: effective population sizes; N_{ROH}: number of ROHs; O: outgroup; P1; P2: conspecific individuals; P3: potential introgressor; PPC: Pairwise population concordance test; ROH: runs-of-homozygosity; WGW: western gray whale; YBP: years before present; θ: theta; θ_{genome}: observed heterozygosity; θ_{noROH}: heterozygosity outside ROHs

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Availability of data and materials

Genome data were from Genbank acc. No. SRR5495100, SRR5495104, and SRR5495108.

Authors' contributions

ABO and JAD conceived the work and planned the research design; JWB, VVV and CGC helped obtain funding, requisite permits, and samples; RW, ZK and ABO analysed the data. ABO and JAD wrote the manuscript with input and insights from JWB, VVV, and CGC. All authors approved the final version of the manuscript.

Ethics approval and consent to participate

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author details

[1]Department of Forestry & Natural Resources, Purdue University, West Lafayette, IN 47905, USA. [2]Department of Horticulture & Landscape Architecture, Purdue University, West Lafayette, IN 47907, USA. [3]School of Forensic and Applied Sciences, University of Central Lancashire Preston, Preston PR1 2HE, UK. [4]Kronotsky State Nature Biosphere Reserve, Elizovo, Kamchatka 684010, Russia. [5]The Institute of Environmental and Human Health, Department of Environmental Toxicology, Texas Tech University, 1207 Gilbert Drive, Lubbock, TX 79409, USA. [6]Department of Wildlife & Fisheries Sciences, Texas A&M University, College Station, TX 77843, USA.

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Population Structure of Sakhalin Gray Whales (*Eschrichtius robustus*) Revealed by DNA Sequences of Four mtDNA Genes

Vladimir A. Brykov, Kseniya V. Efimova, Anna Brüniche-Olsen, J. Andrew DeWoody, and John W. Bickham

Abstract

Two stocks of gray whales (*Escrichtius robustus*), eastern and western, traditionally were considered to inhabit the North Pacific Ocean. The western gray whale migration was along the coast of Asia between summering grounds in the Sea of Okhotsk and wintering grounds presumed to be in the South China Sea. The eastern gray whale migration was along the coast of North America between summering grounds mainly in the Bering and Chukchi Seas and wintering grounds in the coastal lagoons of Baja, Mexico. The status of the current population of gray whales that summers in the Sea of Okhotsk, mainly near Sakhalin Island, Russia, is of uncertain affinity because the western stock previously was considered extinct, some members of the Sakhalin population are known to winter in Mexico, and an Asian wintering ground for this species has never been precisely located. A previously published analysis of 84 nuclear loci showed the Sakhalin population to be a mixed-stock aggregation comprised of animals with distinct "eastern" and "western" SNP genotypes. In the study reported here, a mitochondrial DNA (mtDNA) analysis of Sakhalin gray whales was conducted using control region and three protein coding gene sequences to test if animals with "western" genotypes might be descendants of the western stock. It was postulated that such a population would likely have distinct mtDNA haplotype lineages as observed in other marine mammals sundered in the North Pacific Ocean basin. From the mtDNA sequence data, haplotype networks were generated separately for the control region and the concatenated protein sequences. No clades of related haplotypes were found among the "western" genotype animals in either haplotype network. This is not consistent with long-term isolation during the Pleistocene as seen in many other marine mammals with similar distributions. Rather, the "western" and "eastern" genotypes likely have diverged recently, possibly since the end of commercial whaling in the early 20th century, but more likely post-Pleistocene.

Key words: gene flow, genetic structure, migration, western gray whales

АННОТАЦИЯ

Традиционно считалось, что в северной части Тихого океана обитают две популяции серых китов (*Escrichtius robustus*): восточная и западная. Западная популяция серых китов мигрирует вдоль побережья Азии между летними участками нагула в Охотском море и предполагаемыми зимними участками нагула в Южно-Китайском море. Миграция восточной популяции серых китов происходит вдоль побережья Северной Америки между летними участками нагула, преимущественно в Беринговом и Чукотском морях, и зимними участками нагула в прибрежных лагунах мексиканского штата Баха. Принадлежность существующей популяции серых китов, находящихся в течение летнего сезона в Охотском море, преимущественно у о. Сахалин, не установлена, так как ранее западное стадо

считалось вымершим. При этом известно, что некоторые особи сахалинской популяции зимуют у побережья Мексики, а участки зимнего нагула данного вида в азиатском регионе никогда не были точно определены. Опубликованные ранее исследования по 84 ядерным локусам показали, что сахалинская популяция представляет собой смешанную популяционную группировку с отличающимися «восточными» и «западными» SNP-генотипами. Для проверки возможности происхождения животных с «западными» генотипами от животных западного стада нами проведен анализ митохондриальной ДНК (мтДНК) сахалинских серых китов с использованием контрольного региона и 3-х белок-кодирующих последовательностей. Предполагалось, что подобная популяция, по всей вероятности, имеет характерную гаплотипическую родословную мтДНК, как и в случае с другими видами морских млекопитающих, обитающих в водах северной части Тихого океана. По данным последовательностей мтДНК были построены гаплотипические сети отдельно для контрольного региона и отдельно на основе объединенных последовательностей белок-кодирующих генов. Ни в одной из гаплотипических сетей среди особей западного стада не было выявлено специфических «западных» гаплотипов , что противоречит гипотезе о долговременной изоляции в период плейстоцена, характерной для ряда других морских млекопитающих с аналогичными распределениями. Скорее всего, «западные» и «восточные» генотипы разошлись недавно; и это могло произойти после завершения китобойного промысла в начале XX века, однако более вероятным представляется разделение в пост-плейстоцен.

Ключевые слова: генетическая структура, генный поток, западная популяция серых китов, миграция

INTRODUCTION

In 2010, a satellite tag was placed on "Flex", a male gray whale summering in the Sea of Okhotsk near Sakhalin Island, Russia (Fig. 1) in order to track him to the unknown western North Pacific wintering grounds thought to be in the South China Sea. On 12 December 2010, Flex instead was tracked from Sakhalin to the coast of North America. In 2011, transmitters were placed on two females, "Agent" and "Varvara," that were feeding off of Sakhalin Island. Both were tracked travelling towards the east, and Varvara was tracked from Sakhalin to the eastern gray whale wintering grounds in the coastal lagoons of Baja California, Mexico, and then back to the Sea of Okhotsk (Mate et al. 2015). The study of Mate et al. (2015) was a landmark in gray whale science because it immediately upended the conventional wisdom of decades of North Pacific (NP) gray whale research. Specifically, it had been assumed two populations, or stocks, of gray whales are found in the North Pacific: western gray whales (WGWs) that migrate along the Asian coast between summering grounds in the Sea of Okhotsk and wintering grounds somewhere in Asia; and eastern gray whales (EGW) that migrate between summering grounds mainly in the Bering and Chukchi Seas and wintering grounds in Mexico. The result has been an exhaustive reappraisal of gray whale stock structure hypotheses, including a 5-year "Rangewide Review of the Population Structure and Status of North Pacific Gray Whales" (Rangewide Review) conducted by the Scientific Committee of the International Whaling Commission (IWC) (IWC 2014, 2018).

North Pacific gray whales were hunted extensively during the 1800's and early 1900's by commercial whalers. WGWs were hunted primarily by Korean and Japanese whalers in the first half of the 20th century (Rice and Wolman 1971; Brownell and Chun 1977). EGWs were hunted by United States and Canadian whalers, and the independence of the two stocks was established based on presumed geographic isolation across the NP Ocean basin, and because hunting pressure on one population did not impact the other. This

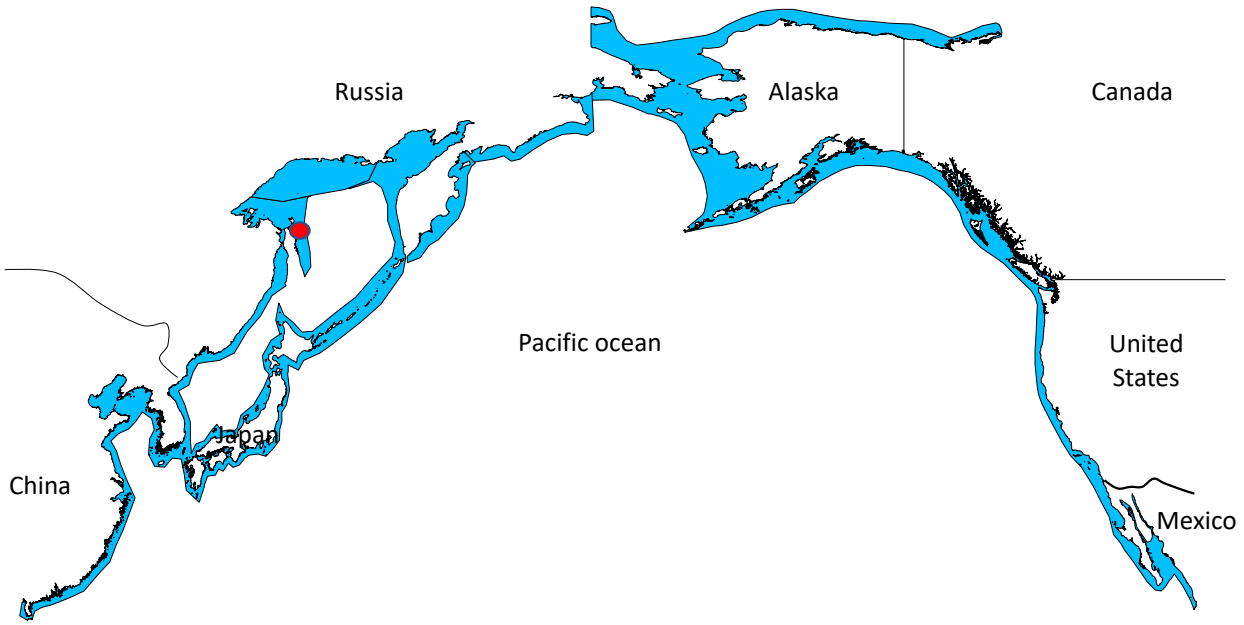

Figure 1. Distribution of North Pacific gray whales. Habitat range is shown with blue shade and sampling location for western gray whales off Sakhalin Island is shown with a red dot. This map is redrawn from the IUCN range map (https://www.iucnredlist.org/species/8097/50353881).

is explained in the report of the first IWC Rangewide Review (IWC 2014, p. 11) which states, "Brownell reported that the large catches (>1,750 gray whales) by Japanese modern whalers in the East Sea of Korea from 1890–1966, but mainly in the first third of the 20th century (Kato and Kasuya 2002), came at a time when the population of gray whales in the eastern Pacific was seriously depleted as a result of 19th century whaling. This mismatch in the timing of peak catches in the eastern and western North Pacific is consistent with the hypothesis of separate populations." This conclusion is corroborated by the historical catch data summarized in Appendix A of Bradford (2003). The Asian harvest was so great that by 1966 the WGW was considered by some to be extinct (Bowen 1974; Weller et al. 2002). However, this opinion was not shared by Brownell and Chun (1977) who documented sporadic sightings of gray whales in Asian waters during the early and mid-20th century. Nonetheless, the conclusion of Brownell and Chun (1977: p. 238) was as follows: "Therefore, we believe the western Pacific stock of gray whales will become extinct in the near future unless meaningful international protection is achieved." In the late 1960s and the 1970s, some gray whales were sighted in the Sea of Okhotsk, South China Sea, and the Sea of Japan (Omura 1974), and gray whales were observed in waters northeast of Sakhalin Island in the 1980s (Blokhin et al. 1985). It was assumed that the Sakhalin whales were surviving WGWs, and the population was estimated to be 100–200 individuals by Berzin and Yablokov (1978, cited in Ilyashenko 2011). While both WGW and EGW populations were hunted to near extinction, the EGW population has rebounded and now numbers approximately 27,000 (Durban et al. 2017), a number which exceeds most estimates of pre-whaling abundance (Henderson 1984). Based on photo-identification studies of the gray whales feeding off Sakhalin Island and the southern and eastern coasts of Kamchatka, the WGW population is estimated to consist of 320–410 individuals (Cooke et al. 2017) and is considered endangered by the IUCN (Cooke 2018).

The historical concept of separate stocks of gray whales on the eastern and western sides of the NP Ocean basin was supported by the catch data mentioned above, as well as genetics studies based on mtDNA and nuclear microsatellites (LeDuc et al. 2002; Lang et al. 2011). A similar biogeographic track is shared with some other marine mammals also possessing genetically differentiated eastern and western populations in the NP, such as Steller sea lions (*Eumetopias jubatus*) (Bickham et al. 1996; Baker et al. 2005; Harlin-Cognato

et al. 2006). However, recent genetic studies as well as the results of the IWC's 5-year Rangewide Review (IWC 2018) are indicative of alternative, plausible, stock-structure hypotheses. In a genetics study based on single nucleotide polymorphisms (SNPs, *n*=84 loci; Brüniche-Olsen et al. 2018a), Sakhalin gray whales were shown to comprise a mixed-stock aggregation containing individuals with either of two distinct genotypes as well as admixed individuals. Previous studies that have suggested dispersal between the eastern and western North Pacific within the last 10 ky based on mtDNA (Alter et al. 2015) are consistent with this. These distinct genotypes, as well as admixed genotypes, also were possessed by whales sampled at the EGW wintering grounds in Mexico but at substantially different frequencies. A "western" genotype was predominant in the Sakhalin population and an "eastern" genotype was predominant in Mexico. While it is tempting to assume that these two genotypes are representative of the historical EGW and WGW populations, the "western" genotype whales are of uncertain origin. Are these the descendants of the WGWs that migrated along the Asian coast that were previously believed to have been hunted to extinction? Alternatively, the "western" genotype whales might be a distinct subpopulation of EGW that has differentiated genetically because of a founder effect and/or genetic drift in a small population, a concept considered as plausible by the IWC's Rangewide Review (IWC 2018). Sakhalin whales with either of the "western" and "eastern" genotypes, as well as mixed, are known to migrate to Mexico. In this group are included reproductive females of both "eastern" and "western" genotypes (M. J. Scott, unpublished observations). Given the long migration between the Sea of Okhotsk and Mexico, and the fact that mating in gray whales takes place during the fall migration, within-group matings for the Sakhalin population might be a higher probability than outbreeding with EGWs who mainly begin the fall migration from the Bering and Chukchi Seas.

To determine if the Sakhalin whales with "western" genotypes are the descendants of the WGWs requires a different approach than simply estimating a statistically significant F_{ST} as was observed in the early studies that compared EGW and WGW samples (LeDuc et al. 2002; Lang et al. 2011). In those studies, it was established that the overall population of whales near Sakhalin have different microsatellite allele and mtDNA haplotype frequencies than EGWs. However, that is not informative about the historical identities of the whales that currently summer off the coast of Sakhalin. Moreover, the presence of the two distinct SNP genotypes in the Sakhalin population was not known at the time of those early studies, so all Sakhalin whales were grouped together for analyses.

In this paper the following question is posed: Are the gray whales that currently summer off the coast of Sakhalin Island descendants of WGWs that migrated along the Asian coast? This question is addressed by sequencing four mtDNA genes from Sakhalin gray whales characterized as having "eastern", "western", or admixed nuclear SNP genotypes. These data are used to test hypotheses of the historical origin of the Sakhalin whales. The null hypothesis is that the "western" and "eastern" genotypes detected with SNPs (Brüniche-Olsen et al. 2018a) differ as a result of long-term isolation of two populations on either side of the North Pacific Ocean during the Pleistocene, i.e., the traditionally recognized WGW and EGW stocks. A trans-NP distribution is shared with other marine mammals, fish, and even terrestrial organisms. This was illustrated by Harlin-Cognato et al. (2006) who studied the phylogeography of Steller sea lions in this region and stated that "Congruence in the distribution of genetic diversity for a wide variety of plants and animals suggests glacial vicariance shaped the history of these species in a similar fashion." If this is the case for NP gray whales, then one would expect to see clades of related haplotypes in the phylogeny of NP gray whales with some clades unique to the Sakhalin population, and more specifically to animals with "western" genotypes. Note that if the Sakhalin "western" genotype whales are the descendants of the WGWs, they represent WGWs that have dispersed into the EGW population (at least those that migrate to Mexico; it is unknown if all or only part of the Sakhalin whales migrate to Mexico; IWC 2018).

The alternative hypothesis is that the "western" and "eastern" genotypes have originated as a result of recent dispersal of EGW into the Sea of Okhotsk, with subsequent divergence due to founder effect and/or drift. Although the isolation between these two genotypes might pre-date commercial whaling and be on the order of hundreds or a few thousands of years (i.e., post-Pleistocene), or possibly following the near-

extirpation of the WGW stock in the 20th century, it would not show the degree of strong differentiation including clades of related haplotypes expected of populations isolated on opposite sides of an ocean basin through the Pleistocene. In the case of recent dispersal, haplotypes would be expected to be shared among the "eastern" and "western" genotype whales, but with different frequencies, and no clades of haplotypes unique to the "western" genome animals. Also, one would not expect to find many, if any, unique haplotypes with such recent divergence, but the small sample size of "eastern" genotype whales in this study prevents unique haplotypes from being a meaningful metric. It is implicit that the extinction of the WGW, or simply their absence from the samples because they are not found at Sakhalin, is what prevents the observation of clades of related haplotypes.

In order to test the two hypotheses of gray whale population structure, extended mtDNA sequences including the non-coding control region as well as three protein-coding genes (*COI*, *Cyt b*, and *ND2*) were produced from 65 Sakhalin gray whales. Previous studies of Sakhalin gray whale mtDNA have included only control region (LeDuc et al. 2002; Lang et al. 2011) or multiple mtDNA genes (Meschersky et al. 2015) and have shown no evidence of unique haplotype lineages in the Sakhalin whales. However, those studies predated Brüniche-Olsen et al. (2018a) and thus a mixed sample of "eastern" genotype and "western" genotype whales likely were included. MtDNA divergence, analyzed separately using the control region alone and using an extended sequence of three protein coding genes, was estimated for "eastern" and "western" genotype whales sampled near Sakhalin.

MATERIALS AND METHODS

A total of 75 skin samples of gray whales was obtained by the remote biopsy method in accordance with permission of the Russian Federal Supervisory Natural Resources Management Service (Rosprirodnadzor) along the coast of Sakhalin Island, Pil'tun Bay in August–September of 2012 (16 samples), 2013 (8 samples), 2014 (27 samples), 2015 (9 samples), and 2016 (15 samples). A total of 65 individual gray whales are represented among these samples as determined by unique SNP genotypes and photographic identification (Brüniche-Olsen et al. 2018a).

The tissues were stored in ethanol and shipped to the Laboratory of Genetics, National Scientific Center of Marine Biology, Far East Branch of the Russian Academy of Sciences (NSCMB FEB RAS, Vladivostok, Russia). Total genomic DNA was extracted using the standard phenol-chloroform method (Sambrook et al. 1989) or with a NucleoSpin® Tissue Kit (MACHEREY-NAGEL GmbH & Co.). Amplifications were performed using the DreamTaq DNA polymerase (Thermo Fisher Science, USA). The primers and conditions described by Alter et al. (2009) were used to amplify 621 base pairs of the mtDNA control region (CR) (including tRNA-Pro). The full 1,153 base pair sequence of the cytochrome *b* (Cyt*b)* gene was obtained using overlapping pairs of primers developed by the Laboratory of Genetics, GW-CYTB F 5'- TACCATTAACCCCAGAAACGAACCAC -3' and GW-CYTB R 5'- GAGTCTTAGGGAGGTGTGGTTTGTCT -3'; and GW-CYTB F2 5'- ATGGGTCTGAGGCGGTTTTTCTGTAG -3' and GW-CYTB R2 5'- GAAGTGGAAGGCAAAGAAGCGTGTTA -3'. The following pair of primers was selected for the subunit 2 of the NADH dehydrogenase gene (*ND2*): CET_ND2_F (5'-CATACCCCGAAAATGTTGGT-3') and CET_ND2_R (5'-TAGGGCTTTGAAGGCTCTTG-3') described in Meschersky et al. (2015), combined to produce a 1,058 base pair amplicon. Amplification conditions for Cyt*b* and *ND2* were as follows: denaturation at 95°C - 3 minutes, followed by 37 cycles at 95°C - 30 sec, annealing of primers at 54°C - 60 se., chain extension at 72°C - 90 sec, and final extension at 72°C - 5 minutes. The cytochrome oxidase I (COI) gene fragment with a length of 650 base pairs was amplified using the primers that were also developed by the Laboratory of Genetics, GW-COI F 5'- ACCTACTCGGCCATCTTACCTA -3' and GW-COI R 5'- AAGCCTAAGAACCCGATGGATA -3'. Amplicons were subsequently purified using Exonuclease I (Exo I) and Shrimp Alkaline Phosphatase (rSAP) (New England Biolabs). The sequencing reactions were performed using BigDye Terminator v. 3.1 kit (Perkin-Elmer, Foster City, California, USA) in accordance with the manufacturer's recommendations. Capillary electrophoresis was performed using the automated ABI Prism GA3500 Genetic Analyzer

using a 50 cm capillary assembly with POP-7 polymer. Sequences were assembled using the Geneious R11 software (v11.0.3, Biomatters Limited, Auckland, New Zealand). The similarity of the obtained sequences to those of other available sequences in GenBank was determined by a BLASTn search (Altschul et al. 1990). Sequence data were deposited in GenBank under accession numbers: MH046943-MH047185, MH064256–MH064334.

CLUSTALW (Thompson et al. 1994) was used for sequence alignment. We analyzed the control region and a concatenation of the three protein coding sequences separately. Summary statistics and demographic change parameters were calculated with DNASP v5.10.1 (Librado and Rozas 2009). Genetic diversity was quantified as the number of haplotypes (h), haplotype diversity (h_{div}), the number of segregating sites (S), average number of nucleotide differences (k), and nucleotide diversity (π). Demographic changes were quantified with Tajima's D (Tajima 1989) and Fu's F (Fu 1997).

POPART (Leigh 2015) was used to construct neighbor joining networks for each of the alignments. Genetic differentiation was measured using the fixation metric G_{ST} (Hedrick 2005) and differentiation metrics φ_{ST} (Excoffier et al. 1992; Meirmans 2006) and D (Jost 2008). These were estimated in R (Team 2017) using ADEGENET v2.1.1 (Jombart 2008) and MMOD v1.3.3 (Winter 2012). Estimates and 95% CI across all loci for G_{ST}, φ_{ST} and D were based on 100 bootstraps replicates to identify variation across each point estimate. Fisher's exact test using 1,000 repetitions was used to test for allelic differentiation among subpopulations.

Of the 65 individuals, 46 were previously genotyped at 84 autosomal SNP loci (Brüniche-Olsen et al. 2018a). Genetic admixture coefficients (Q) results from Brüniche-Olsen et al. (2018a) were used to divide the dataset into three groups: "eastern", admixed or "western". The Q-values were estimated with LEA (Frichot and François 2015), which is similar to Bayesian clustering programs like STRUCTURE (Pritchard et al. 2000), where individual admixture coefficients are estimated from the genotypic matrix. The 46 individuals were grouped according to the following Q-values: eastern ($Q < 0.200$), admixed ($0.200 < Q < 0.800$), and western ($Q > 0.800$) for the summary statistics, demographic change and network analyses. Only individuals classified as "eastern" and "western" were included in the G_{ST}, φ_{ST} and D analyses. Our justification for using the LEA Q-values is based on the fact that independent LEA and STRUCTURE analyses produced highly similar results despite these two methods being based on different algorithms. In the LEA program, estimates of ancestry coefficients are calculated using least-squares estimates, whereas in STRUCTURE a likelihood model is used to calculate them. LEA and STRUCTURE were shown to produce similar results (Frichot et al. 2014), but LEA performed better under certain conditions. Specifically, the performance of LEA was better than that of the binomial model used by STRUCTURE where there are high levels of inbreeding, which appears to be the case in Sakhalin gray whales (Brüniche-Olsen et al. 2018b). Only a few individuals would have been assigned to different groups had the values based on the STRUCTURE analysis been used instead.

RESULTS

Of the 65 individuals, the control region (621 bp) was amplified for 64, and the protein coding regions (2,833 bp) were amplified for all individuals. There were 19 individuals with control region and protein coding regions sequenced for which SNP genotypes are not available. These are included in the haplotype networks (see Figs. 2 and 3) but not in Table 1. Variation in sample sizes from 5–32 individuals among the "western" genotype, "eastern" genotype, and admixed groups, respectively, are shown in Table 1. A total of 14 haplotypes were observed in the control region; of these, 9 were found in the "western" genotype group, 4 in the "eastern" genotype group, and 2 in the admixed group (Table 1a). Furthermore, the "western" genotype group was shown to have higher h_{div}, S and higher π than the eastern and admixed groups. Overall, no sign of demographic change was found for the entire dataset or in the "western" and "eastern" genotype groups; only in the admixed group was an indication of a population decline ($F > 0$) shown. A similar pattern was shown in

Table 1. Summary statistics for a) the mitochondrial control region sequence (621 bp) of 45 Sakhalin gray whales with known SNP genomes, and b) the mitochondrial protein coding sequences (2,833 bp) of 46 Sakhalin gray whales with known SNP genomes are given. Determination of groups was based on individual ancestry coefficients (see main text for details). For each group the number of individuals (n), number of haplotypes (h), haplotype diversity (h_{div}), number of segregating sites (S), average number of nucleotide differences (k), nucleotide diversity (π), Tajima's D, and Fu's F are given.

	Group	*N*	*h*	h_{div}	*S*	*k*	π	*D*	*F*
a)	Western	32	9	0.774	32	9.6	0.018	1.53	0.97
	Eastern	8	4	0.643	22	7.1	0.012	-0.83	-0.82
	Admixed	5	2	0.600	16	9.6	0.015	1.83	1.96*
	All	45	14	0.763	33	9.3	0.018	1.06	0.49
b)	Western	32	11	0.802	27	7.3	0.0036	0.31	-0.69
	Eastern	9	6	0.833	18	4.0	0.0014	-1.94*	-2.40*
	Admixed	5	3	0.800	13	7.6	0.0027	1.58	1.68
	All	46	18	0.808	29	6.6	0.0024	0.28	-0.28

* denotes $p < 0.05$

the summary statistics for the protein coding regions with the "western" haplotype group having more haplotypes ("western" h = 11, "eastern" h = 3, and admixed h = 3) and higher S and higher π than the "eastern" haplotype and admixed groups (Table 1b), but a lower h_{div}. A population expansion ($F < 0$) was identified in the "eastern" group, but none of the other groups showed indication of demographic change.

Two high-frequency haplotypes were observed in both networks (Figs. 2 and 3). In the control region, the high frequency haplotypes were represented by 69% of the individuals (Fig. 2). In the protein coding network, they were represented by 60% of the individuals (Fig. 3). For the control region, there was no indication of individuals identified as "western", "eastern" or admixed to cluster together (Fig. 2). A slight indication was shown of "western" individuals clustering in part of the protein-coding network (Fig. 3).

Measures of G_{ST}, φ_{ST}, and D between whales with "western" and "eastern" genomes based on Q-values were higher for the control region G_{ST} = 0.355 (95% CI: 0.008–0.702), φ_{ST} = 0.247 (95% CI: -0.142–0.635), and D = 0.273 (95% CI: 0.001–0.545), than the protein coding sequences G_{ST} = 0.129 (95% CI: -0.204–0.462), φ_{ST} = -0.044 (95% CI: -0.410–0.322), and D = 0.104 (95% CI: -0.178–0.386). Fisher's exact test, p = 0.034 for the control region and p = 0.013 for the protein coding sequences, were suggestive of our predefined groupings being genetically differentiated according to maternally inherited DNA sequences.

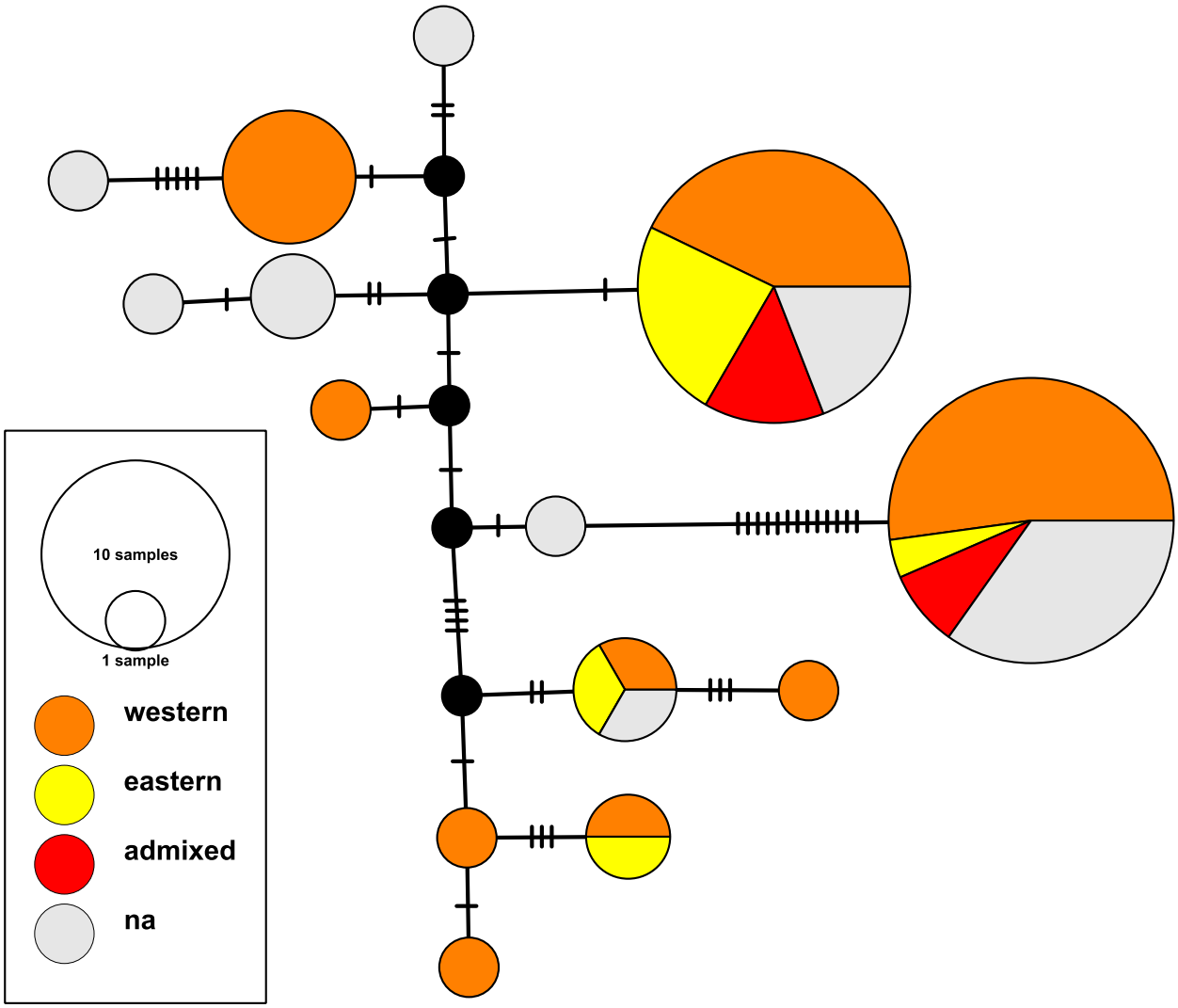

Figure 2. Haplotype network for the mitochondrial control region sequence. The haplotype frequency is indicated by the area of each circle and mutations are indicated on branches with hatch marks. The frequency of western (orange), eastern (yellow), and admixed (red) individuals based on autosomal SNPs (see main text for details) as well as individuals without autosomal SNP admixture coefficient information (gray) are indicated with color for each haplotype. Inferred haplotypes are represented by black dots.

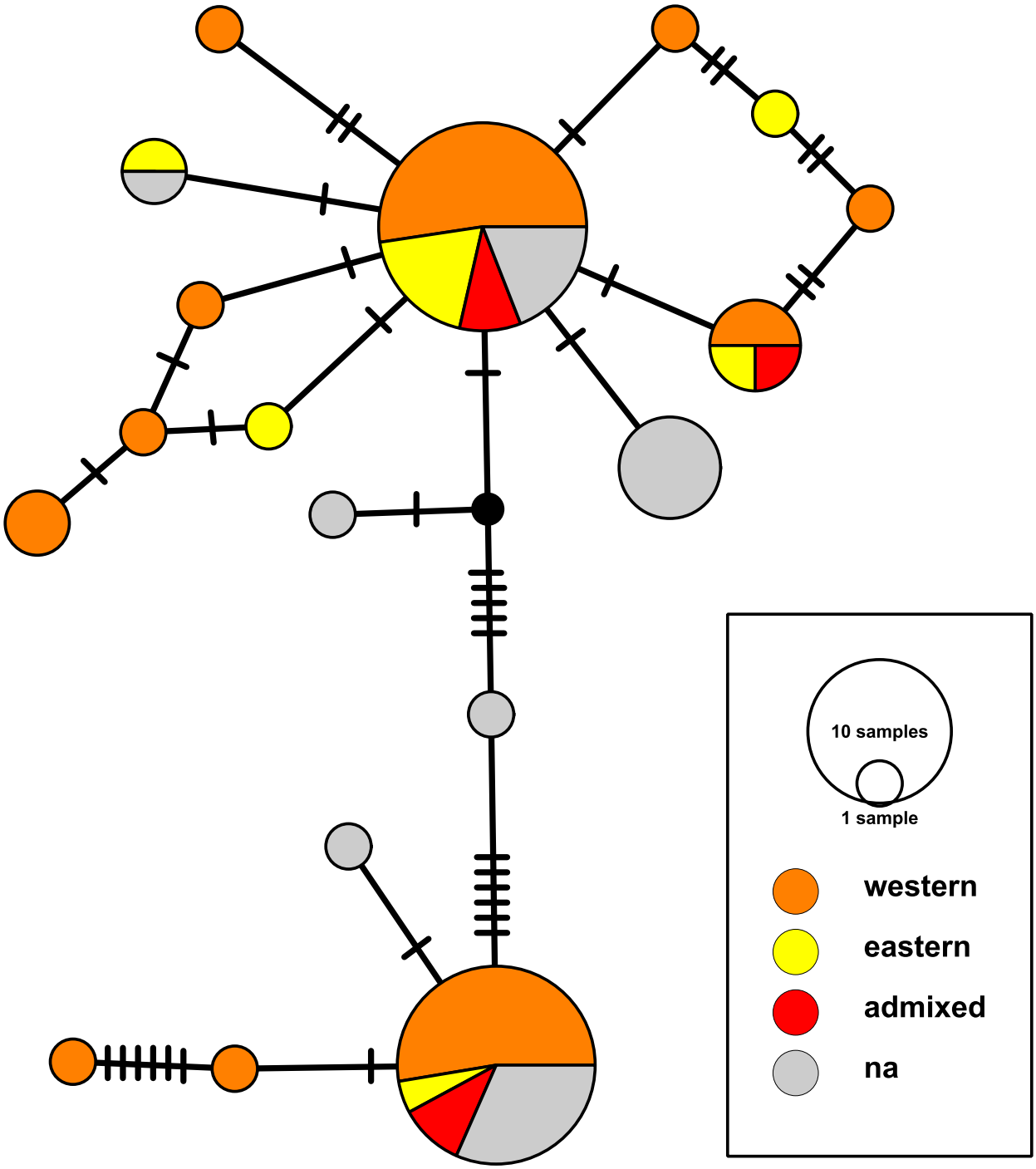

Figure 3. Haplotype network for the protein coding gene sequence. The haplotype frequency is indicated by the area of each circle and mutations are indicated on branches with hatch marks. The frequency of western (orange), eastern (yellow), and admixed (red) individuals based on autosomal SNPs (see main text for details) as well as individuals without autosomal SNP admixture coefficient information (gray) are indicated with color for each haplotype. Inferred haplotypes are represented by black dots.

DISCUSSION

Significant population structure in mtDNA sequences was revealed by Fisher's exact test for both the control region and protein coding genes. Thus, haplotype frequencies, whether identified by control region or protein coding sequences, were found to differ significantly between "eastern" and "western" genotype whales. This is indicative of the LEA scores measuring meaningful differences and that these two groups of whales likely have originated from different populations. The high degree to which there is ongoing or very recent gene flow (i.e., within a few generations) is indicated by the number of whales of admixed genotypes.

Measures of mtDNA diversity (*h, S, k, and* π) for both the control region and the protein coding genes are indicative of higher diversity in the "western" genotype whales compared to the "eastern" and admixed genotype whales (Table 1). However, limitations due to the small sample size of the "eastern" genome group that cause an underestimate of genetic variation in the very large EGW population, should be noted. Previous studies have shown higher mtDNA diversity for the EGW population than the small Sakhalin WGW population (LeDuc et al. 2002; Lang et al. 2011). More extensive sampling is needed to obtain better estimates of mtDNA diversity of the "eastern" and "western" genotype whales.

Haplotype networks for the control region and protein coding genes are shown in Figures 2 and 3, respectively. A comparison of the Figure 2 of this paper with Figure 3 in Lang et al. (2011), both of which are based on control region sequences, show that "western" genome whales from Sakhalin have haplotypes distributed throughout the network (Fig. 2), as does the larger sample of Sakhalin whales studied by Lang et al. (2011) but for which the SNP genotypes are not known. Haplotypes of "eastern" genotype animals also are found throughout the network in Figure 2, as are EGW haplotypes in Figure 3 of Lang et al. (2011).

The absence of any indication of a clade of similar haplotypes unique to the WGW in Lang et al. (2011) and in "western" genotype animals (Fig. 2) is consistent with the alternative hypothesis, that the "western" genotype whales are likely a subpopulation of the EGW population (i.e., not likely the descendants of the WGW population that migrated along the coast of Asia). It is also consistent with the mtDNA control region study of Alter et al. (2015), whose Figure 1 dates ostensible dispersal events between western and eastern Pacific gray whales to <10 kya. However, the hypervariable control region in mammals is known to be prone to extensive homoplasy in the form of recurrent substitutions at certain variable positions (Phillips et al. 2009). It was shown by Phillips et al. (2009) that accounting for the homoplastic substitutions is necessary to obtain a fully resolved haplotype network. To illustrate the significance of this, Phillips et al. (2011) were able to resolve ostensible long-range dispersal of Steller sea lions as being the result of homoplastic mutations, not dispersal. In this study, recurrent substitutions in the control region were not investigated, but it is likely that they are present, so the protein coding genes were analyzed separately. In the haplotype network shown in Figure 3, as in Figure 2, two common alleles that are distantly related are seen, and "western" genotype whales are found throughout the network. These patterns have been observed in all mtDNA studies of gray whales. An examination of Figure 1 in Meschersky et al. (2015), which is a haplotype network based on two protein coding genes and the control region, and the Figure 3 of this paper confirms this. Moreover, as shown in Figure 3, both "eastern" and "western" genotype whales are present in both of the distantly related common haplotypes. Therefore, there does not appear to be strong evidence of clades of related haplotypes that are specific to "western" genome whales, even with the extended three protein coding genes.

It is also useful to compare the phylogeographic patterns of gray whales to other baleen whales. While baleen whales often show distinct phylogeographic patterns including clades of related haplotypes in comparisons of populations between ocean basins (Archer et al. 2013; Jackson et al. 2014; Alter et al. 2015), comparisons within ocean basins, as in this study, might not show such a pattern due to the high vagility of and dispersal capability of these animals. For example, in neither the North Pacific right whale, *Eubalaena japonica*, nor the North Pacific humpback whale,

Megaptera novaeangliae, are clades of related haplotypes found in comparisons made between populations that are otherwise strongly differentiated by mtDNA haplotype frequencies (Baker et al. 2013; Pastene et al. 2013). Clearly, a long period of isolation is needed for the establishment of clades of related haplotypes, and in species with high dispersal capabilities inhabiting Oceans without strong geographic boundaries it is possible that gene flow prevents this. Then why should we expect WGWs and EGWs to have clades of related haplotypes?

One unique aspect of gray whale distribution is that it is tightly correlated with coastal habitats. This is because gray whales are adapted to feed mainly on benthic organisms found in relatively shallow waters, and it is the only baleen whale species to do this. Thus, the Steller sea lion, which is also more closely tied to shallow waters and coastal habitats, seems to be a better comparison than pelagic species of baleen whales. And secondly, in the studies conducted on right whales and humpback whales only mtDNA control region sequences were used. Thus, the problem of recurrent mutations that mimic gene flow might obfuscate the finding of clades of related haplotypes if such have ever been established. The bowhead whale (*Balaena mysticetus*) might be an example of this. Two populations of bowhead whales are found in the North Pacific Ocean, one that inhabits the Sea of Okhotsk and the other in the Bering, Chukchi, and Beaufort Seas (BCB). As with the gray whales, the bowhead population in the Sea of Okhotsk is very small and endangered, and the BCB population is large. Studies that employed only control region sequences (Alter et al. 2012 and references therein) found four haplotypes among 24 Sea of Okhotsk bowhead whales, all of which were shared with BCB whales. Baird et al. (2018) examined control region and two protein coding gene sequences from seven Sea of Okhotsk whales and a large number of BCB whales and found five haplotypes of which three were unique to the Sea of Okhotsk whales. Of these five haplotypes, no clear examples of clades of related haplotypes were found, although two haplotypes were found that were one step different; one being a shared haplotype and the tip haplotype unique. Also, the five haplotypes found in the Sea of Okhotsk are restricted to one part of the very large 141-haplotype network. Thus, examination of the extended sequence allows for a higher degree of resolution and a greater probability of finding clades of related haplotypes.

It should be recognized that this study is based on a small sample size, especially of the "eastern" genotype whales (N = 8). Thus, the results and conclusions can be considered as preliminary, but they nonetheless are the best indicators available of the historical relationships of gray whales currently summering at Sakhalin Island. When other lines of evidence are considered, namely that a sizeable number of Sakhalin whales have been confirmed to migrate to North American waters (Mate et al. 2015) and the number of gray whales observed in Asian waters south of the Sea of Okhotsk is small (Weller et al. 2008), the weight of evidence seems to be mounting that there is continuity in the gray whale gene pool, in contrast to the established view of discontinuity.

In conclusion, the analysis of mtDNA control region and three protein coding genes of gray whales summering near Sakhalin Island in the Sea of Okhotsk, Russia, failed to reveal the presence of clades of related haplotypes specific to the "western" genotype whales as identified by nuclear SNP loci. Rather, both "western" and "eastern" genotype animals had haplotypes found throughout the network. This is inconsistent with the null hypothesis of historical divergence (e.g., due to Pleistocene isolation) but consistent with the alternative hypothesis that the "western" and "eastern" genotypes originated as a result of recent dispersal of EGW into the Sea of Okhotsk. In the absence of archaeological or historical samples from the range of the WGW in Asia, further testing of this hypothesis is needed by employing larger sample sizes of Sakhalin whales. In particular, more whales with the minority "eastern" genome need to be analyzed. Other approaches to explore the historical demography of the "western" and "eastern" genotypes that can be applied to whole genome sequences as well as mitogenomic analyses need to be extended beyond the three whole genomes analyzed in Brüniche-Olsen et al. (2018b). The significance of this study is that the current mtDNA and nuclear SNP data suggest that the Sakhalin whales with "western" genotypes may simply be a geographical isolate of the larger EGW gene pool.

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Addresses of authors:

VLADIMIR A. BRYKOV

National Scientific Center for Marine Biology
Russian Academy of Sciences
Far Eastern Branch
Vladivostok, Russia
vlbrykov@mail.ru

KSENIYA V. EFIMOVA

National Scientific Center for Marine Biology
Russian Academy of Sciences
Far Eastern Branch
Vladivostok, Russia
xengen88@gmail.com

ANNA BRÜNICHE-OLSEN

Department of Forestry and Natural Resources
Purdue University
West Lafayette, IN 47907 USA
abruenio@pursue.edu

J. ANDREW DEWOODY

Departments of Forestry and Natural Resources
and Biological Sciences
Purdue University
West Lafayette, IN 47907 USA
dewoody@purdue.edu

JOHN W. BICKHAM

Department of Wildlife and Fisheries Sciences
Texas A&M University
College Station, TX 77843 USA
bickham@tamu.edu

Status of western gray whales off northeastern Sakhalin Island, Russia in 2011

ALEXANDER M. BURDIN[1], OLGA A. SYCHENKO[1], MAXIM M. SIDORENKO[2]

Contact e-mail: fewr@mac.com

[1] Kamchatka Branch of Pacific Institute of Geography, Far East Branch - Russian Academy of Sciences, Petropavlovsk, Kamchatka, RUSSIA

[2] Pacific Oceanological Institute, Far East Branch, Russian Academy of Sciences, Vladivostok, RUSSIA

ABSTRACT

The western gray whale population is critically endangered and its continued ability to survive is of concern. The most recent population assessment, using a Bayesian individually-based stage- structured model, resulted in a median 1+ (non-calf) estimate of 130 individuals (90% Bayesian CI = 120-142). The collaborative Russia-U.S. research program on western gray whales summering off northeastern Sakhalin Island, Russia, has been ongoing since 1995 and has produced important data that has be used to determine the conservation status of this critically endangered population. This paper reviews findings from 2011 research activities and combines such with data from previous years, in some cases ranging back to an opportunistic survey in 1994. Photo-identification research conducted off Sakhalin Island in 2011 resulted in the identification of 83 whales, including twelve calves and two previously unidentified non-calves. Three new reproductive females were recorded in 2011, resulting in a minimum of 29 females now known to have produced calves at some point during the study. When 2011 data are combined with results from 1994-2010, a catalog of 200 photo-identified individuals has been compiled. In 2010 and 2011, a satellite tagging study on gray whales off northeastern Sakhalin Island collected photo-identification images. With data use permission from the International Whaling Commission, these photographs were processed and incorporated into our photo-identification catalog, bringing the total number of identified whales to 205.

KEYWORDS: WESTERN GRAY WHALE; RUSSIA; POPULATION BIOLOGY; BEHAVIOR; CONSERVATION

INTRODUCTION

As with other species of baleen whales, gray whales annually migrate great distances from the breeding grounds in the subtropical waters to cold and productive northern regions. Two genetically separated populations of gray whales exist in the Eastern North Pacific region. The eastern (California-Chukchi) population is abundant (about 22,000 whales (Punt and Wade, 2010), breeds in the warm shallow lagoons off Baja California, and feeds in summer time in the Chukchi and Bering seas. The other population is the western (Korean-Okhotsk), which is extremely endangered numbering about 130 whales, including only 29 reproductive females producing calves once in about 2-3 years (Cooke, 2010).

Western gray whales travel for thousands of miles to feed on the abundant soft-bottom benthic communities in the western part of Bering and Okhotsk Seas. This feeding period is extremely important for these slow breeding whales, and any disturbance preventing, reducing or limiting feeding can potentially lead to stress in and compromise the health of these whales. The near-shore affinity of gray whales makes them particularly vulnerable to environmental fluctuations and anthropogenic activities. For the past decade, industrial development in the coastal waters of northeastern Sakhalin, namely oil and gas development and related exploration (including seismic surveys, offshore platform installation, pipeline construction, dredging, vessel traffic) became a cause for concern, especially since the oil and gas fields overlap with the primary feeding ground of western gray whales (Blokhin and Burdin, 2001; Gailey *et al.*, 2011). Many individual whales return annually to the same feeding sites off northeastern Sakhalin Island, indicating a site-specific dependence to this geographic area (Weller *et al*., 2007). This critically important habitat is especially vital for nursing females and their calves, as female energetic requirements are increased during lactation, and calves need to be ready to separate and begin to feed on their own.

The western gray whale population is critically endangered and its continued ability to survive is of concern (Weller *et al*., 2002a; Reilly *et al*., 2008). Hunted to such low numbers in the mid 20th century that some thought it to be extinct, the population remains highly depleted today (Weller *et al*., 2002a; Cooke *et al*., 2008). The International Whaling Commission (IWC) and the International Union for Conservation of Nature (IUCN) have each expressed serious concern about the status of this population and have called for urgent measures to be taken to help ensure its protection (see Reilly *et al*., 2008; IWC, 2004; Reeves *et al*., 2005).

Recent data obtained by a satellite tagged gray whale from Sakhalin Island (Mate *et al*. 2011), along with photo-identification matches (Weller *et al*., 2011), has shown that some whales migrate to Mexico to the well-known breeding grounds. But in November 2011, a female gray whale stranded in China in the Taiwan Strait area (Zhu, 2012). This record indicates some whales still inhabit the Asian coast, south from Korea. This novel information on gray mixing should stimulate further research on the gray whales coming to Russian waters during the summer because the number of the Korean-Okhotsk stock of gray whales may be even smaller than previously estimated (Weller *et al*., 2011).

This report reviews summary findings from 2011 research activities on western gray whales off Sakhalin Island in the Russian Far East and integrates new information with data from previous years, in some cases ranging back to 1994. Discussion of the current status of the population and a review of threats to its continued survival, including potential impacts associated with large-scale oil and gas development activities on the summer feeding ground and entrapments in trap nets off Japan during migration, are provided herein.

METHODS

The overall consistency in research design, data collection techniques and data analysis maintained in 2011 allowed inter-annual comparisons to be made. Additional information, collected during more limited surveys off Piltun in 1994 and 1995 (Brownell *et al.*, 1997; Weller *et al.*, 1999), is also presented here to better describe inter-annual trends and facilitate a long-term interpretation for some results. Data from these 1994 and 1995 studies include gray whale photographs obtained between 7-12 September 1994 during the filming of a wildlife documentary by H. Minakuchi (for description see Weller *et al*., 1999) and from 14-20 August 1995 during a pilot study to determine the feasibility of conducting boat- and shore-based research in the study area (Brownell *et al.,* 1997).

Study area

The study area is located near Zaliv Pil'tun (referred to as Piltun Lagoon) on the northeastern shore of Sakhalin Island, Russia (Fig 1). The lagoon is approximately 80-90 km long and 15 km across at its widest point. A single channel connecting the inner lagoon with the Okhotsk Sea occurs at 52° 50' N and 143° 20' E, and has considerable biological influence on the surrounding marine environment. A lighthouse, near the lagoon channel, served as the base from which studies reported here were conducted. The nearshore marine environment of the study site is mostly sand substrate, characterized by a gradually sloping and broad continental shelf. Water depths within 5 km of shore are mostly less than 25 m deep. Despite the similarity of Piltun Lagoon to the coastal lagoons used during the winter by eastern gray whales off Baja California, Mexico, whales do not enter this lagoon.

Photo-identification surveys

Gray whales have distinctive body markings, such as natural coloration and pigmentation patterns, as well as scars that are unique to an individual and can be used for individual recognition. Boat-based photo-identification surveys were conducted on all good weather days during the 2011 study period. Identical methodology was employed during each survey, with the primary objective of encountering and photographically identifying as many whales as possible. Previous photo-identification data gathered in the Piltun area between 1995 and 2010 used right-side dorsal flank markings for identification (Brownell *et al.*, 1997; Weller *et al.*, 1999, 2006a), and for the sake of intra- and inter-annual reliability, we continued this methodological approach. Attempts were made to photograph the right dorsal flank of each whale, followed by efforts to photograph the left dorsal flank and fluke. The majority of whales identified to date now have images of right and left flanks as well as ventral surface of flukes in the photo-identification catalog allowing for useful identification images to be collected from nearly any body region. The western gray whale photo-identification catalog complied by our Russia-U.S. research program is available on request to all interested parties (Weller *et al*., 2006a).

Photographic surveys involved slow travel in a 4.5 m outboard-powered inflatable boat. To photograph whales we used a Nikon D7000 digital camera with a 100-400 mm Nikon lens. Measures of environmental conditions, water depth, geographic position, and group size were recorded for each group photographed.

In 2010 and 2011, a satellite tagging study on gray whales off northeastern Sakhalin Island collected photo-identification images (see Mate *et al*., 2011). With data use permission from the International Whaling Commission, these photographs were processed and incorporated into our photo-identification catalog.

RESULTS

Survey effort and photo-identification catalog

Fourteen photo-identification surveys, with a total of 77.2 hrs spent at sea and 32.7 hrs spent in direct observation of 83 whale groups, were conducted between 28 June and 26 August in 2011 (Table 1). The most surveys in 2011 were conducted in July (10 surveys). One photo-ID survey was completed in June, and due to the poor weather conditions (heavy fog and high sea state), only three surveys were conducted in August. Between 1994 and 2011, 200 western gray whales have been identified during 384 boat-based surveys off northeastern Sakhalin Island (Table 1). Ninety-six of the whales in the photo-catalog were animals first identified as calves, while the remaining 104 whales were considered non-calves (i.e. adults or subadults). In combination with the additional photo-identification data from the aforementioned satellite tagging study (Mate *et al*., 2011), our western gray whale catalog contains a total of 205 identified individuals. However, not all of these 205 individuals are considered to be alive (see Cooke *et al*., 2008).

Table 1. Annual survey effort, groups encountered, and whales identified in 1994-2011.

Year	Sampling Period	Number of Surveys	Observation Hours	Groups Encountered	Whales Identified
1994	09/07 - 09/12	1			9
1995	08/15 - 08/19	5	10.1	23	28
1997	07/09 - 09/08	22	33.4	114	47
1998	07/06 - 09/29	35	50.5	125	54
1999	06/29 - 10/13	56	122	434	69
2000	06/25 - 09/16	40	56.5	365	58
2001	06/25 - 09/25	49	101.8	448	72
2002	07/01 - 09/25	36	75.6	411	76
2003	07/15 - 09/13	22	41.7	219	75
2004	07/29 - 09/12	21	33.8	194	94
2005	07/04 - 09/09	20	40.9	160	93
2006	07/23 - 08/25	10	24.1	96	79
2007	07/26 - 09/09	20	32.2	187	83
2008	07/08 - 08/21	12	47.0	38	45
2009	06/24 – 08/26	17	67.0	126	82
2010	08/09-08/26	4	11.5	40	42
2011	06/28-08/26	14	32.7	83	83
Overall		384	780.8	3063	200 [1] (205) [2]

[1] The number of whales identified annually includes resightings of individuals from previous years, resulting in a total of 200 identified individuals. The number of whales identified does not correspond to the size of the population.

[2] The total number of identified individuals in the catalog is 205 when data collected during a separate satellite tagging study (see Mate et al., 2011) are included.

Eighty-three naturally marked individual whales, including 12 calves, were identified during 2011 (Table 2). Of the 71 non-calves identified in 2011, 69 whales (97.2%) had previous sightings in the Piltun area during 1994-2010 photographic efforts (Table 2). The mean pod size for all groups (n=83) encountered during 2011 was 2.2 ± 1.47 ranging from 1 to 8 individuals per pod. The majority of sightings were of single whales (39.8%) and groups of two (32.5%). Two groups were encountered with the largest group size of eight individuals. The first sighting of a large group occurred on 18th July. Eight adult whales, all known from previous years, were observed feeding together. The second group of eight whales was sighted on 28th July and consisted of individuals of different ages interacting with

each other: three mother-calf pairs, one calf from 2010 (now a yearling), and a non-calf individual new to the Sakhalin catalog.

Forty-two individual gray whales were observed only once throughout the season; twenty-four whales were sighted twice. The maximum number of resightings in 2011 was seven, recorded for a calf that was observed both with its mother and alone (after separation from the mother). Two individuals identified as calves in 2010 were also sighted this year. One of them was photographed three times throughout the 2011 season. Also, four calves of 2009 were encountered this year; all of them were observed off Sakhalin in 2010 as well.

Table 2. Annual sighting trends and resighting percentages, 1994-2011.

Year	Whales Identified	Number of Calves	New Non-Calves	% Non-Calves Previously Identified
1994[1]	9			
1995[1]	28	2	20	23.1%
1997	47	2	25	44.4%
1998	54	8	5	89.1%
1999	69	3	12	81.8%
2000	58	3	3	94.5%
2001	72	6	6	90.9%
2002	76	9	3	95.5%
2003	75	11	2	96.9%
2004	94	8	3	96.5%
2005	93	6	4	95.4%
2006	79	4	3	96.0%
2007	83	9	2	97.3%
2008	45	3	0	100.0%
2009	82	7	2	97.6%
2010	42	3	1	97.4%
2011	83	12 (15)[2]	2	97.2%

[1] Data from 1994 and 1995 were opportunistic and pilot in nature (respectively) and are thereby viewed as incomplete for some of the reported values.

[2] Total of 15 calves identified in 2011 when data collected during a separate satellite tagging study (see Mate *et al.*, 2011) are included.

Mother-calf pairs

Eleven mother-calf pairs and one already weaned calf were identified in 2011. This is the highest number of calves identified off northeastern Sakhalin among all years of our research. In addition, two more mother-calf pairs and another weaned calf were photographed by the satellite tagging team, summing up the total number of calves identified in 2011 to 15. All thirteen mothers have been sighted in the study area prior to 2011, however, three of them have never been observed in previous years with calves. Therefore, a total of 29 known reproductive females have been documented between 1995 and 2011. One of the females observed as a mother in 2011, also had a calf in 2009, and was first identified in 1998 as a calf herself. We presume that this is her second calf and her first calving interval was 2 years. All other nine females have had multiple offspring during the 1995-2011 study.

The first sighting of a mother-calf pair in 2011 occurred during our second photo-ID survey on 7 July. Eight different mother-calf pairs were identified in July, and three other pairs were sighted in August only. The calf that was already weaned prior to the first sighting was observed on 20 August in association with two mother-calf pairs.

Two mother-calf pairs and one weaned calf photographed during the satellite tagging study were sighted in August and September.

Biopsy sampling

Our second research objective during the 2011 survey was biopsy sampling of gray whales observed in the area. A total of 14 biopsy samples were obtained in 2011. Eight of these samples were from calves of this year; one sample was taken from a calf of 2010, and one from the calf of 2009.

DISCUSSION

A number of biological parameters in concert with a variety of human-related threats, as identified during the current long-term study and discussed below, raise concern about the ability of the western gray whale population to rebound from its highly depleted state and highlight the importance of continuing the long-term Russia-U.S. collaborative research and monitoring program.

Population size

The size of the western gray whale population is extremely small compared to most other baleen whale populations. Photo-identification studies off northeastern Sakhalin Island have identified a total of 200 individual whales during 384 surveys conducted between 1994 and 2011. Although the photo-catalog now contains 205 whales (combining satellite tagging data), not all of these individuals are assumed to be alive. The most current mark-recapture analysis conducted estimated the abundance for the population to be 99 (95% CI = 90-109) in 2003 (Bradford *et al*., 2008). A population assessment by Cooke *et al*. using a Bayesian individually-based stage-structured model fitted to the same photo-identification data as used in the mark-recapture studies, but also including data from 2004 through 2007 has recently been completed. Should current population and demographic trends continue, this assessment projected a median 1+ (non-calf) estimate of 130 (90% Bayesian CI = 120-142) in 2008 (Cooke *et al*., 2008).

Reproduction and survival

Although calves are being born annually, the limited number of known reproductive females in combination with relatively low calf survival is likely to be limiting potential population growth (Bradford *et al*., 2006; IISG, 2006; Cooke *et al*., 2008). In recent years, the calving interval in the western population appears to be shifting from a three-year interval to a two-year interval (Weller *et al*., 2009). If this change persists, the general increase in calf production will continue and, in turn, contribute to an increase (albeit slow) in the growth rate of the population.

Mother-calf pairs

Thirteen mother-calf pairs were identified during the 2011 season. All thirteen mothers have been sighted in the study area prior to 2011, however, three of them have never been observed in previous years with calves. Therefore, a total of 29 known reproductive females have been documented between 1995 and 2011. The annual return of reproductive females while pregnant, resting and lactating indicates that the nearshore Sakhalin Island feeding area is of significant importance to the continued survival of this population. The behavior of these females indicates that this feeding ground is vital to population survival and growth.

Threats to the population

In addition to the biological difficulties (e.g., small population size, low number of reproductive females) that western gray whales face, the onset of large-scale oil and gas development programs off Sakhalin Island in the mid-1990s introduced new threats to the future survival of the population (Weller *et al*., 2002a; Reeves *et al.*, 2005; IISG, 2006). Sakhalin Island is a region rich with large reserves of offshore oil and gas that, until recently, have been unexploited. Industrial activities on the continental shelf of this region have steadily increased in the past ten years and are scheduled to expand at a rapid pace into the future. Oil and gas development activities that may negatively impact western gray whales include: (1) disturbance from underwater noise associated with seismic surveying (Weller *et al*., 2002b; 2006b, 2006c), pipeline dredging, ship and helicopter traffic and platform operations; (2) direct interactions between whales and an oil spill or other waterborne chemicals, ships, and possible entanglements in cables or lines; and (3) habitat changes related to seafloor modifications associated with dredging and sand pumping activities that may adversely impact gray whale prey (for reviews see Reeves *et al.*, 2005; IISG, 2006).

The number of individual whales photo-identified on the nearshore feeding ground in 2008 was very low in comparison to 2009 and previous years with a similar amount of spatial and temporal survey effort (see Table 1). Given the short nature and small number of surveys in 2010, a direct comparison with 2009 data was inappropriate;

nonetheless 42 whales identified during four surveys suggest 2010 was similar to previous years except 2008. In 2011, a high number of individual gray whales were encountered, which is comparable to the results of 2009-2010. While the low numbers observed in 2008 continues to be of concern, it is clear that results from 2009-2011 are more typical. It is possible that the observed pattern in 2008 was anomalous and was simply attributable to natural variation in behavior. It is also plausible, however, that the change reflected whales being displaced from the feeding area or, worse, indicates partial abandonment of what has traditionally been a critical feeding habitat (especially for mother-calf pairs) for the population. While natural variation in food resources and other biological factors are being investigated by industry-sponsored research groups, additional investigations need to be undertaken to examine the possible contributions of pile driving activities and a seismic survey that both occurred in close proximity to the nearshore feeding ground in summer 2008. Until more conclusive explanations can be drawn with regard to the low number of whales observed in 2008, the influence of industrial activities cannot be ruled out as contributing factors.

Another significant threat to the western gray whale population involves incidental catches in coastal net fisheries, particularly off Japan, within their migratory route (Weller *et al*., 2002a; Kato *et al*., 2005, 2006, 2007; Brownell *et al*., 2007; Weller *et al.,* 2008). In 2005, three female western gray whales (one mother-calf pair and one yearling) died in fishing nets on the Pacific coast of Japan during their northward migration. Unfortunately, in 2007 another young female western gray whale died after being entrapped in a trap net also on the Pacific coast of Japan (Anonymous, 2007a,b,c; Brownell *et al*., 2007; Kato *et al*., 2007; Weller *et al*., 2008). Projections from recent population assessments suggest that if this level of net-related mortality continues, there is a high probability the population will decline to extinction (Cooke *et al*., 2008). In addition, an analysis of anthropogenic scarring of western gray whales found that 18.7% (n = 28) of 150 individuals identified between 1994 and 2005 were determined to have been previously entangled in fishing gear (Bradford *et al.*, 2009), further highlighting the overall risks coastal fisheries pose to western gray whales. Finally, while nothing is known about net entrapments or entanglements in other regions (e.g., Korea and China) within the range of the population, it is likely that coastal net fisheries outside of Japan also contribute to some level of mortality.

Although there are historical data on gray whales sightings in waters off Japan, South Korea and China, and also documented net entrapments near Japan, the wintering grounds for western population remain unclear (Weller *et al.* 2008). Some western gray whales are seen near Kamchatka, and both intra-annual and intra-seasonal exchange of individuals between feeding grounds off Sakhalin and Kamchatka are documented (Tyurneva *et al*. 2010). In 2010, a satellite tagging project was initiated off northeastern Sakhalin (Mate *et al*., 2011) [1]. A male gray whale, which was observed as a calf in 1997 and sighted in most years of study in the Piltun area, was tagged and tracked during October 2010–February 2011. This individual traveled over 7500 km from Sakhalin feeding grounds to the Oregon coast (USA). Five more whales observed on the feeding grounds off Sakhalin in different years were confirmed with photographic matches to the whales from a eastern North Pacific catalog (Weller *et al*. 2011). This highlights that the range and potential threats this population may face may be on a larger scale than previously anticipated.

Such a wide range in distribution makes whales vulnerable to other unknown threats to the western gray whale population including continued mortality from an undetermined level of suspected poaching in the central portion of the range (Brownell and Kasuya, 1999; Baker *et al*., 2002), as well as a potential increase in the likelihood of disturbance, exposure to pollution, and probability of ship strikes due to substantial nearshore industrialization and shipping congestion throughout the migratory corridor(s).

Genetics

Previous genetic research on the western gray whale population has documented clear genetic differentiation from the eastern population on the basis of mitochondrial DNA haplotype frequencies (LeDuc *et al*., 2002). Given the small size of the western population and its isolation from the eastern population, the potential for continued loss of genetic diversity due to genetic drift or removal of individuals with rare alleles is of concern (Lang *et al*., 2004; 2005). The limited number of females in the population may hinder reproductive output and in turn slow population recovery. The male bias observed for calves indicates lower recruitment of females into the adult population. This pattern further perpetuates the problem of a limited number of females being available to reproduce. Although, the recent genetics results of comparing microsatellite markers show some degree of movements between western and eastern populations, it supports their recognition as two separate populations (Lang *et al*., 2010).

CONCLUSIONS

Based on the results reported here, it is clear that the western gray whale population is precariously balanced between survival and extinction. In addition to the variety of biological factors that may be limiting population

growth, large-scale oil and gas development programs that may alter the prey base or introduce disturbance to feeding whales, as well as entrapment and entanglement in fishing gear, especially in trap nets off Japan, are of serious concern with regard to the future survival of the population.

Given the continued uncertainty regarding the ability of the western gray whale population to increase from its depleted state, impacts from oil and gas development activities off the northeastern Sakhalin Island coast need to be closely monitored and stringently mitigated to reduce disturbance to the lowest possible level. In addition, net entrapments of western gray whales off Japan and possibly elsewhere can lead the population to extinction (IISG, 2006; Cooke *et al*., 2008; Brownell *et al*., 2007; Weller *et al*., 2008). Thus, human related mortality during migration and in the (yet to be determined) wintering area(s) must be addressed and mitigated to the lowest possible level. Where scientific knowledge is lacking, the precautionary principle should be applied as the best measure of protection. With this in mind, the photo-identification and genetic biopsy research conducted since 1995, and reviewed here, must be continued to further monitor survival of individuals, describe the overall population trend and to recommend further conservation and protection measures.

In conclusion, protection of the Sakhalin Island feeding habitat, including the coastal lagoon systems that appear integrally related to the high benthic biomass used by the whales in the nearshore area, is clearly paramount to successful conservation of the western gray whale population. The unique method of benthic feeding by these whales makes them an "umbrella" species (Hooker and Gerber, 2004), whereby protection of their habitat provides protection for the biological diversity of the entire northeastern Sakhalin Island shelf. Thus, the feeding habitat of the western gray whale needs to be considered a "hot spot" for conservation planning now and in the future and every effort should be taken to protect its biological integrity. In continuation of this research and looking for the development of additional western gray whale conservation measures, the next step should be intensifying research of gray whales off Kamchatka.

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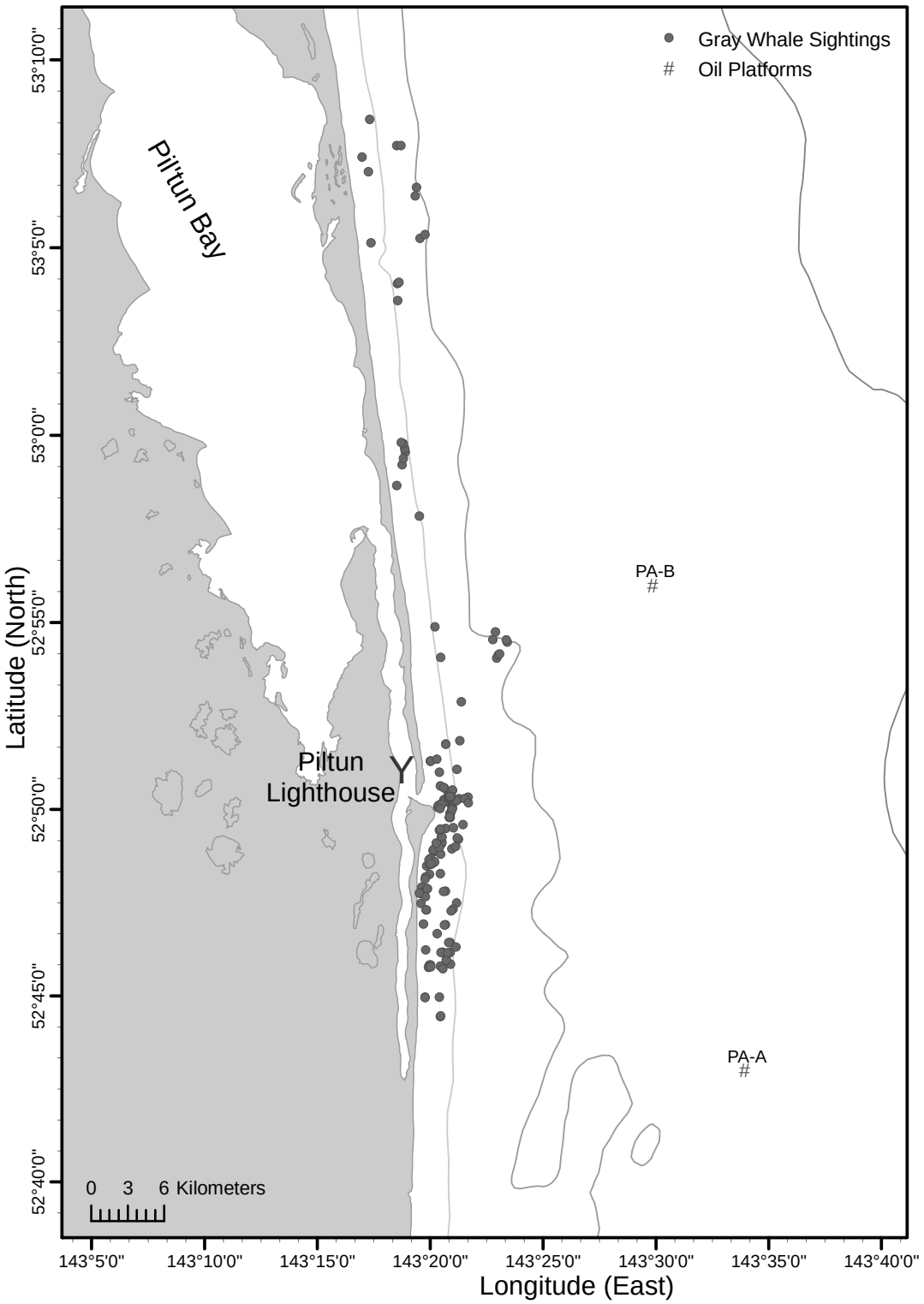

Fig.1 Gray whale sightings in the study area in 2011.

Updated analysis of abundance and population structure of seasonal gray whales in the Pacific Northwest, 1998-2010

(SC/M12/AWMP2-Rev)

John Calambokidis, Jeffrey L. Laake, Amber Klimek

Abstract

The existence of a small number of Eastern North Pacific gray whales that spend the spring, summer and fall feeding in coastal waters of the Pacific Northwest has been known for some time and localized short-term studies have examined aspects of the natural history of these animals. We report the results of a 13-year (1998-2010) collaborative study examining the abundance and the population structure of these animals conducted over a number of regions from Northern California to British Columbia using photographic identification. Some 14686 identifications representing 1031 unique gray whales were obtained. Gray whales seen after 1 June (after the northward migration) were more likely to be seen repeatedly and in multiple regions and years and therefore 1 June was used as the seasonal start date for the data included in the abundance estimates. Gray whales using the Pacific Northwest in summer and fall include two groups: 1) whales that return frequently and account for the majority of the sightings and 2) apparent stragglers from the migration seen in only one year, generally for shorter periods and in more limited areas. Abundance estimates for whales present in summer and fall using four different methods over different geographic scales revealed the abundance of animals to be at most a few hundred individuals. All of the estimators except those based on Lincoln-Petersen, which was likely biased by the violation of population closure, showed an increase in abundance in the late 1990s and early 2000s. This was during the period the eastern North Pacific gray whale population was experiencing a high mortality event and this created an apparent influx of animals into the area. While estimates during that period may have been altered by this event, the abundance since then has been very stable. Recent matches of photo-identified gray whales from the Pacific Northwest to other regions have provided new insights into the movement of some of these individuals including matches to Barrow, Alaska. The proportion of calves documented was generally low but varied dramatically among years and may have been biased downward by weaning of calves prior to entry in the study area or prior to much of the collaborative seasonal effort. Observations of calves returning to the Pacific Northwest in subsequent years documents one possible mechanism for recruitment. The results we present will be valuable in assessing the impacts of potential resumption of a gray whale hunt by the Makah Tribe.

1 Introduction

Although most gray whales in the Eastern North Pacific stock migrate each spring from calving lagoons in Baja Mexico to feeding grounds in the arctic, the existence of gray whales that spend the spring, summer and fall feeding in coastal waters of the Pacific Northwest has been known for some time. Starting in the 1970s, photographic identification demonstrated that some whales returned regularly to feed off the west coast of Vancouver Island (Darling 1984). The proximity of these whales to the traditional whale hunting grounds of the Makah Tribe coupled with the Tribe's interest in resuming gray whale hunts in the 1990s, made determination of the status and number of these whales of greater importance to management.

Beginning in 1996, a collaborative effort among a number of research groups was initiated to conduct a range-wide photographic identification study of gray whales in the Pacific Northwest (Calambokidis et al. 2000, 2002b). An initial publication of findings from 1998 demonstrated there was considerable movement of individual whales among sub-areas from northern California to southeastern Alaska (which we broadly refer to as the Pacific Northwest) and also provided initial estimates of the abundance of whales within that geographical area (Calambokidis et al. 2002a). The ability to look at movements and employ more sophisticated capture-recapture models, however, was restricted by the lack of multiple years of data with broad geographic coverage. A subsequent report by Calambokidis et al. (2004) characterized the group of whales feeding in these survey areas during the summer-fall period as a "Pacific Coast Feeding Aggregation" (PCFA). They proposed that a smaller area within the PCFA survey areas – from Oregon to Southern Vancouver Island (OR-SVI) – was the most appropriate area for abundance estimation for managing a Makah gray whale hunt (Calambokidis et al. 2004). Subsequently the IWC has adopted the term PCFG for Pacific Coast Feeding group so we will use PCFG in place of PCFA.

The collaborative effort to collect photographic identifications of gray whales from California to Alaska has continued since 1998 and these data now cover 13 years (1998-2010) and span fifteen survey regions along the coast from Southern California to Kodiak, Alaska (Figure 1). We provide estimates of abundance for the summer-fall seasons (1 June to 30 November) for survey regions comprising different combinations of subareas within this range.

2 Methods

Gray whales were photographed during small boat surveys conducted from California to Alaska by Cascadia Research, National Marine Mammal Laboratory and collaborating researchers between 1998 and 2010. Gray whale identifications were divided into the following regions (Figure 1): 1) SCA: Southern California, 2) CCA: Central California, 3) NCA: Northern California, 4) SOR: Southern Oregon, 5) OR: central Oregon, 6) GH+: Gray's Harbor and the surrounding coastal waters, 7) NWA: Northern Washington coast, 8) SJF: Strait of Juan de Fuca, 9) NPS: Northern Puget Sound, 10) PS: which includes southern Puget Sound, Hood Canal (HC), Boundary Bay (BB) and San Juan Islands (SJ), 11) SVI: Southern Vancouver Island, 12) WVI: West Vancouver Island, 13) NBC: Northern Van-

couver Island and coastal areas of British Columbia, 14) SEAK: Southeast Alaska, and 15) KAK: Kodiak, Alaska. The NWA and SJF survey areas together make up the Makah Usual and Accustomed grounds (MUA). With some exceptions, research groups work primarily in one or two regions. Details of identifications obtained by the different research groups are are summarized in Tables 1-2.

Each year from 1998 to 2010, between 548 and 1500 identifications were obtained of gray whales totaling 14686 photos of 1031 unique gray whales for the entire period (Table 1). These were conducted from March through November with most effort from June to September. Surveys were most numerous in British Columbia, along the south and west coasts of Vancouver Island and just north of Vancouver Island (Table 2).

2.1 Photographic Identification Procedures

Procedures during surveys by different research groups varied somewhat but were similar to one another in identification procedures. When a gray whale was sighted, the time, position, number of animals, and behaviors were recorded. Whales were generally approached to within 40-100 m and followed through several dive sequences until suitable identification photographs and associated field notes could be obtained.

For photographic identification of gray whales, both left and right sides of the dorsal region around the dorsal hump were photographed when possible. Most identification photographs were obtained with 35mm cameras most often with large 300mm lenses. Researchers also photographed the ventral surface of the flukes for further identification when possible. The latter method was not as reliable since gray whales did not always raise their flukes out of the water. Markings used to distinguish whales included pigmentation of the skin, mottling, and scarring, which varied among individuals. These markings have provided a reliable means of identifying gray whales (Darling 1984). We also identified gray whales using the relative spacing between the knuckles along the ridge of the back behind the dorsal hump. The size and spacing of these bumps varies among whales and has not changed throughout the years these whales have been tracked, except with injury. Figure 2 shows typical photographs and features used in making gray whale identifications.

Comparisons of whale photographs were made in a series of steps. All photographs of gray whales were examined and the best photograph of the right and left sides of each whale (for each sighting) were selected and printed (7 x 2.5 inch). To determine the number of whales seen during the year, the prints were then compared to one another to identify whales seen multiple days. Finally a comparison was made to the CRC catalog of whales seen in past years. Whale photographs that were deemed of suitable quality but did not match our existing catalog (compared by two independent persons) were considered "unique" identifications and assigned a new identification number and added to the catalog.

2.2 Data Analysis

The abundance of gray whales was estimated with open and closed population models for four nested spatial scales consisting of contiguous survey regions (Figure 1; Table3) 1)

NCA-NBC: the survey regions from Northern California (NCA) through Northern Vancouver Island/British Columbia (NBC), 2) OR-NBC: survey regions from southern Oregon through NBC, 3) OR-SVI: survey regions from southern Oregon through Southern Vancouver Island (SVI), and 4) MUA-SVI: the survey regions from MUA which includes Northern Washington coast (NWA) and Strait of Juan de Fuca (SJF) and SVI . The proposed hunt by the Makah Tribe would be in NWA.

Gray whales photographed and identified anytime during the period between 1 June and 30 November (hereafter referred to as the "sampling period") within the defined region were considered to be "captured" or "recaptured". For each unique gray whale photographed, a capture history was constructed using 13 years of data from 1998-2010. For example, the capture history 0100100100000 could represent a gray whale photographed in 1999, 2002 and 2005 in the PCFG. The same gray whale may have had a capture history 0100100000000 for a smaller spatial scale such as OR-SVI or may not have been seen at all (0000000000000) and would not be used for the smaller spatial scale.

Multiple "detections" of a single whale within the sampling period were not treated differently than a single detection. A "1" in the capture history meant that it was detected on at least one day during the sampling period. However, multiple detections in the same year were used to construct an observed minimum tenure (MT) for each whale. MT was defined as the number of days between the earliest and latest date the whale was photographed with a minimum of one day for any whale seen.

2.2.1 Abundance using closed population models

Closed models for capture-recapture assume that the population is both geographically and demographically closed with no losses or gains. Closure would not be a reasonable assumption for the entire 13 year period but previous analysis has assumed closure for two consecutive years (e.g., Calambokidis et al. 2004). For those abundance estimates, a Lincoln-Petersen (LP) estimator (Seber 1982) was used in which each of the consecutive years (June-November) was a sampling occasion. Those estimates were based on the assumption that all whales that were available to be photographed in year y were also available to be photographed in year y+1 and vice versa. If new whales joined in y+1 or whales seen in year y did not return in y+1, the closure assumption would be violated. It is well known that the LP estimator is unbiased if there are only losses or only gains (Seber 1982) but not both (Kendall 1999). The only exception is a population with completely random movement into and out of the population but that is not plausible with gray whales because with approximately 20,000 whales there would be few if any matches between years if movement in and out of the PCFG was completely random.

The losses and gains each year are primarily from "transient" whales that are seen in one of the years and are never seen again in any other year. To remove this source of bias, we developed the following ad-hoc approach to remove the transients. For each pair of years in the computation of abundance with the LP estimator, we only used whales that were seen in one or more years other than the years being considered. For example, in computing an abundance estimate with 1999 and 2000 we only used whales that were also seen in 1998 or at least one year after 2000. This removed any transients that would have only been seen in either 1999 or 2000. It also removes those seen only in both years; while

these are technically not single-year transients their removal was unavoidable using this approach. This was done for each year pairing and we have called this estimation method "Limited LP". We would expect these estimates to be biased low at the end of the time sequence because new whales at the end of the time sequence have had little or no opportunity to be sighted again and thus would not be included in the analysis. The bias will be apparent by comparing the estimates for 2007 and 2008 from Calambokidis et al. (2010) and the same estimates in this paper with the data extended through 2010.

2.2.2 Abundance using open population models

In addition to the closed models, we fitted open population models to the 13 year time series of capture history data for each spatial scale to estimate abundance and survival. Open models allow gains due to births/immigration and losses due to deaths/emigration. Using the RMark interface (Laake and Rexstad 2008) to program MARK (White and Burnham 1999), we fitted a range of models to the data using the POPAN model structure. The POPAN model structure (Schwarz and Arnason 1996) provides a robust parametrization of the Jolly-Seber (JS) model structure in terms of a super population size (N), probability of entry parameters (immigration), capture probability (p), and survival/permanent emigration (φ).

It is essential to consider the population structure and its dynamics to build adequate models. In particular, we know from previous analysis of a subset of these data (Calambokidis et al. 2004) that some whales were seen in only one year between 1 June and 30 November and were never seen again. Transient behavior is a well-known problem in capture-recapture models and it is often addressed using a robust design which involves coordinated multiple capture occasions within each year and typically assumes closure within the sampling period (June-November). Region-wide coordinated surveys may be possible but would be difficult with variation in weather conditions. Also, the closure assumption within the year would be suspect due to variable timing of whales arrivals and departures into the PCFG, so it would require nested open models. We know from prior analysis that whales newly seen in year (y) were less likely to return (i.e., seen at some year >y) than previously seen whales but also newly seen whales that stayed longer during their first year (i.e., longer MT) in the PCFG were more likely to return. Likewise, previously seen whales were more likely to be seen in the following year (y+1), if they had a longer MT in year y. Calambokidis et al. (2004) postulated that these observations were consistent with whale behavior that was determined by foraging success.

Transient behavior in which an animal is seen only once can be modeled by including a different "first year" survival (Pradel et al. 1997) for the newly seen animals. Survival in the time interval after being first seen is dominated by permanent emigration rather than true mortality. Survival in subsequent time intervals represents true survival under the assumption that animals do not permanently emigrate except in their first year. Pradel et al. (1997)were working with release-recapture data (Cormack-Jolly-Seber) where modeling this transient effect on survival is straightforward. For a Jolly-Seber type analysis where the first capture event is also modeled, the inclusion of a transient effect is less easily accommodated. We considered two approaches to accommodate the "transient" effect in these open models to remove the transients from the estimate of abundance. We will refer

to these as JS1 and JS2.

Approach JS1 The first approach divided the whales into cohorts based on the year in which they were first seen ("newly seen"). In the models their first year survival could differ from subsequent annual survival as in Pradel et al. (1997). The first year survival was also allowed to vary as a function of MT. "Newly seen" is not a particularly useful concept for the first year of the study (1998), because all whales were being seen for the first time. Thus, we also considered a model that allowed for a different first year survival and effect of MT for 1998 than for years after 1998 and a model in which each cohort had a different first year survival to allow for different transient proportion in each year if this was not adequately modeled by MT. We also considered models that allowed a different first-year survival for whales identified as calves under the presumption that their true survival might be lower but that their probability of returning to the PCFG might be higher. Discussion at the 2012 intersessional AWMP meeting led to consideration of an additional covariate which split whales into 2 groups for estimation of post-first-year survival. Whales seen initially as calves and any whale newly seen in 1998 or was in the CRC catalog because it had been seen prior to 1998 were put in one group and the remaining whales newly seen in 1999 or later were put in another group. The expectation was that the first group would have higher post-first-year survival because many of the newly seen whales that entered after the stranding event in 1999/2000 might eventually emigrate. When this covariate was included it made such a large improvement that any model without it would have no support. Therefore, it was included in all 10 models for survival (Table 5).

In Calambokidis et al. (2010) we estimated a cohort-specific super-population size for each cohort using the median MT covariate value for unseen whales but during the April 2011 AWMP meeting it became apparent that this may lead to bias in estimating abundance. Therefore, we used the method outlined in the 2011 AWMP report which is similar to the method used by Calambokidis et al. (2004) in that we assume that all whales in the PCFG for the first year are seen so the super-population size for each cohort is the number seen and thus there are no unknown covariate values. We fixed capture probability (p) and probability of entry (pent) to 1 for each cohort in their entry year. We are not interested in the number of transient whales so we used an estimator of abundance for non-transient whales (2011 AWMP report) which is a modification of the Jolly-Seber estimator which for any year can be expressed as:

$$\hat{N} = n/\hat{p} = (u+m)/\hat{p}$$

where $n = u+m$, n is the number seen in a year being composed of new animals (u=unmarked) and previously seen animals (m=marked), and $\hat{p}$ is the capture probability estimate. For the PCFG we are assuming that any new whale is sighted ($p = 1$) and we are only interested in estimating the abundance of whales that will remain part of the PCFG which is portion of the new whales that do not permanently emigrate from the PCFG. We can modify the estimator for year j as follows:

$$\hat{N_j} = u_j\hat{\phi}_j + m_j/\hat{p_j}$$

where ϕ_j is the first year survival rate of "new" whales. When$\phi$and p contain whale specific covariates like minimum tenure (MT) the estimator becomes:

$$\hat{N}_j = \sum_{i=1}^{u_j} \hat{\phi}_{ij} + \sum_{i=1}^{m_j} 1/\hat{p}_{ij}.$$

To obtain an abundance estimate for 2010, we assumed that the parameter for first year survival intercept in that year was the same as in 2009. A variance-covariance matrix for the abundance estimates was constructed using the variance estimator in Borchers et al. (1998) for a Horvitz-Thompson type estimator with an adaptation for the first component of the abundance estimator for prediction of number of new whales that do not permanently emigrate. For the estimated capture probabilities (p) not fixed to 1, we fitted 3 models that varied by time (year) and/or varied by MT in the previous year (Table 5).

We used Test 2 and Test 3 results from the Cormack-Jolly-Seber structure (Lebreton et al. 1992) as a general goodness of fit for the global model and as a measure of possible over-dispersion creating the lack of fit. We fitted each combination of models for S (survival) and p (capture probability) and used AICc (Burnham and Anderson 2002) to select the most parsimonious model of the 30 fitted models. Model averaging was used for all models to compute estimates and unconditional standard errors and confidence intervals.

Approach JS2 The first approach will certainly underestimate the abundance in the initial years and particularly in the first year where the abundance estimate is less than or equal to the number seen in the first year because m=0 in the first year. As previously unseen non-transient whales are "discovered" the abundance estimator should approach the true abundance. However, that may distort any assessment of population trend and growth, so we devised the following alternative approach. If we assume that transient whales are those that are seen once and never seen again, then we can remove those from the data and use the remaining capture histories from whales seen in at least 2 years to estimate the abundance trend of non-transients with a standard POPAN model that estimates both p and pent and abundance through time. For this analysis we ignored covariates because they are not known for whales that enter but are not seen in the year they enter. Covariates for ϕ are less important because we are effectively assuming that transients have $\phi = 0$ and the non-transients have a common survival rate. We fitted a single model with time varying p and pent and a constant ϕ and used the derived estimates of abundance for the POPAN model of the data from NCA-NBC only. This is an admittedly ad-hoc approach and we expect that ϕ will be biased high because some of those seen only once will be non-transients that died before they were resighted. The abundance estimates at the end of the time series will be biased low because those newly seen in the 2010 and those seen in 2009 not resighted in 2010 are removed. Also, for the JS models it is not possible to estimate both a time-varying pent and p for for 1998 without constraints. We chose to set $p = 1$ for that year which will likely underestimate abundance.

A better approach would be a Jolly-Seber model that allowed for a mixture of entrants of transients with $\phi = 0$ and non-transients similar to the closed version of Conn et al. (2011) but we are unaware of any existing software that will fit that model. Current JS mixture models in MARK allow a mixture for p but it does not carry the mixture through to the remainder of the parameters like ϕ.

2.3 Simulation

We performed a small-scale simulation study to investigate the properties of the various estimators of abundance that we have used. We considered 2 scenarios with constant ϕ=0.95 for non-transient whales, ϕ=0.0 for transient whales which are assumed to permanently emigrate and never return and for all whales a time constant p with values of 0.7 and 0.8 which cover the range of estimated probabilities for the gray whale data. In the first scenario, we simulated a population at equilibrium in which the number of new non-transients and transients matched the expected number of mortalities of non-transient whales ($N(1-\phi)$). In the second scenario, we used the observed number of transients (seen only in one year) and recruits to the non-transients from the PCFG gray whale data from NCA-NBC and a initial population size of 120 non-transients from previous years still alive in 1998. We constructed a single population entry structure for each scenario but then simulated 100 replicates of the survival and capture process. Even though p was constant in the simulated data, we fitted each open model with time varying p to make them similar to the real data analysis and to make the more similar to the closed estimators which estimate a separate p for each year. The biggest impact will be in the first abundance estimate in 1998 because it is necessary to assume p=1 which will result in an underestimate. For that reason we drop the first estimate which also makes the comparison to closed estimators consistent because we only get a single estimate for 1998-1999 which is assigned to 1999. We summarized the abundance time series for the 100 replicates for each estimator to examine bias in abundance and trend.

3 Results

The database from all thirteen years (1998-2010) contains 14686 records; however 2291 are replicate identifications of whales on the same day. The database contains photographs of 1031 unique whales seen from Southern California to Kodiak, Alaska with an average of 12 sightings/whale (range: 1- 240) where a "sighting" is one or more photographs on a day. Only 50.3% of the whales were seen on more than one day but many of these identifications are from early in the season during the migration as well as from peripheral areas such as Kodiak, Alaska (Table 6).

3.1 Seasonality

Whales have been photographed in every month of the year (Table 6) but with very few during December-February when most of the whales are in or migrating to Mexico and survey effort is reduced. Previous analysis of these data have always used 1 June - 30 November as the sampling period to describe the whales in the PCFG because whales seen prior to 1 June are more likely to be whales that are migrating through the region. The separation between May and June is clearly supported by the data. For example, of the 1031 unique whales, 286 whales were only seen before 1 June and 84.3% of those were only sighted once. In comparison, of the 745 whales sighted between June and November, 39.7% were only sighted once. If sightings in Alaska are excluded, then only 32.7% of the 630 were seen only once.

The break between May and June is apparent in various measures such as proportion of whales sighted more than once, sighted in more than one region, and sighted in more than one year (Figure 3). However, the break is more apparent if we separate out SJF, NPS and SVI from the other survey regions (Figure 4). The difference across months is not as strong for inland waters of Washington and British Columbia (NPS, SJF) because these are whales that have diverted from the migration and are either more likely to remain after 1 June or demonstrate high year-to-year fidelity during spring such as with NPS. Also, even though Southern Vancouver Island (SVI) is in the main migration corridor and not an inland water, the pattern across months is also weaker because the sampling has been focused on the spring herring spawn in Barkley Sound (effectively an inland waterway) and has purposefully undersampled passing migrant whales (Brian Gisborne, pers. comm.). The break between May and June is much more apparent for NWA and the other areas in the migration corridor which is consistent with the northbound migration of gray whales proceeding past Washington through May. Resighting rates of whales seen after 1 June remained high through November.

The proposed Makah gray whale hunt in the Makah Usual and Accustomed area (NWA and SJF) may occur in NWA after 30 November and prior to 1 June. A hunt conducted in spring (March-May) potentially could take whales from the PCFG although those chances are less in NWA than in SJF. There have been 118 whale sightings in NWA prior to 1 June of which 30% (35) were of whales that were seen in the PCFG after 1 June at some time. We tested whether this result was biased by the quality of photographs or the selection process by also looking at the resighting rate of only a subset of the animals with highest quality photographic identifications from that period. We found 17 of 48 (35%) were resighted after 1 June, fairly close to the 30% found with all whales. In comparison, 46 whale sightings were in SJF prior to 1 June of which 70% (32) were of whales that were seen in the PCFG after 1 June at sometime, emphasizing the importance of restricting a hunt to coastal waters of the MUA (i.e., the NWA) to limit the take of whales from the PCFG.

3.2 Regional Sighting Patterns

There is considerable variation in the annual regional distribution of numbers of whales photographed during the sampling period (Table 7) which is in part due to variation in effort. Although not a true measure of effort, the number of days whales were seen (Table 8) does reflect the amount of effort as well as abundance of whales. In particular, in comparison to other regions, the large number of sightings in SVI partly reflects large numbers of sampling days by Brian Gisborne who has routinely sampled SVI 2-3 days a week. On the other hand, the decline in sightings in SVI during 2007 was not due to reduced effort but to the distribution of whales with many of the whales having moved to waters off Oregon and Washington (Calambokidis et al. 2009b).

Whales were sighted across various survey regions and the interchange of whales (Table 9) between survey regions during 1 June - 30 November depends on proximity of the regions (Calambokidis et al. 2004). Of the whales sighted in regions from SOR to NBC, depending on the region, from 57.8% to 72.7% of the whales were seen at some point within MUA-SVI (Figure 6). However, whales seen in California or Alaska were less likely to be

seen in MUA-SVI.

If we look at latitudes of sightings of individual whales across the 13 years using whales that have been sighted on at least 6 different days (Figure 7), we see that sightings of some whales are highly clustered; whereas, sightings of other whales are highly dispersed across several regions. We defined each whales primary range by the 75% inner quantile which is the middle of the range that includes 75% of the locations. The length of the 75% inner quantile in nautical miles exceeded 60 nautical miles (or 1 degree of latitude) for 41.2% of the whales (Figure 8) and it was more than 180 nautical miles for more than 17.9% of the whales. Thus, it makes little sense to compute an estimate of abundance for any region that spans less than a degree of latitude.

There was a large variation in the frequency of sightings for whales (Table 10). Most whales that were seen during June-November 1998-2010 in the PCFG (NCA to NBC) were only seen in one year and the whales that were seen in more years were sighted more often each year and therefore represented a large proportion of the sightings (Figure 9). Likewise, examination of MT in the first sighting year demonstrates that whales who stay longer in their first year were more likely to be seen in a following year (Figure 10). Whales "first" seen in 1998 includes some whales that were truly new to the PCFG in that year but many were only "new" because it was the first year of the study. This is evident (Figure 10) in the much higher proportions for 1998 than for the other years. These relationships are important in the capture-recapture models for abundance estimation. In a closed model, these transients can cause bias because there are both gains and losses. In an open population model, whales that do not return after their first year (a large percentage in this analysis) would appeared to have not survived because they have permanently emigrated (with a small fraction that died).

3.3 Mothers and calves

Mother and calf data were only available from some collaborators and much of the effort in the PCFG occurs during and after the period of weaning. Likely due to those a factors, a relatively low proportion of calves have been sighted from the summer and fall sightings of gray whales through 2010 (Table 11). Through 2010, 35 different gray whales identified as PCFA whales were seen as definite or probable mothers with calves representing 45 likely births, eight whales were seen with calves multiple seasons (two or three). Despite the many years of study, only two individuals were sighted with calves in three separate years, the most documented, however, in one of these cases one of the calves was documented prior to the 1998 start of regular effort. One individual (ID#81) was observed with a calf in 2001, 2003, and 2009 and the other individual (ID#67) was seen with a calf in 1995, 2002 and 2004.

Overall, 3 of the 45 occurred prior to 1998, leaving 42 or just over three per year during our primary study period 1998-2010 (Table 12). These likely represent a minimum estimate of the births occurring because: 1) collaborators did not always note the presence or absence of calves, 2) as described below, calves weaned from their mothers, making them unidentifiable as calves, as early as June and July. Both these factors would tend to result in underestimates of the presence of calves.

The number of mothers of calves seen varied dramatically by year from 0 to 9 and was

concentrated in a four-year period (2001-2004) which accounted for 28 of the 45 sightings of known mothers with calves. During this 4-year period an average of 7 calves were seen while an average of 1.5 calves per year was seen in the other nine years (14 calves in 9 years). Even among these known or suspected mothers, the proportion of years they were seen where they had a calf average only 14% although it was 39% and 36% during the peak years of 2001 and 2002, which would be closer to what would be expected if females were getting pregnant almost every other year. The most recent year of data, 2010, also showed a higher number of calves from known PCFG whales with 4 documented mothers and calves out of 12 known mothers seen (33%). While these years with higher number of calves were likely higher birth years, it is also possible that longer weaning times those years may have contributed to a higher proportion of new calves still with their mothers being documented.

In 20 cases, a calf was seen associated with its mother early in the season and then the mother or the calf was resighted later in the season separately, suggesting weaning had occurred. The latest a mother was seen still seen associated with its calf was 6 September (CRC 67 with calf CRC 698 in 2002) and there were indications of separation of calves from their mothers as early as June. In two cases either the mother or calf was seen separated in June, however, in neither case was the calf resighted in the future year (although the mother was) suggesting these calves may not have survived. In at least eight cases the weaning had occurred prior to a July sighting (and possibly earlier).

Of the 35 likely mothers documented, 23 had been seen four or more years in the study area (12 had been seen only 1, 2, or 3 years). Even those animals with long sighting histories were seen with calves in only a small proportion of the years but as shown in Table 11, often the initial sighting of these animals was in late August or later, past the period when weaning may have occurred.

Some of these whales commonly seen in the Pacific Northwest were sighted with calves outside of this region and the somewhat atypical locations may suggest they may behave differently in years they have a calf. One mother (ID#281) was regularly sighted in the PCFA area every year from 1999 to 2007. In only one of those years was she with a calf (2002) and in 2008 she was seen on 19 April off Santa Barbara, S California apparently in the migration with a small calf but neither of them were seen that year in any of our effort farther north from Northern California to SE Alaska. Another case not included in our summary because the calf was never seen in the our study area and also there was uncertainty of who was the mother, was an apparent calf (ID 962) sighted off San Miguel Island on 27 July 2006 but which was accompanied by two adults (ID 359 and 718) both of whom were seen in most years from 2002 to 2008 in the Pacific Northwest (N California to SE Alaska), but not in 2006. Both the mothers and calves from these two sightings were not seen in the Pacific Northwest in their birth year (despite the mothers being seen most other years) and were only opportunistically sighted outside the region, suggesting there may be additional calves born to animals that use the Pacific Northwest that perhaps do not come into sampled areas (either within or outside the Pacific Northwest) in their birth year. This would negatively bias estimates of the number of calves born to these animals.

One important question in evaluating the population structure of the gray whales using the Pacific Northwest feeding areas is how animals are recruited to this group. We examined the sighting histories of the identified calves to determine if they tended to be seen in

future years. Animals that were not seen in future years could reflect either mortality in the first year of life or animals that did not continue to feed in the Pacific Northwest in future years. There were 42 calves or suspected calves identified with their mothers through 2010 in the study area with 38 of these seen through 2009 and which had at least one subsequent year they would have had an opportunity to have been seen. Just over half of these (21 or 55%) had been seen in a year subsequent to the year they were calves. Using only the 30 calves seen through 2004 (to allow a longer follow up period to resight animals, 19 (63%) have been resighted in a later year. The 37% not seen in a following year could be the result of: 1) the calf dying, 2) the calf not returning to the area or not yet resighted during its return, 3) the calf not being recognized by photo-ID since calves can undergo changes in markings rapidly especially if not seen for several years. Given all these factors the resighting rate of calves does suggest a high proportion of surviving calves appear to become part of the small feeding aggregation that uses the Pacific Northwest.

3.4 Open Population Capture-Recapture Models

If the yearly cohorts were pooled, Test2+Test3 statistics indicated a significant lack of fit for the PCFG and subsets (Table 13) primarily resulting from Test 3. This was expected due to the different "survival" rates of previously seen whales (true survival) and newly seen whales of which many never returned (i.e., permanently emigrated) (Table 14) . By separating the cohorts, survival for each cohort was time-varying and thus each cohort has a separate first year survival. In this case, the goodness of fit test (Test 2 only) did not demonstrate a lack of fit except for OR-NBC and NCA-NBC. For those regions, we estimated over-dispersion values of $\hat{c}$=1.79 and $\hat{c}$=2.09 respectively, to adjust AICc and estimated standard errors. The lack of fit for those regions is probably related to the inclusion of NCA, WVI and NBC which are at the fringes of the PCFG. Effort in NCA and WVI has been less regular than the other survey regions and whales in NBC have a higher degree of interchange with Alaska.

The best fitted model (Table 15) was always model 2 for p with capture probability varying across years and higher when MT was greater in the previous year. For φ the best model was either model 4 or 5 with roughly equal support for each model. Both models included a separate first year survival which depends on MT. In both models the intercept for first year survival in 1998 differs from the other years and in model 5 the slope for MT differs for 1998. These results were consistent with Calambokidis et al. (2004) who demonstrated strong support for the effect of MT on first year survival (Figure 11-12) and capture probability (Figure 13) in the following year for all spatial scales. These results differ from Calambokidis et al. (2010) due to the use of MT directly rather than a median centered value. Use of MT with median centering was necessary to construct open model abundance estimates in the manner described in Calambokidis et al. (2010). However, that was not necessary for JS1 and JS2 and use of MT directly resulted in lower AICc values.

There was large year to year variation in capture probability. The values for MUA-SVI ranged from 0.23 to 0.97 depending on the year and value of MT (Figure 13). The lowest values were from 2007 which reflects the temporary emigration of whales from MUA and SVI to waters offshore of Oregon in that year.

First year survival estimates were dominated by permanent emigration. For MUA-SVI,

the estimates varied from 0.42 to 0.51 for non-calf whales with MT=1 in their first year and from 0.80 to 0.94 for MT>80 in their first year (Figure 11). For calves, they were slightly higher but there was little support for a different first year calf survival. Survival subsequent to the first year was assumed to be constant but was less for non-calf whales that were newly seen in 1999 or later. Post-first-year suvival for calves and whales present in 1998 or earlier presumably represents true survival assuming there was little permanent emigration after the first year. Those estimates were 0.97 (se=0.0088), 0.972 (se=0.0078), 0.971 (se=0.0093) and 0.968 (se=0.0093) for MUA-SVI, OR-SVI, OR-NBC, NCA-NBC respectively. The post-first-year survival estimates for whales that entered in 1999 or later and not identified as a calf were 0.864 (se=0.0217), 0.878 (se=0.0183), 0.871 (se=0.0228) and 0.881 (se=0.0217) for MUA-SVI, OR-SVI, OR-NBC, NCA-NBC respectively.

3.5 Abundance and Recruitment

For MUA-SVI, OR-SVI, OR-NBC, and NCA-NBC annual estimates of abundance were constructed with LP, Limited LP and model averaged values for JS1 and JS2 (Figure 14, Tables 16-23). Estimates in Figure 14 are only shown for 1999-2010 because with the closed models only 12 estimates can be constructed with the 13 years of data and with the open models $p = 1$ for 1998 so it will be an underestimate. In general, the JS1 and JS2 estimates were similar to the Limited LP estimates because they are all removing the transients from the estimates. In contrast, LP attempts to estimate the total abundance which includes transient whales; however, as we show below with the simulation, it is positively biased because there are losses and gains in each set of years and even the trend is unreliable.

The Limited LP abundance estimates for 2010 are biased low because new whales that enter that year have no chance to be re-sighted and thus they were excluded even though some may return in the ensuing years. To a lesser degree, the estimate for 2009and possibly 2008 are influenced in a similar manner because the whales may have been simply not seen yet even though they are returning. The bias is evident by comparing the higher estimates for 2007 and 2008 in Tables 18- 19 to the same values given in Calambokidis et al. (2010) using data through 2008. This same problem occurs with JS2 because new whales that enter in 2010 are excluded because they are all presumed to be transients. Likewise, those that enter in 2009 and are non-transients but are not seen in 2010 are also excluded. This is not a problem for JS1 which includes those data and predicts the proportion of new whales that are non-transients based on the value of MT in their first year seen.

The JS1 sequence provides the best estimate for current N_{min} from 2010 because the LP estimator is biased high and the JS2 and Limited LP estimates for 2010 are biased low. The values of N_{min} range from 104 (Table 20) to 173 (Table 21) across the four spatial scales. To gain a sense for how these values might be relevant to estimating a possible level of removal (e.g., due to harvest) we computed the MMPA's Potential Biological Removal (PBR) (typically reserved for stock-level assessments). Using the PBR formula, with a default Rmax of 4% and a recovery factor of 1, the PBR for the smallest region considered (MUA-SVI), would be 2.1 and the PBR for the largest region (NCA-NBC) would be 3.5 .

New whales have continually appeared annually and many of these new (non-calf) whales have subsequently returned and been re-sighted (Table 14). In MUA-SVI from 1999-2010 ,

an average of 21.2 (range: 5.0, 56.0) new whales were seen each year. Of these new whales, on average 9.4 (range: 1.0, 19.0) whales returned and were seen in subsequent years. Currently recruitment appears to be offset by losses (either mortality or permanent emigration) as the abundance estimates have been fairly stable for the last 8 or 9 years. Presumably if there was a directed harvest recruitment would increase but if the take was 2-4 whales, it will take 5 to 10 years to see much change.

The AWMP implementation trials for the gray whale assessment is based on 1+ abundance. It is not possible to identify every calf when they entered and many were likely missed because much of the survey effort was conducted when calves could have been weaned. As an approximation to the 1+ abundance, we removed observed calves from the u_j in JS1. For NCA-NBC, there were 37 observed calves during the 13 years, but the total reduction in abundance across all years was approximately 20 because the JS1 estimator discounts newly seen whales based on their predicted survival probability. The reduction for OR-SVI is less because there were fewer calves observed in the smaller region. The sequence of estimates for NCA-NBC and OR-SVI are provided in Table . These estimates do not exclude whales first seen as calves in the abundance estimates when they were age 1 or older.

3.6 Abundance Simulation

The simulations clearly showed the positive bias that occurs with the LP estimator when a portion of the population are transients that are only in the population for one occasion (Figure 15). The LP estimates were greater than both total abundance and the abundance of the non-transients. When there was a decreasing trend in transients and an increase in non-transients as with the PCFG gray whales, the LP estimator produced a flat trend hiding the abundance increase. The bias in LP can be demonstrated algebraically. Assume that the population between 2 occasions is constant at N but only a proportion δ remains throughout both occasions and the remaining proportion $1-\delta$ are transient individuals which are only available in each occasion. The number of unique individuals in the population during the 2 occasions is $N\delta + 2N(1-\delta)$. The transient individuals at time 1 have no chance to be seen at time 2 and vice versa. The expected value of the LP estimator is $E(\hat{N}) = Np_1 * Np_2/(N\delta p_1 p_2) = N/\delta > N$. The proportional bias is $(1-\delta)/\delta$ for the annual abundance and $(\delta^2 - 2\delta + 1)/(2\delta - \delta^2)$ for the total unique number of individuals present at any time. Both are positive unless δ=1. For consecutive pairs of years, if δ changes so does the bias which can distort any trend.

The limited LP had far less bias for the non-transient abundance although it tended to underestimate slightly at the beginning and end of the time series due to the way it was constructed. Excluding the initial 1998 estimate, there was also only a slight negative bias for JS1 and JS2, although the latter did better at the beginning of the time series and the former at the end of the time series which was expected due to the way they were constructed. For JS1 and JS2, the estimated population growth rates were generally slightly higher than the true rates (Table 25) except for the end of the series for JS2 due to the negative bias in abundance. Both JS1 and JS2 were less variable than the limited LP rates. If estimates from JS1 or JS were used to fit a generalized logistic growth model it would bias RMax, the maximum rate of increase, and z, the exponent that controls the

location of the inflection point but it would not affect the conclusion that the population is above MNPL, maximum net productivity level, with the abundance pattern evident in the PCFG abundance. The sequences of JS1 and JS2 abundance estimates for the PCFG were quite similar so you would expect the same conclusion from either; however, given that JS1 does not suffer from bias at the end of the sequence, the JS1 abundance estimates from 1999-2010 would provide the best sequence for the population growth assessment.

3.7 Movements outside the PCFG area

Gray whale photographic identifications obtained since the analysis in Calambokidis et al. (2010) have revealed additional long distance matches of gray whales of potential significance to the status of whales in the Pacific Northwest. These are described below representing three specific insights that came from some of these specific comparisons.

3.7.1 Matches to western gray whales

A comparison of Cascadia's entire catalog of photo-identified whales regardless of location or time of year was made to gray whales identified in the western North Pacific off Sakhalin Island. No matches of known PCFG whales were found between these collections. As reported in Weller et al. (2011), six matches were found between these two collections but these six whales were known in the Cascadia catalog. As reported in Weller et al. (2011), the WNP/ENP catalog comparison resulted in six confirmed matches of individuals, including three known males and two known females. All six of the matches were from only two days of effort off southern Vancouver Island, with three whales identified on 2 May 2004 and three on 25 April 2008 by collaborators Brian Gisborne and Wendy Szaniszlo. While the above findings have major implications regarding western gray whales, one other implication relates to whales feeding in the PCFG. That this many (six) matches found to western gray whales was surprising even if most western gray whales did migrate through this area. The Cascadia ENP catalog focuses on gray whales seen in summer and fall and has a relatively small sample of a few hundred gray whales from the spring migration. Given the approximately 20,000 gray whales likely migrating in spring through the PCFG area, finding six matches to the small western gray whale population seems highly improbable. It suggests that western gray whales that come to the eastern wintering grounds may spend periods feeding in the spring in the PCFG area prior to making their longer migration to the west. This could account for their higher probability of having been photographed. Given that the sightings were from just two days, it also could have been more coincidental that these identifications were taken from a potentially associated group of gray whales going to feeding areas in the western North Pacific.

3.7.2 PCFG whales identified near Barrow, Alaska

Of greater significance to the potential status of PCFG whales, two matches were found to nine gray whales identified near Barrow, Alaska and provided by the North Slope Borough (thanks to Craig George and Lori Quakenbush). Five of these were identified in August 2006 and four in August and early September of 2010. Two of these were determined to be

whales identified in other regions. Most surprisingly, one of the whales identified in 2010 off Barrow (CRC ID 850) had been seen in the PCFG area three years in the summer and fall. Sightings included a total of 10 resightings: two days in September and October 2004 and September and October 2006 in the Strait of Juan de Fuca and in June 2008 off west Vancouver Island. The 2nd whale identified off Barrow in August 2006 (CRC ID 1010), was resighted on a single day (24 March 2007) off southern Vancouver Island, consistent with an animal caught in migration. While a single whale out of nine identified off Barrow to be an animal intermittently seen as a part of the PCFG is more anecdotal, it does demonstrate that at least some of the whales seen in repeat years in the PCFG area do travel and feed to some of the farthest away feeding areas.

3.7.3 Photo-identification of satellite tagged migrating gray whales

Additional insights into some of the movements of PCFG whales were gained from recent photo-identification matches to satellite tagged gray whales. Movements of five gray whales were tracked by satellite tags as they migrated north from S Vancouver Island north through British Columbia (Ford et al. ress). Comparison of photographs of these whales to Cascadia's catalog revealed that thee of the five were whales previously identified:

- CRC ID 307 (tag 1 tagged 26 March 2009 in Ford et al. ress): This whale was identified twice in June 1998 and July 1998 off W Vancouver Island but not identified again until the photographed 26 March 2009 in the tagging effort. It transmitted 13 days moving 1,354 km to 58.1N at an average speed of 4.9 km/h (Ford et al. ress).
- CRC 178 (tag 2 in Ford et al. ress): This animal is another long history animal with 94 sightings starting in 1995 almost every year since in many regions including many in WA as well as BC. After being tagged on 24 March 2010, it transmitted 16 days moving 893 km to 55N at an average speed of 1.1 km/h (Ford et al. ress). Unlike the other two tags of matched whales Tag 2 hung around Hesquiat and looks like may have visited Cape Caution before heading north.
- CRC 135 (tag 3 in Ford et al. ress): After being tagged on 24 March 2010, it transmitted 8 days moving 1,141 km to 56.6 N at an average speed of 5.8 km/h (Ford et al. ress). This whale has been identified 168 times every year from 1998 to 2010 in many regions but mostly off S Vancouver Island. These identifications were from June on. These resightings included 29 on 2010 after it had been tagged and appeared to migrate north and were from 9 June to 14 September all at the south end of Vancouver Island near where the tagging had occurred.

There are a couple of important things these satellite tag data reveal. They suggest that some of the PCFG whales may migrate at least part way north and appear to be migrants prior to returning south to primary feeding areas in the PCFG. Only one of the three (ID 135) was actually documented feeding back south in the tag year and the other two either did not come back to the PCFG area that year or where there but did not happen to be photo-identified. The finding of a PCFG whale migrating north of the PCFG area in spring was also revealed by one of the gray whales tagged by OSU in fall 2009 that kept transmitting into spring 2010 (Mate et al. 2011). That animal after spending some time in the southern Vancouver Island area after migrating north from Baja, then continued north to Icy Bay in the Gulf of Alaska before the tag stopped transmitting. While that

animal had been identified in the PCFG in 7 different years going back to 1985, most of these sightings were at the northern end of the PCFG (north of Vancouver Island) and was last identified in 2007 prior to being tagged in December 2009.

While at least two of these animals (Tags 1 and 3) appeared to be migrating animals, it is likely they were engaged in some type of behavior different than typical gray whales from the overall migration otherwise it seems highly improbable that three of the five tagged whales were known PCFG whales given how small a proportion of the overall gray whale migration would be PCFG whales.

4 Discussion

The population structure of gray whales using the Pacific Northwest in summer and fall is complicated and involves two elements. One group of whales return frequently and account for the majority of the sightings in the Pacific Northwest during summer and fall. This group is certainly not homogeneous and even within this group, there is some degree of preference for certain subareas. Despite widespread movement and interchange among areas, some of these gray whales are more likely to be seen returning to the same areas they were seen before. The second group of whales are apparent stragglers encountered in this region after the migration. These animals are seen in only one year, tend to be seen for shorter periods that year, and in more limited areas.

The existence of these two groups in the study area and their dynamics complicate estimating abundance. The various methods we used here for estimating abundance try to deal with this in different ways. The estimates from the unadjusted Lincoln Petersen incorporate whales from both of these groups and the inclusion of the stragglers violates the closure assumption and creates a positive bias. This explains the higher estimate obtained with this method. Even the trend can be distorted as we demonstrated in the simulations. The Limited Lincoln Petersen estimate specifically excludes the stragglers and only estimates the abundance of whales that return after the year of the initial sighting. It is useful except for the last year in which new whales that may return are excluded because they have not had a chance to return. The Limited Lincoln Petersen estimates were similar to the JS1 and JS2 estimates from the open models which also attempt to estimate the non-transient abundance. Excluding 1998, the JS1 sequence of abundance estimates provides the most reliable assessment of trend in the non-transient abundance and the best estimate of current abundance in 2010.

Despite extensive interchange among subregions in our study area, whales do not move randomly among areas. Abundance estimates were lower when using more limited geographic ranges but these more limited areas do not reflect closed populations. While the use of geographically stratified models can be useful in cases where populations have geographic strata they use (see for example Hilborn 1990), this would be difficult in our case because of the frequent sightings of animals in multiple regions within the same season and these models typically only allow an animal to be sighted in one strata per period. This could be dealt with by assigning animals to only a single region per season but this would be forcing the data into a somewhat inaccurate construct.

Several studies have considered the question of gray whale population structure. There

is widespread agreement that at least two populations of gray whales in the North Pacific exist, a western North Pacific population (also called the Korean population) and an eastern North Pacific (ENP) population (sometimes called the California population) (Swartz et al. 2006; Angliss and Outlaw 2008; Rugh et al. 1999). The population structure of the gray whales feeding in the Pacific Northwest has remained in question and only a few studies have examined this. Steeves et al. (2001) did not find mtDNA differences in a preliminary comparison of gray whales from the summer off Vancouver Island and those from the larger ENP population. Ramakrishnan et al. (2001) did not find evidence that the Pacific Northwest whales represented a maternal genetic isolate, although even very low levels of recruitment from the larger overall population would prevent genetic drift. More recently, Frasier et al. (2011) generated mtDNA sequences from a larger sample of gray whales from Vancouver Island than tested by Steeves et al. (2001). They found significant differences in the haplotype frequencies between that sample and mtDNA sequence data reported for ENP gray whales, most of which were animals that stranded along the migratory route. The Frasier et al. (2011) samples were from a relatively small area; however,Lang et al. (2011) evaluated biopsy samples from California to southern Vancouver Island in the PCFG and ENP samples from whales sampled north of the Aleutians and also found significant mtDNA halpotype frequency differences. These two studies provide the strongest evidence to date that the Pacific Northwest whales might be sufficiently isolated to allow maternally inherited mtDNA to differ from the overall ENP population.

Population structure in other large whales has been the subject of recent inquiry and has revealed diverse results for different species. Clapham et al. (2008) examined 11 subpopulations of whales subjected to whaling that were extirpated possibly due to the loss of the cultural memory of that habitat and concluded subpopulations often exist on a smaller spatial scale than had been recognized. Studies of other baleen whales, particularly humpback whales, have shown evidence of maternally directed site fidelity to specific feeding grounds based on photographic identification studies (Calambokidis et al. 1996, 2001, 2008). This high degree of fidelity to specific feeding areas is often discernible genetically. In the North Pacific strong mtDNA differences were found among feeding areas even when there was evidence of low level of interchange from photo-ID (Baker et al. 2008). Similar findings were documented for humpback whales in the North Atlantic which feed in different areas but interbreed primarily on a single breeding ground (Palsboll et al. 1995) like ENP gray whales. In the North Pacific the differences for humpback whales were often dramatic. For example, humpback whales that feed off California have almost no overlap in mtDNA haplotypes with humpback whales feeding in Southeast Alaska (Baker et al. 1990, 1998, 2008). One difference between humpback and gray whales is the coastal migration route of gray whales which means gray whales going to arctic waters to feed would migrate right through the feeding areas to the south. Other species of large whales have not shown as strong site fidelity to specific feeding grounds. Blue whales have undergone an apparent shift in their feeding distribution in the North Pacific apparently due to shifting oceanographic conditions (Calambokidis et al. 2009a). Fin whales in the North Pacific have long migrations and while there do not appear to be multiple distinct feeding areas as was the case for humpback whales, there were some distinct and isolated apparently non-migratory populations (Mizroch et al. 2009; Berube et al. 2004).

Even though the population structure of gray whales off the Pacific Northwest remains

unresolved, there is a consistent group of animals that use this area and we provide several estimates of their abundance. Different abundance methods and geographic scopes yield varied results but all suggest the annual abundance of animals using the Pacific Northwest for feeding through the summer is at most a couple hundred animals depending on the estimating method and how broadly the region is defined geographically.

The apparent rapid increase in the abundance estimates derived from the limited LP and Jolly-Seber models in the first five years of this study appear incompatible with this being a relatively distinct group since it would require a high rate of external recruitment, however, the exact rate of this increase should be viewed with caution. This rapid increase at the start of our study occurred during a period the overall eastern North Pacific gray whale population was experiencing a high mortality event that included unusually high numbers of gray whales showing up in areas they were not common. The simulation did show that the initial estimates were negatively biased low and would over-estimate recruitment but reflected the general trend. We did expand the analysis to include the 1996 and 1997 data and the 1998 estimate did increase by about 7% but the sampling prior to 1998 was opportunistic and not broad scale, so it is possible that some of the "new" whales seen during 1999-2001 may have been present in the PCFG prior to 1998 in areas that were not sampled and included in the CRC database. The high rate of increase in the late 1990s and early 2000s should be verified with additional data such as compiling photographic identifications for this area from multiple sources to attempt to verify if the abundance of animals prior to the start of our study was as low as suggested by these trends. Even though the rate of increase may be too high, we believe the abundance did increase and now appears to be relatively stable since 2002.

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Table 1: Contributions of numbers of photos by reseach group for 1998-2010and resulting number of uniquely identified whales. Totals for whales are unique whales across all research groups.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Whales
Brian Gisborne	373	343	779	585	435	883	325	429	527	117	525	368	633	358
Canada Fisheries/Oceans	0	0	0	0	0	0	0	0	0	0	0	0	12	11
Carrie Newell	0	0	0	0	0	0	0	0	13	73	0	20	2	46
CERF	101	150	251	466	295	180	781	11	42	11	38	4	7	107
CRC	170	231	118	79	135	112	182	33	62	102	95	56	76	388
Dawn Goley-HSU	21	89	60	75	71	0	0	0	0	0	44	19	88	183
Jan Straley-UASE	0	0	0	0	0	7	0	0	1	1	0	0	0	7
Jeff Jacobsen-HSU	0	0	0	0	0	0	0	0	0	1	0	6	129	57
Jim Darling	50	0	0	35	14	0	0	0	0	0	0	0	0	59
MAKAH	0	0	0	0	0	0	44	58	142	84	247	131	53	158
MAKAH-NMML	0	0	0	0	0	0	0	0	0	0	0	80	27	56
NMML	132	194	135	128	88	76	0	133	93	39	143	9	7	341
North Slope Borough	0	0	0	0	0	0	0	0	5	0	0	0	7	9
Opportunistic	4	12	1	1	0	0	0	1	29	48	23	64	49	95
OSU	0	0	0	0	0	0	0	0	0	0	0	20	0	18
UAF	0	0	0	0	0	0	0	0	0	0	25	0	23	40
UVIC	351	159	128	0	121	0	0	0	0	1	0	16	0	139
Volker Deecke	39	42	28	11	0	0	0	0	50	0	0	0	0	74
Wendy Szaniszlo	0	0	0	0	0	0	0	125	67	71	144	5	24	107
Photo Totals	1241	1220	1500	1380	1159	1258	1332	790	1031	548	1284	798	1137	
Whale Totals	156	248	176	198	253	178	195	205	191	158	221	222	218	1031

Table 2: Regional distribution of numbers of photos and resulting number of uniquely identified whales by reseach group for 1998-20102010. Totals for whales are unique whales across all research groups. NPS is northern Puget Sound and PS includes southern Puget Sound, San Juan Islands, Hood Canal and Boundary Bay.

	CA	NCA	SOR	OR	GH+	NWA	SJF	PS	NPS	SVI	WVI	NBC	SEAK	KAK
Brian Gisborne	0	0	0	0	0	0	0	1	0	6133	186	2	0	0
Canada Fisheries/Oceans	0	0	0	0	0	0	0	0	0	12	0	0	0	0
Carrie Newell	0	0	0	108	0	0	0	0	0	0	0	0	0	0
CERF	0	0	0	0	0	0	0	0	0	0	0	2337	0	0
CRC	29	101	185	140	211	90	23	68	444	33	0	120	7	0
Dawn Goley-HSU	0	430	0	37	0	0	0	0	0	0	0	0	0	0
Jan Straley-UASE	0	0	0	0	0	0	0	0	0	0	0	0	9	0
Jeff Jacobsen-HSU	0	105	28	3	0	0	0	0	0	0	0	0	0	0
Jim Darling	0	0	0	0	0	0	0	0	0	6	93	0	0	0
MAKAH	0	0	0	19	0	227	513	0	0	0	0	0	0	0
MAKAH-NMML	0	0	0	0	0	69	38	0	0	0	0	0	0	0
NMML	0	8	42	0	0	263	283	0	22	196	179	13	0	171
North Slope Borough	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Opportunistic	24	2	0	35	0	1	27	34	77	9	1	11	7	0
OSU	0	20	0	0	0	0	0	0	0	0	0	0	0	0
UAF	0	0	0	0	0	0	0	0	0	0	0	0	0	48
UVIC	0	0	0	0	0	0	0	0	0	1	775	0	0	0
Volker Deecke	0	0	0	0	0	0	0	1	0	122	0	43	4	0
Wendy Szaniszlo	0	0	0	0	0	0	0	0	0	241	195	0	0	0
Photo Totals	53	666	255	342	211	650	884	104	543	6753	1429	2526	27	219
Whale Totals	36	205	85	105	97	216	129	42	51	352	214	116	21	121

Table 3: Survey regions and region subsets used for abundance estimation. Numbers refer to locations on the map in Figure 1.

Survey Region	Region Description	NCA-NBC	OR-NBC	OR-SVI	MUA-SVI
(1) SCA = Southern California					
(2) CCA = Central California					
(3) NCA = Northern California	Eureka to Oregon border; mostly from Patricks Pt. and Pt. St George	x			
(4) SOR = Southern Oregon		x	x	x	
(5) OR = Oregon Coast	Primarily central coast near Depoe Bay and Newport, OR	x	x	x	
(6) GH+ = Gray's Harbor	Waters inside Grays Harbor and coastal waters along the S Washington coast	x	x	x	
(7) NWA = Northern Washington	Northern outer coast waters with most effort from Cape Alava to Cape Flattery	x	x	x	x
(8) SJF = Strait of Juan de Fuca	US waters east of Cape Flattery extending to Admiralty Inlet (entrance to Puget Sound)	x	x	x	x
(9) NPS = Northern Puget Sound	Inside waters and embayments from Edmonds to the Canadian border				
(10) PS = Puget Sound	Central and southern Puget Sound (S of Edmonds), including Hood Canal, Boundary Bay, and the San Juan Islands				
(11) SVI = Southern Vancouver Island	Canadian waters of the Strait of Juan de Fuca along Vancouver Island from Victoria to Barkley Sound, along West Coast Trail	x	x	x	x
(12) WVI = West Vancouver Island		x	x		
(13) NBC = Northern British Columbia	British Columbia waters north of Vancouver Island, with principal effort around Cape Caution	x	x		
(14) SEAK = Southeast Alaska	Waters of southeastern Alaska with the only effort in the vicinity of Sitka				
(15) KAK = Kodiak, Alaska					

Table 5: Model specifications for survival (φ) and capture probability (p) parameters in POPAN models for gray whale photo-identification data. For survival models, β_0 is the baseline intercept for non-transient survival. Fy is 1 if it is year the whale was first seen and 0 otherwise. Fc is 1 for 1998 cohort and 0 otherwise. C is 1 if identified as a calf in its first year and 0 otherwise. R is 1 for calves or any whale seen in 1998 or was already in the catalog prior to 1998 and 0 otherwise. β_r is an adjustment to post-first-year survival. MT is minimum tenure value of a whale and β_M is the estimated slope parameter for φ or p. $\beta_{M,1998}$applies only to 1998 and $\beta_{M,1999}$ applies to 1999-2010. $\beta_{Fy,1999}$ is the first-year survival intercept adjustment for cohorts 1999-2009 and $\beta_{Fy,c}$ represents 11 cohort-specific first year survival parameters for 1999-2008. β_{CF} is an adjustment for calf first year survival and β_{CM} is an adjustment for calves to the slope of MT for survival. For the capture probability models, β_t has 11 levels for t=2000,...2010 and β_0 represents the 1999 value. For 1998 p=1.

Model	Parameter Logit Formula	Number of parameters
φ		
1	$\beta_0 + \beta_{Fy} Fy + \beta_r R(1-Fy)$	2
2	$\beta_0 + \beta_{Fy} Fy + \beta_M MT\, Fy + \beta_r R(1-Fy)$	3
3	$\beta_0 + \beta_{Fy,1998} Fy + \beta_{Fy,1999}(1-Fc) Fy + \beta_r R(1-Fy)$	3
4	$\beta_0 + \beta_{Fy,1998} Fy + \beta_{Fy,1999}(1-Fc) Fy + \beta_M MT\, Fy + \beta_r R(1-Fy)$	4
5	$\beta_0 + \beta_{Fy,1998}\, Fy + \beta_{Fy,1999}(1-Fc)\, Fy + \beta_{M,1998} MT\, Fy + \beta_{M,1999}(1-Fc)\, MT\, Fy + \beta_r R(1-Fy)$	5
6	$\beta_0 + \beta_{Fy,1998} Fy + \beta_{Fy,c} Fy\,(1-Fc) + \beta_M MT\, Fy + \beta_r R(1-Fy)$	14
7	$\beta_0 + \beta_{Fy,1998} Fy + \beta_{Fy,c} Fy\,(1-Fc) + \beta_M MT\, Fy + \beta_{CF} C\, F_y + \beta_r R(1-Fy)$	15
8	$\beta_0 + \beta_{Fy,1998} Fy + \beta_{Fy,c} Fy\,(1-Fc) + \beta_M MT\, Fy + \beta_{CF} C\, F_y + \beta_{CM} C\, MT + \beta_r R(1-Fy)$	16
9	$\beta_0 + \beta_{Fy,1998}\, Fy + \beta_{Fy,1999}(1-Fc)\, Fy + \beta_{M,1998} MT\, Fy + \beta_{M,1999}(1-Fc)\, MT\, Fy + \beta_{CF} C\, F_y + \beta_r R(1-Fy)$	6
10	$\beta_0 + \beta_{Fy,1998}\, Fy + \beta_{Fy,1999}(1-Fc)\, Fy + \beta_{M,1998} MT\, Fy + \beta_{M,1999}(1-Fc)\, MT\, Fy + \beta_{CF} C\, F_y + \beta_{CM} C\, MT + \beta_r R(1-Fy)$	7
p		
1	$\beta_0 + \beta_t$	12
2	$\beta_0 + \beta_t + \beta_M MT$	13
3	$\beta_0 + \beta_M MT$	2

Table 6: Regional distribution of numbers of whales seen by month for 1998-2010.

	1	2	3	4	5	6	7	8	9	10	11	12
CA	0	1	3	7	5	2	6	6	6	1	0	1
NCA	0	0	0	0	9	44	93	52	28	74	40	16
SOR	0	0	0	2	0	0	24	22	52	32	0	0
OR	0	0	0	0	3	10	32	50	46	43	0	0
GH+	2	1	14	40	14	17	2	0	27	1	0	0
NWA	4	0	8	34	69	18	47	69	58	37	5	0
SJF	0	0	3	10	20	20	27	35	52	73	47	11
PS-HC-BB-SJ	0	1	6	21	8	9	5	2	1	1	3	1
NPS	0	2	16	28	30	12	1	0	0	0	0	0
SVI	1	1	63	55	79	175	208	164	128	51	14	7
WVI	0	1	2	5	2	44	135	127	87	15	0	0
NBC	1	0	0	0	2	24	76	101	82	0	0	0
SEAK	0	0	0	0	0	12	4	1	3	0	5	0
KAK	0	0	0	0	0	17	23	52	44	0	0	0

Table 7: Regional distribution of numbers of whales seen during June-November for 1998-2010.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
CA	0	1	0	5	0	0	4	0	3	0	0	3	6
NCA	15	38	27	32	37	15	3	0	0	1	47	26	63
SOR	0	0	0	2	46	24	13	1	0	23	15	2	15
OR	17	31	8	15	0	0	16	4	9	38	6	12	18
GH+	0	1	1	1	0	0	1	0	0	38	0	2	0
NWA	21	7	9	31	7	19	0	19	44	13	27	25	22
SJF	17	4	5	2	1	9	21	18	21	14	49	34	4
PS-HC-BB-SJ	3	8	4	0	0	0	0	1	0	0	0	4	0
NPS	0	0	10	0	0	0	0	0	0	0	0	2	2
SVI	60	45	52	102	66	90	86	91	70	34	77	77	63
WVI	57	66	53	29	85	9	0	53	40	13	23	23	10
NBC	23	26	23	40	44	51	91	12	21	5	21	3	4
SEAK	5	6	0	1	0	6	0	1	2	3	0	0	0
KAK	0	0	0	0	42	4	0	48	0	0	23	0	17

Table 8: Number of days in which whales were seen for each region and year from 1998-2010from 1 June - 30 November.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
CA	0	1	0	2	0	0	2	0	1	0	0	2	3
NCA	7	8	20	13	20	2	2	0	0	2	9	16	21
SOR	0	0	0	1	4	1	1	1	0	3	1	1	5
OR	6	9	5	7	0	0	1	1	7	38	1	11	4
GH+	0	1	1	1	0	0	1	0	0	3	0	1	0
NWA	22	10	7	11	3	9	0	12	13	6	8	5	14
SJF	16	9	9	4	2	15	5	14	18	26	34	25	4
PS-HC-BB-SJ	3	11	4	0	0	0	0	2	0	0	0	4	0
NPS	0	0	1	0	0	0	0	0	0	0	0	2	3
SVI	91	87	82	55	68	66	48	73	59	36	72	71	80
WVI	54	46	28	7	10	3	0	6	14	27	31	5	2
NBC	39	50	53	43	34	29	53	11	16	9	13	2	8
SEAK	2	3	0	1	0	3	0	1	2	2	0	0	0
KAK	0	0	0	0	4	2	0	7	0	0	5	0	2

Table 9: Interchange of whales across regions for all years (1998-2010) for June-November. The diagonal is the number of unique whales seen in that region over the13 year time span. Here PS includes NPS and CA represents SCA and CCA.

	CA	NCA	SOR	OR	GH+	NWA	SJF	PS	SVI	WVI	NBC	SEAK	KAK
CA	20												
NCA	4	197											
SOR	4	45	83										
OR	2	51	46	104									
GH+	1	12	8	14	42								
NWA	2	39	36	50	21	124							
SJF	1	17	12	25	14	54	112						
PS	0	0	0	0	0	1	2	31					
SVI	6	59	43	64	29	100	73	1	270				
WVI	2	40	29	51	24	74	57	1	141	206			
NBC	2	11	9	24	14	31	26	2	73	70	113		
SEAK	0	1	1	2	1	2	3	0	7	8	10	21	
KAK	0	4	1	3	0	1	0	0	8	6	6	1	121

Table 10: Number of photographs by month in all regions and years(1998-2010)for a sample of whale IDs.

	1	2	3	4	5	6	7	8	9	10	11	12
6	0	0	0	0	2	2	1	5	3	3	1	0
80	0	0	0	1	8	29	63	61	20	2	0	0
141	0	0	3	1	0	6	20	32	10	0	0	0
204	0	0	0	0	0	6	19	38	31	7	3	0
246	0	0	0	0	0	0	1	2	0	0	0	0
272	0	0	0	0	0	0	0	1	0	0	0	0
302	0	0	2	1	7	13	27	30	19	0	0	0
328	0	0	15	0	0	1	31	24	19	0	2	0
373	0	0	0	0	0	0	2	0	0	0	0	0
399	0	0	0	1	8	10	0	0	0	0	0	0
426	0	0	0	0	1	0	0	0	0	0	0	0
453	0	0	0	0	1	0	0	0	0	0	0	0
482	0	0	0	0	2	0	0	0	0	0	0	0
518	0	0	0	0	0	0	0	1	0	0	0	0
545	0	0	0	0	1	0	0	0	0	0	0	0
571	0	0	0	0	1	2	2	0	0	0	0	0
596	0	0	0	0	0	3	2	0	0	0	0	0
623	0	0	0	0	0	0	2	0	0	0	0	0
648	0	0	0	0	0	0	0	2	0	0	0	0
683	0	0	0	0	0	1	9	0	2	4	0	0
709	0	0	0	0	0	3	2	2	0	0	0	0
735	0	0	0	0	0	0	0	1	0	0	0	0
760	0	0	0	0	0	1	11	9	7	0	0	0
788	0	0	0	0	0	4	0	8	1	1	0	0
815	0	0	0	0	0	2	6	0	0	0	0	0
844	0	0	0	0	0	0	0	1	0	0	0	0
869	0	0	0	0	0	0	0	1	0	0	0	0
897	0	0	0	0	0	0	0	0	3	0	0	0
928	0	0	0	0	0	2	0	0	0	0	0	0
955	0	0	1	0	0	0	0	0	0	0	0	0
980	0	0	0	0	0	0	0	0	1	0	0	0
1007	0	0	1	0	0	0	0	0	0	0	0	0
1033	0	0	0	0	0	0	1	0	0	0	0	0
1059	0	0	0	0	0	1	0	2	0	7	0	0
1085	0	0	0	0	0	0	2	0	0	0	0	0
1110	0	0	0	0	0	0	0	0	0	3	0	0
1135	0	0	0	1	0	0	0	0	0	0	0	0
1160	0	0	0	0	0	2	0	0	0	0	0	0
1185	0	0	0	2	0	0	0	0	0	0	0	0
1211	0	0	0	0	3	1	0	0	0	0	0	0
1236	0	0	0	0	0	0	0	2	0	1	0	0
1261	0	0	0	0	0	0	0	1	0	0	0	0

Table 11: History of mothers seen with calves during study. Each year a whale was seen, the first confirmed sighting date is shown for that year. Years where a calf was documented are shown with an asterisk. Total years seen includes 16 sightings of whales during 1984,1988, 1990-1993 that are not shown but no calves were seen in those few cases.

Mother ID	Calves	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Years seen
43	2	9-Jul*	22-Jul	15-Jul	9-Aug	11-Jul	16-Jul	19-Jun	18-Jul*	12-Jul	24-Jun	4-Jul		7-Jul					16
67	3		19-Jul*	2-Jul	6-Jul		10-Aug			7-Aug*		4-Jun*	3-Aug	4-May					9
80	2	25-Aug	23-Jun	8-Aug		8-Jun	27-Jun	3-Jul	7-May	22-May*	27-Apr	25-Jun	18-Jun*						12
81	3		19-Aug		23-Sep	14-Jun	21-Jun	29-Jul	20-Jun*	24-Jun	28-Jul*	23-Jul	3-Jul	4-Jul	16-Jun		16-Jul*		14
91	1					23-Jun		22-Jul	15-Aug	5-Jul*	17-Jun		23-Jun		11-Jul	18-Jun			9
92	2			27-Jul	9-Aug	4-May	30-Jun	29-Jul	9-Jul	4-Aug	27-Jul	11-Jul	27-Jun*	18-Jun	8-Jun	22-May	4-Apr	5-Jun*	16
93	1			17-Jul	23-Sep	14-Jun	22-Jun	12-Aug	21-Jun	16-Jul	2-Aug	30-Jun*		4-Jul		18-Jun	8-Jun		14
94	1	4-Aug				27-Jun	6-Jul	24-Jul	7-Jul	15-Jul	23-Jul	5-Aug	13-Jul	18-Mar	8-Jul*	8-Jul	2-Jun	31-Mar	15
101	1	22-Jun	6-Sep	5-Sep		11-Jun	8-Jul	29-Jul	8-Jun	9-Jul	9-Aug	15-Jun*	1-Aug	7-Jun	8-Jun	28-Jun	24-Apr	15-Jun	19
105	1	9-Jul*				17-Jun	9-Jun	20-Jul	22-Jun	3-Jul	2-Aug	23-Jul	24-Jul	28-Jul	22-Jun				11
120	1								13-Jun*	11-Jun		2-Jun						6-Jul	4
143	1					27-Jun	29-Jun	1-May	6-Jul	29-Jul*	17-Aug		5-Sep	12-Mar	24-Mar	22-Jun	14-Aug	10-Mar	12
144	1					11-Jul	13-Aug	6-Sep	6-Jul	5-Jul*	30-Mar	19-Jun	26-May	4-Jul	31-Mar	25-May	4-Apr	26-Mar	13
175	1		22-Jul	13-Jun	27-Jun	26-May	9-Jun	29-May	15-Jun	3-Jul	12-May*	30-Jun	21-Jul	4-Jul	15-Jul				13
216	1				27-Jun	23-Aug	30-Jul	29-Jun	15-Jun	15-Jul	26-Jul*	4-Jun	9-Jun						9
232	2					6-Jul		30-Jul	5-Jul*	15-Aug	9-Jun*								5
237	1					23-Jul	25-Jul	4-Jul	5-Jul	1-Jul	29-Apr*	19-Jul							7
281	2						20-Jul	15-Jul	21-Jun	17-Aug*	5-Sep	19-Jul	13-Aug	7-Jul	14-Sep	19-Apr*	14-Aug		12
291	1					1-Oct	12-Jul	24-Aug	8-Jun*	4-Aug	25-Jun	24-Jul	21-Jul	5-Jul		20-Oct	14-Nov	6-Aug	12
312	2					12-Jun*			7-Jul									22-Jun*	3
321	1					25-Jun*													1
372	1						26-Jun	9-May		4-Aug	15-Jul	25-Jun*	7-Jul	3-Jul	1-Sep		10-Jul	5-Aug	10
566	1							6-Jul		17-Aug		14-Aug	2-Sep					22-Jun*	5
575	1								5-Jun*										1
581	1								5-Jun*					4-Jul	30-Jun				3
596	1								26-Jun*	3-Jul									2

Table 11: continued

Mother ID	Calves	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Years seen
612	1							23-Jun	1-Aug*	1-Jul	5-Jun	1-Jul	18-Jul	5-Nov					7
668	1									6-Sep		22-Sep			19-Aug			9-May*	4
683	1									25-Jul*		27-Oct	18-Jun						3
684	1									4-Jul*	11-Aug								2
717	1									3-Jul*									1
801	1										7-Jul	2-Aug	3-May*						3
815	1											19-Jun*				14-Jul			2
973	1														14-Sep*			6-Aug	2
993	1													1-May	14-Aug*				2
Calves	45	2	1	0	0	2	0	0	9	9	5	5	3	0	3	1	1	4	

Table 12: Sighting histories of calves identified in the study area. First separate date represents sighting of either the calf or mother alone. An asterisk by the calf ID implies it is suspected to be a calf; others are all known to be calves.

Calf ID	Mother ID	First date w/ mother	Last date w/ mother	First separate date	1994	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Yrs
104	105	9-Jul-94	9-Jul-94		1																1
107	43	9-Jul-94	4-Aug-94		2	1	2	7	1	34	10	1	15	11	9	10	3	12			14
169*	67	19-Jul-95	23-Jul-95			4					3	5	10	5	3	7	2	5			9
246*		11-Aug-98	17-Aug-98					3													1
307	312	28-Jun-98	9-Jul-98					2													1
310	321	25-Jun-98	4-Jul-98	6-Jul-98				3	1												2
583	581	5-Jun-01	4-Oct-01								5	1	6		6	2	12	13			7
584	81	20-Jun-01	18-Jul-01	22-Jul-01							3	1		27	3	4	2				6
595	596	26-Jun-01	29-Jun-01								3										1
611	43	18-Jul-01	31-Jul-01	28-Oct-01							4						1				2
620	232	5-Jul-01	31-Jul-01								2										1
626	291	8-Jun-01	8-Jun-01	15-Jun-01							2										1
657	281	17-Aug-02	6-Sep-02									2	1		1	1	3	2			6
682	80	22-May-02	29-Jul-02	18-Aug-02								6	23	2	7	10	3	13			7
685	684	4-Jul-02	4-Aug-02									5									1

Table 12: continued

Calf ID	Mother ID	First date w/ mother	Last date w/ mother	First separate date	1994	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Yrs
686	717	3-Jul-02	3-Jul-02									3									1
687	683	25-Jul-02	29-Jul-02									2				7	1	3			4
688	91	5-Jul-02	15-Jul-02	6-Sep-02								6	5	4	10	11	2	4			7
698*	67	7-Aug-02	6-Sep-02	14-Oct-02								4	8	1	12	9	1	10			7
714	144	5-Jul-02	4-Aug-02									1				6		16			3
720	143	29-Jul-02	3-Sep-02	30-Sep-02								1	10	7	6	5	6	18			7
786	232	9-Jun-03	3-Jul-03	15-Jul-03									11	6	2	16	5	11			6
797	81	28-Jul-03	28-Jul-03	30-Jul-03									1	2	7	18	12	11			6
798*	175	12-May-03	12-May-03	16-Jun-03									1								1
860*	216	26-Jul-03	28-Jul-03	26-Aug-03									3	4	4	9	2	1			6
811	815	19-Jun-04	17-Jul-04											5							1
814	372	25-Jun-04	30-Jun-04											2							1
818	101	17-Jul-04	17-Jul-04	20-Aug-04										2	2	5	2				4
819	67	4-Jun-04	27-Aug-04	22-Sep-04										8	6	20	20	14			5

Table 12: continued

Calf ID	Mother ID	First date w/ mother	Last date w/ mother	First separate date	1994	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Yrs
824	93	30-Jun-04	11-Jul-04	14-Aug-04										4	8			9			3
862*	801	3-May-05	3-May-05	21-Jul-05											5						1
863	92	27-Jun-05	24-Jul-05	4-Aug-05											10						1
882	80	18-Jun-05	19-Jun-05	4-Jul-05											3	10	13	14			4
976*	973	14-Sep-07	14-Sep-07														1				1
990	94	8-Jul-07	5-Aug-07														4	7			2
994	993	5-Aug-07	14-Aug-07														1				1
1066	281	19-Apr-08	19-Apr-08															1			1
1173	81	16-Jul-09	18-Jul-09																2		1
1212	668	9-May-10	9-May-10																	1	1
1234	566	22-Jun-10	1-Jul-10																	2	1
1237	312	22-Jun-10	1-Jul-10	6-Aug-10																4	1
1254	92	5-Jun-10	7-Jul-10	18-Jul-10																20	1

Table 13: RELEASE goodness of fit results for 3 regions using pooled and separate cohorts. When cohorts are separated as groups, Test 3 is always 0 because there are no sub-cohorts.

Region	Cohort	Test	χ^2	df	P
MUA-SVI	Pooled				
		Test 2	53.6	19	0
		Test 3	165.2626	21	0
		Total	218.8626	40	0
	Separate				
		Test 2	56.5057	47	0.1613
OR-SVI	Pooled				
		Test 2	85.9075	25	0
		Test 3	211.3463	21	0
		Total	297.2538	46	0
	Separate				
		Test 2	65.0763	53	0.1235
OR-NBC	Pooled				
		Test 2	126.9031	18	0
		Test 3	333.0608	21	0
		Total	459.964	39	0
	Separate				
		Test 2	89.7225	50	5e-04
NCA-NBC	Pooled				
		Test 2	143.1829	19	0
		Test 3	432.4828	21	0
		Total	575.6657	40	0
	Separate				
		Test 2	102.5383	49	0

Table 14: Number of whales seen each year, number that were new that year in that region, and number that were new and were seen in a subsequent year for whales seen between June-November 1998-2010 in each region. The year a whale was seen as new can vary across regions and if it differs will be later in the smaller region.

Region		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
MUA-SVI	Seen	73	48	60	116	68	96	95	104	93	45	103	97	72
	Non-calf: New	73	13	23	56	22	31	25	21	13	5	17	20	8
	Non-calf: New/Resighted	53	8	15	18	9	19	9	9	5	1	6	4	0
	Calf: New	1	0	0	5	6	3	5	3	0	1	1	1	1
	Calf: New/Resighted	0	0	0	2	4	3	3	1	0	1	0	0	0
OR-SVI	Seen	84	71	67	129	103	110	114	109	100	113	119	107	94
	Non-calf: New	84	26	26	58	40	26	29	21	12	24	18	19	11
	Non-calf: New/Resighted	63	12	17	19	21	17	11	11	4	5	7	5	0
	Calf: New	1	0	0	6	7	3	5	3	0	2	1	1	1
	Calf: New/Resighted	0	0	0	3	5	3	3	1	0	1	0	0	0
OR-NBC	Seen	116	120	113	151	179	154	177	138	130	118	134	113	104
	Non-calf: New	116	50	37	54	51	26	35	22	9	25	20	19	13
	Non-calf: New/Resighted	92	16	21	19	27	16	11	10	2	5	6	5	0
	Calf: New	3	0	0	6	9	3	5	3	0	3	1	1	1
	Calf: New/Resighted	0	0	0	3	7	3	3	1	0	1	0	0	0
NCA-NBC	Seen	130	152	137	174	205	157	179	138	130	119	171	128	147
	Non-calf: New	130	75	54	65	57	21	32	22	9	22	46	25	21
	Non-calf: New/Resighted	101	17	31	25	23	13	10	10	2	7	12	9	0
	Calf: New	3	0	0	6	9	3	5	3	0	3	1	1	3
	Calf: New/Resighted	1	0	0	3	7	3	3	1	0	1	0	0	0

Table 15: Delta AICc and QAICc (for OR-NBC and NCA-NBC models) for 30 models fitted to each set of data.

		φ Model									
Region	p model	1	2	3	4	5	6	7	8	9	10
MUA-SVI	1	120.7	82.5	113.8	81.4	83.1	86.4	88.4	90.3	90.3	86.7
	2	30.6	1.1	25.2	0.0	1.2	7.2	9.2	11.3	3.1	5.1
	3	100.0	69.1	94.3	67.8	69.1	72.7	74.7	76.7	70.9	72.8
OR-SVI	1	170.4	122.6	159.1	120.1	121.4	118.6	120.7	121.9	123.3	124.5
	2	39.6	2.6	30.5	0.0	0.6	0.3	2.4	3.9	2.6	4.2
	3	48.8	12.3	39.7	9.6	10.1	8.7	10.8	12.3	12.0	13.6
OR-NBC	1	137.6	95.3	24.6	89.7	89.6	95.1	96.9	97.3	91.7	92.1
	2	40.4	6.5	24.6	0.7	0.0	7.2	9.0	9.7	2.0	2.7
	3	54.4	20.5	38.4	14.4	13.7	19.3	21.0	21.7	15.7	16.3
NCA-NBC	1	127.0	87.2	105.4	77.0	77.2	83.0	85.1	86.0	79.0	80.0
	2	42.9	10.6	23.8	0.3	0.0	7.4	9.4	10.7	1.8	3.0
	3	57.9	25.3	38.9	15.3	14.9	21.2	23.2	24.4	16.7	17.9

Table 16: Number of whales seen in each year and number seen in both years and abundance estimate ($\widehat{N}$), standard error and minimum population estimate $N_{min} = \widehat{N}e^{-0.864\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ for Lincoln-Petersen estimator applied to consecutive years from 1998-2010 in MUA-SVI and OR-SVI regions.

Region	Year (y)	Seen in year y-1	Seen in year y	Seen in both years	$\widehat{N}$	$se(\widehat{N})$	N_{min}
MUA-SVI	1999	73	48	35	99	6.1	94
	2000	48	60	29	98	8.1	91
	2001	60	116	46	150	8.1	143
	2002	116	68	42	186	14.0	174
	2003	68	96	40	162	12.4	151
	2004	96	95	56	162	8.8	154
	2005	95	104	56	175	10.1	167
	2006	104	93	61	157	7.5	151
	2007	93	45	30	138	11.8	128
	2008	45	103	33	139	10.1	130
	2009	103	97	68	146	5.6	141
	2010	97	72	50	138	7.4	132
OR-SVI	1999	84	71	45	131	8.0	125
	2000	71	67	34	138	11.9	128
	2001	67	129	50	171	9.4	163
	2002	129	103	53	249	18.2	234
	2003	103	110	59	191	11.0	182
	2004	110	114	68	183	8.6	176
	2005	114	109	61	202	11.6	193
	2006	109	100	64	169	8.1	162
	2007	100	113	59	190	10.9	181
	2008	113	119	69	194	9.3	186
	2009	119	107	78	162	5.5	158
	2010	107	94	60	166	8.5	159

Table 17: Number of whales seen in each year and number seen in both years and abundance estimate ($\widehat{N}$), standard error and minimum population estimate $N_{min} = \widehat{N}e^{-0.864\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ for Lincoln-Petersen estimator applied to consecutive years from 1998-2010 in OR-NBC and NCA-NBC regions.

Region	Year (y)	Seen in year y-1	Seen in year y	Seen in both years	$\widehat{N}$	$se(\widehat{N})$	N_{min}
OR-NBC	1999	116	120	70	198	9.5	190
	2000	120	113	66	204	10.8	195
	2001	113	151	84	202	7.4	196
	2002	151	179	106	254	8.5	247
	2003	179	154	119	231	5.8	226
	2004	154	177	117	232	6.1	227
	2005	177	138	97	251	9.3	243
	2006	138	130	92	194	6.2	189
	2007	130	118	74	206	9.5	198
	2008	118	134	73	215	10.4	207
	2009	134	134	84	179	6.0	174
	2010	113	113	68	172	7.6	165
NCA-NBC	1999	130	152	77	255	13.0	244
	2000	152	137	71	292	17.5	277
	2001	137	174	93	255	10.2	247
	2002	174	205	121	294	9.4	286
	2003	205	157	126	254	6.2	249
	2004	157	179	118	237	6.3	232
	2005	179	138	97	254	9.4	246
	2006	138	130	92	194	6.2	189
	2007	130	119	74	208	9.7	200
	2008	119	171	76	266	13.6	255
	2009	171	128	92	237	8.8	229
	2010	128	147	86	218	8.6	210

Table 18: Number of whales seen in each year and number seen in both years and abundance estimate ($\widehat{N}$), standard error and minimum population estimate $N_{min} = \widehat{N}e^{-0.864\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ for limited Lincoln-Petersen estimator applied to consecutive years from 1998-2010 in MUA-SVI and OR-SVI regions.

Region	Year (y)	Seen in year y-1	Seen in year y	Seen in both years	$\widehat{N}$	$se(\widehat{N})$	N_{min}
MUA-SVI	1999	51	41	33	62	2.7	60
	2000	43	52	29	76	5.2	72
	2001	49	77	43	87	2.9	84
	2002	77	56	39	109	6.7	104
	2003	58	86	39	127	8.4	119
	2004	83	78	52	123	5.9	118
	2005	81	92	55	134	6.4	129
	2006	90	82	58	126	5.3	122
	2007	85	42	30	117	9.0	110
	2008	42	92	33	116	7.2	109
	2009	89	78	65	106	2.7	104
	2010	77	60	46	99	4.4	96
OR-SVI	1999	60	54	42	76	2.9	74
	2000	57	58	34	96	6.6	91
	2001	55	90	47	104	3.9	101
	2002	90	86	50	154	9.3	146
	2003	84	99	54	153	8.3	146
	2004	101	96	65	148	6.2	143
	2005	97	98	59	160	8.1	153
	2006	98	90	62	141	6.0	136
	2007	92	95	59	147	7.0	141
	2008	94	107	68	147	5.6	142
	2009	105	90	75	125	3.1	123
	2010	88	78	55	124	5.5	119

Table 19: Number of whales seen in each year and number seen in both years and abundance estimate ($\widehat{N}$), standard error and minimum population estimate $N_{min} = \widehat{N}e^{-0.864\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ for limited Lincoln-Petersen estimator applied to consecutive years from 1998-2010 in OR-NBC and NCA-NBC regions.

Region	Year (y)	Seen in year y-1	Seen in year y	Seen in both years	$\widehat{N}$	$se(\widehat{N})$	N_{min}
OR-NBC	1999	88	82	66	109	2.9	106
	2000	85	96	65	125	4.2	121
	2001	96	118	83	136	2.9	133
	2002	113	156	100	175	3.5	172
	2003	158	143	115	196	4.2	192
	2004	144	153	114	192	4.1	189
	2005	152	123	93	200	6.3	195
	2006	125	121	90	167	4.7	163
	2007	123	99	74	164	5.9	158
	2008	98	119	72	161	6.1	156
	2009	117	96	81	138	3.3	135
	2010	94	86	63	127	4.7	123
NCA-NBC	1999	95	87	70	117	3.1	115
	2000	93	113	70	149	5.4	145
	2001	112	135	91	165	4.2	162
	2002	129	170	113	193	3.6	190
	2003	174	148	122	210	4.3	207
	2004	149	157	115	203	4.6	199
	2005	157	124	94	206	6.6	201
	2006	125	121	90	167	4.7	163
	2007	123	105	74	173	6.8	168
	2008	104	136	75	187	7.6	181
	2009	135	110	90	164	4.2	161
	2010	103	117	77	156	5.1	151

Table 20: JS1 abundance estimates ($\widehat{N}$), standard errors and minimum population estimate $N_{min} = \widehat{N}e^{-0.864\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ using data from 1998-2010 in MUA-SVI and OR-SVI regions.

Region	Year	$\widehat{N}$	$se(\widehat{N})$	N_{min}
MUA-SVI	1998	53	4.2	49
	1999	60	7.9	53
	2000	74	9.5	66
	2001	105	6.9	99
	2002	106	15.4	93
	2003	124	11.7	114
	2004	132	13.8	121
	2005	137	11.8	127
	2006	128	12.2	118
	2007	125	24.4	106
	2008	122	9.2	114
	2009	121	11.6	111
	2010	117	15.9	104
OR-SVI	1998	63	4.2	60
	1999	78	8.4	71
	2000	89	11.9	79
	2001	120	9.2	113
	2002	137	15.2	124
	2003	153	13.8	142
	2004	161	15.5	148
	2005	164	15.7	151
	2006	154	15.3	142
	2007	153	14.5	141
	2008	150	12.5	140
	2009	147	14.9	134
	2010	144	16.8	131

Table 21: JS1 abundance estimates ($\widehat{N}$), standard errors and minimum population estimate $N_{min} = \widehat{N}e^{-0.864\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ using data from 1998-2010 in OR-NBC and NCA-NBC regions.

Region	Year	$\widehat{N}$	$se(\widehat{N})$	N_{min}
OR-NBC	1998	93	5.7	88
	1999	117	10.5	108
	2000	124	11.8	115
	2001	153	10.7	144
	2002	169	8.2	162
	2003	187	13.6	175
	2004	198	12.6	188
	2005	200	20.2	183
	2006	180	16.2	167
	2007	175	21.4	158
	2008	169	15.8	156
	2009	163	20.3	146
	2010	161	21.4	144
NCA-NBC	1998	103	6.4	98
	1999	135	12.0	125
	2000	141	13.2	130
	2001	175	12.6	165
	2002	193	9.3	185
	2003	202	16.5	188
	2004	209	14.9	197
	2005	208	22.6	189
	2006	190	18.8	175
	2007	184	23.1	165
	2008	192	16.1	179
	2009	185	23.2	166
	2010	188	18.7	173

Table 22: JS2 abundance estimates ($\widehat{N}$), standard errors and minimum population estimate $N_{min} = \widehat{N}e^{-0.864\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ using data from 1998-2010 in MUA-SVI and OR-SVI regions.

Region	Year	$\widehat{N}$	$se(\widehat{N})$	N_{min}
MUA-SVI	1998	53	6.1	48
	1999	62	6.7	57
	2000	79	7.6	73
	2001	91	6.6	85
	2002	107	8.0	100
	2003	123	7.2	117
	2004	125	6.4	119
	2005	125	5.8	120
	2006	121	5.8	116
	2007	118	6.7	112
	2008	115	6.4	110
	2009	112	6.7	106
	2010	106	7.1	100
OR-SVI	1998	63	6.7	58
	1999	76	7.4	70
	2000	98	8.9	91
	2001	108	7.4	102
	2002	141	9.1	134
	2003	147	7.4	141
	2004	153	7.1	147
	2005	155	6.0	150
	2006	147	6.5	141
	2007	145	7.0	139
	2008	144	7.2	138
	2009	140	7.5	133
	2010	132	8.0	126

Table 23: JS2 abundance estimates ($\widehat{N}$), standard errors and minimum population estimate $N_{min} = \widehat{N}e^{-0.864\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ using data from 1998-2010 in OR-NBC and NCA-NBC regions.

Region	Year	$\widehat{N}$	$se(\widehat{N})$	N_{min}
OR-NBC	1998	92	10.2	84
	1999	107	10.7	99
	2000	125	11.0	116
	2001	138	10.3	130
	2002	162	9.3	154
	2003	174	9.2	166
	2004	175	8.7	168
	2005	175	8.6	168
	2006	165	9.3	157
	2007	163	10.3	155
	2008	157	10.5	149
	2009	152	10.9	143
	2010	143	11.5	133
NCA-NBC	1998	102	11.7	92
	1999	119	12.3	109
	2000	149	13.1	138
	2001	166	12.0	156
	2002	182	10.6	174
	2003	191	10.6	182
	2004	191	10.3	182
	2005	192	10.2	183
	2006	181	10.9	172
	2007	183	12.1	172
	2008	182	12.1	172
	2009	178	12.3	168
	2010	168	13.1	157

Table 24: JS1 abundance estimates ($\widehat{N}$) and standard errors in OR-SVI and NCA-NBC after exclusion of known calves from the year in which they were identified as calves.

Region	Year	$\widehat{N}$	$se(\widehat{N})$
OR-SVI	1998	63	4.1
	1999	78	8.4
	2000	89	11.9
	2001	117	8.9
	2002	133	15.0
	2003	151	13.7
	2004	157	15.5
	2005	162	15.7
	2006	154	15.3
	2007	152	14.5
	2008	150	12.5
	2009	146	14.9
	2010	143	16.8
NCA-NBC	1998	101	6.2
	1999	135	12.0
	2000	141	13.2
	2001	172	12.6
	2002	189	9.2
	2003	200	16.4
	2004	206	14.9
	2005	206	22.6
	2006	190	18.8
	2007	183	23.1
	2008	191	16.1
	2009	185	23.2
	2010	186	18.7

Table 25: Simulation assessment of bias for in population trend for limitedLP, JS1 and JS2 estimators with p=0.7 and 0.8 with an increasing trend in non-transients and decreasing trend in transients and no trend (lower 2 plots). Value is $(\hat{N}_{t+1} - \hat{N}_t)/\hat{N}_t - (N_{t+1} - N_t)/N_t$ using average estimated abundance and true abundance for each time. Estimate from 1998 was excluded because it is not available for limitedLP and for JS1 and JS2 it was assumed that $p = 1$ for 1998 which will create bias.

	JS1		JS2		Limited LP	
	p=0.7	p=0.8	p=0.7	p=0.8	p=0.7	p=0.8
Trend						
1999	1.9	0.5	1.5	1.3	13.4	13.3
2000	3.8	1.8	0.9	0.5	-3.1	-4.0
2001	0.8	-0.2	1.6	0.3	-0.3	-0.5
2002	2.2	1.7	0.6	0.7	-7.0	-7.2
2003	1.7	1.2	0.5	0.8	-1.1	-0.7
2004	0.5	0.4	0.4	0.7	-0.7	-0.9
2005	1.7	1.3	1.3	1.0	-3.8	-3.8
2006	-0.4	-0.4	0.6	0.9	2.3	3.2
2007	0.0	-0.0	0.3	0.4	1.6	1.0
2008	-0.1	-0.1	-1.7	-1.2	-4.0	-2.8
2009	-0.9	-1.1	-4.0	-4.3	-8.3	-8.0
No Trend						
1999	11.3	8.0	1.3	0.8	7.0	8.2
2000	3.0	1.6	0.8	1.1	1.2	1.7
2001	0.7	0.4	1.0	0.7	1.1	-0.5
2002	0.6	-0.1	1.4	0.5	0.5	0.9
2003	0.4	-0.0	1.2	1.0	0.3	-0.1
2004	-0.4	0.1	0.3	0.7	-0.7	-0.5
2005	0.1	-0.1	0.8	0.6	-1.2	0.1
2006	-0.4	0.0	-0.0	0.4	0.2	-0.3
2007	0.4	0.0	0.7	0.1	-0.6	-0.7
2008	0.2	-0.3	-2.3	-1.5	-2.7	-1.4
2009	0.6	0.4	-4.2	-4.3	-8.7	-9.6

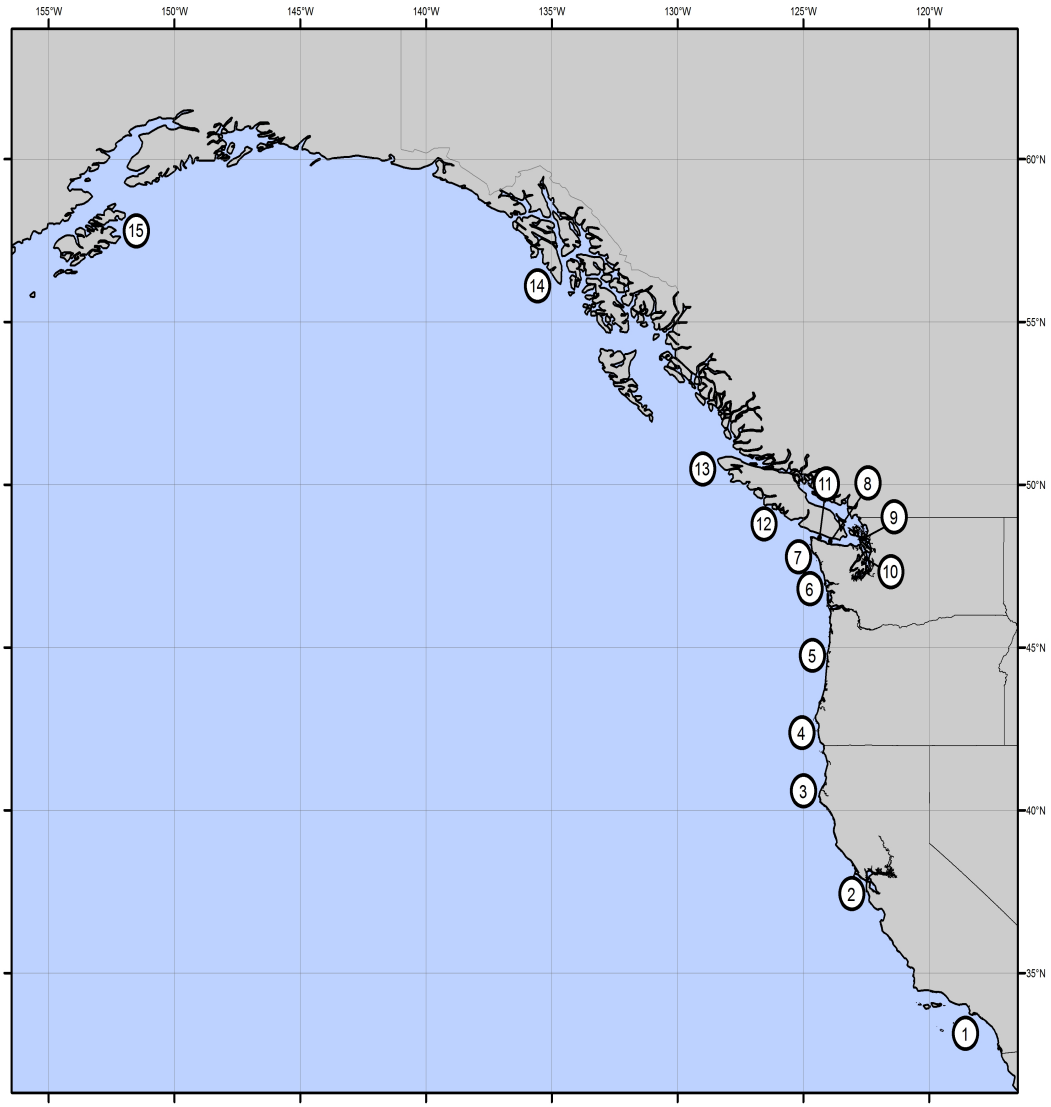

Figure 1: Locations for photo-identifications of gray whales. Numbers refer to values in Table 1.

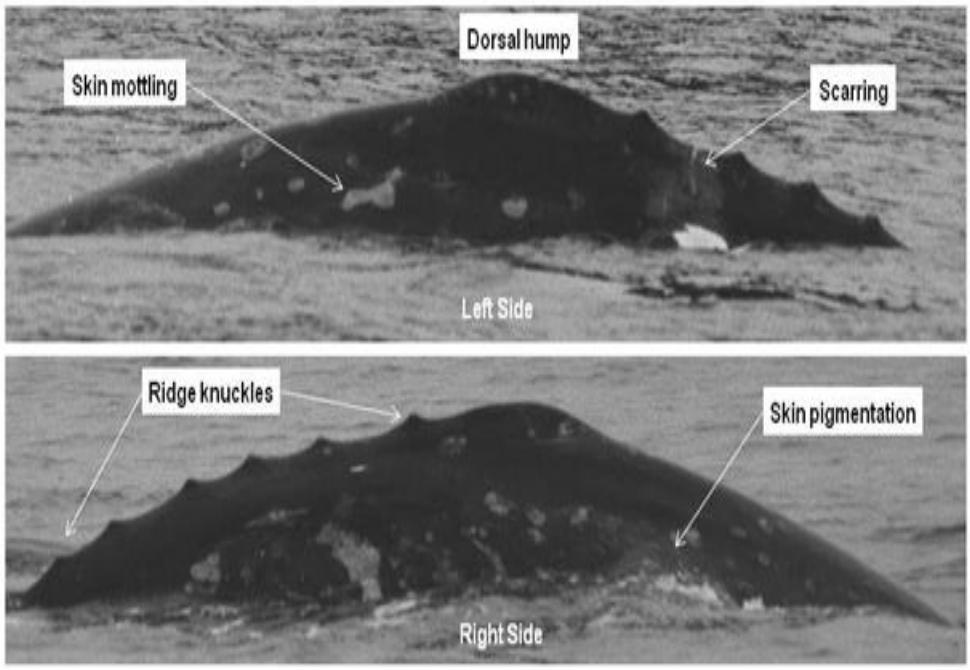

Figure 2: Characteristics used for gray whale photo-identification.

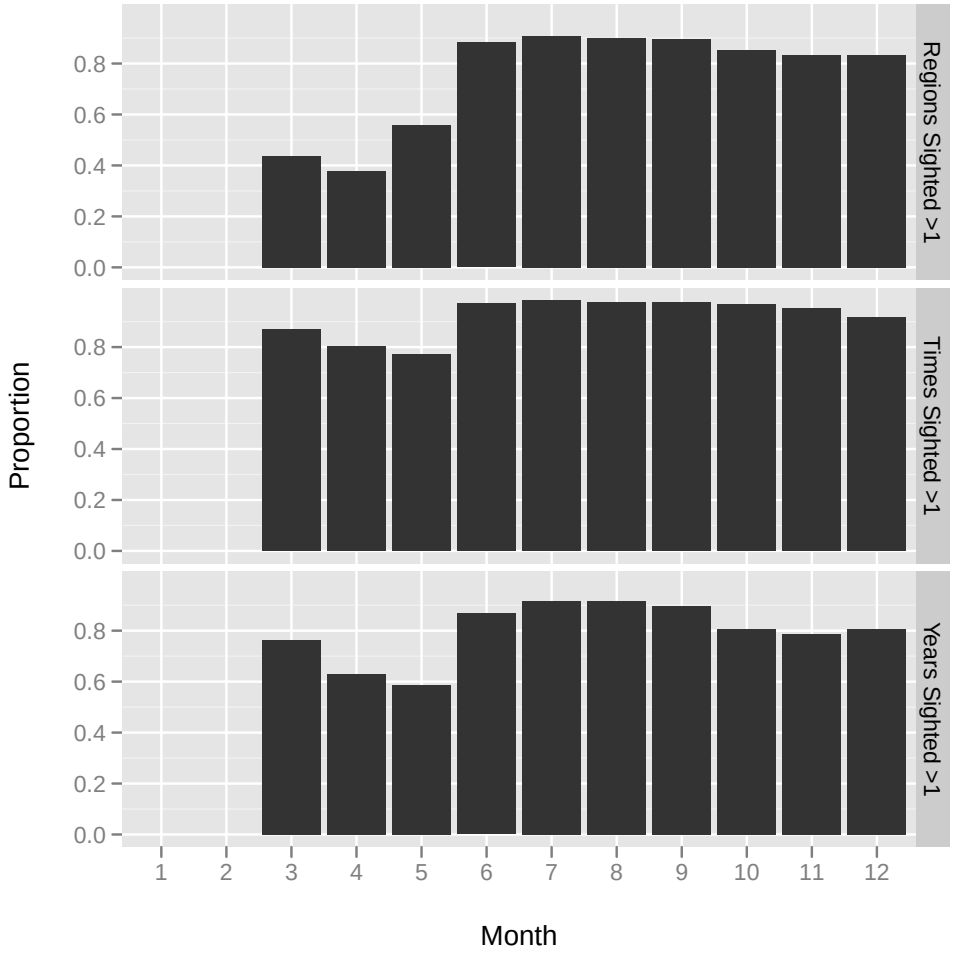

Figure 3: Monthly measures of proportion of whales that were seen in more than one region, seen on more than one day and seen in more than one year. The values include sightings from 1998-2010 in all regions from California to Alaska. Lower values imply whales were simply migrating through the area in a short time frame and were thus less likely to be seen at other times and in other regions. Values are not shown for months with fewer than 20 sightings.

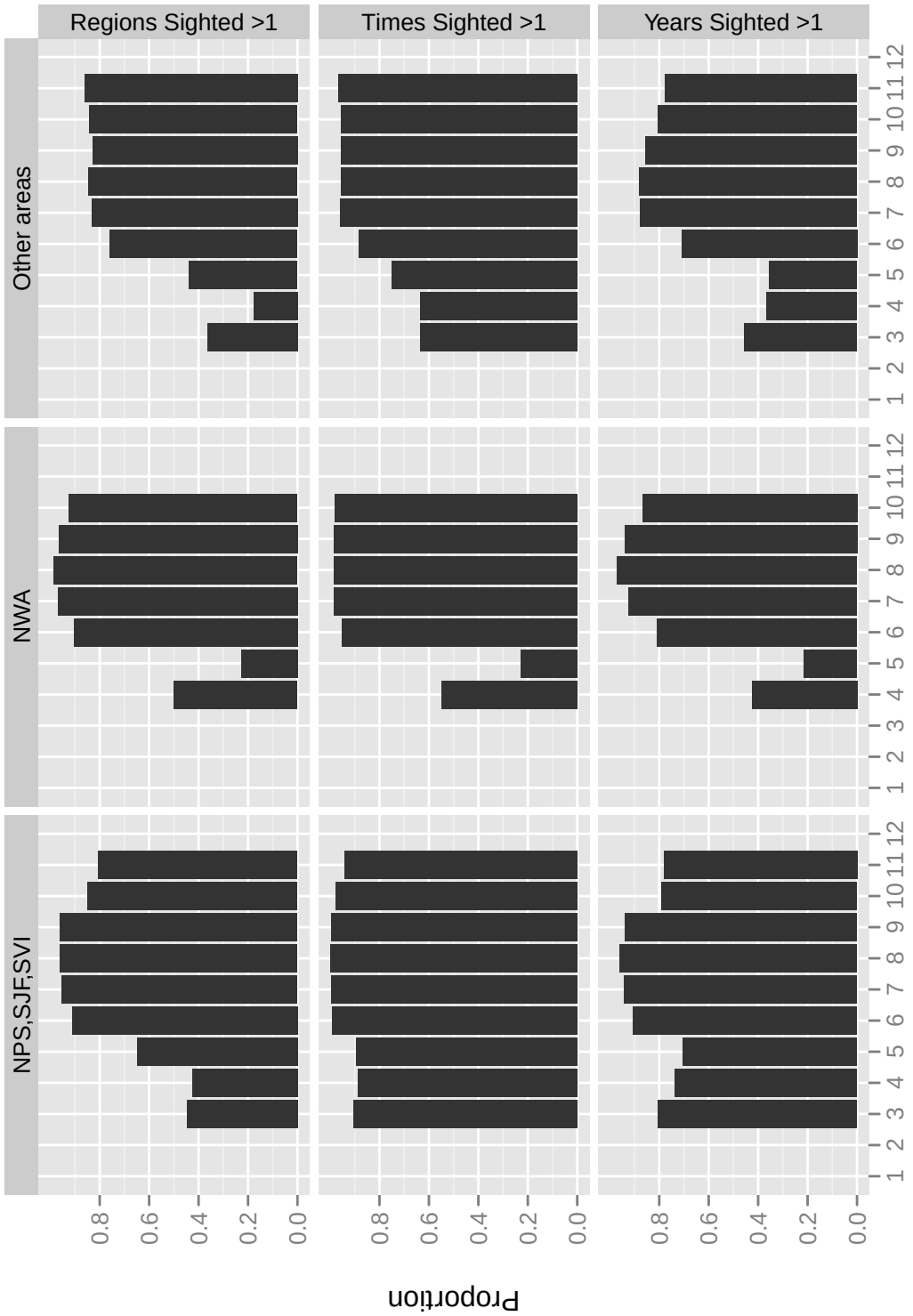

Figure 4: Region and monthly measures of proportion of whales that were seen in more than one region, seen on more than one day and seen in more than one year. The values include sightings from 1998-2010 in all regions from California to Alaska. Lower values imply whales were simply migrating through the area in a short time frame and were thus less likely to be seen at other times and in other regions. Values are not shown for months with fewer than 20 sightings.

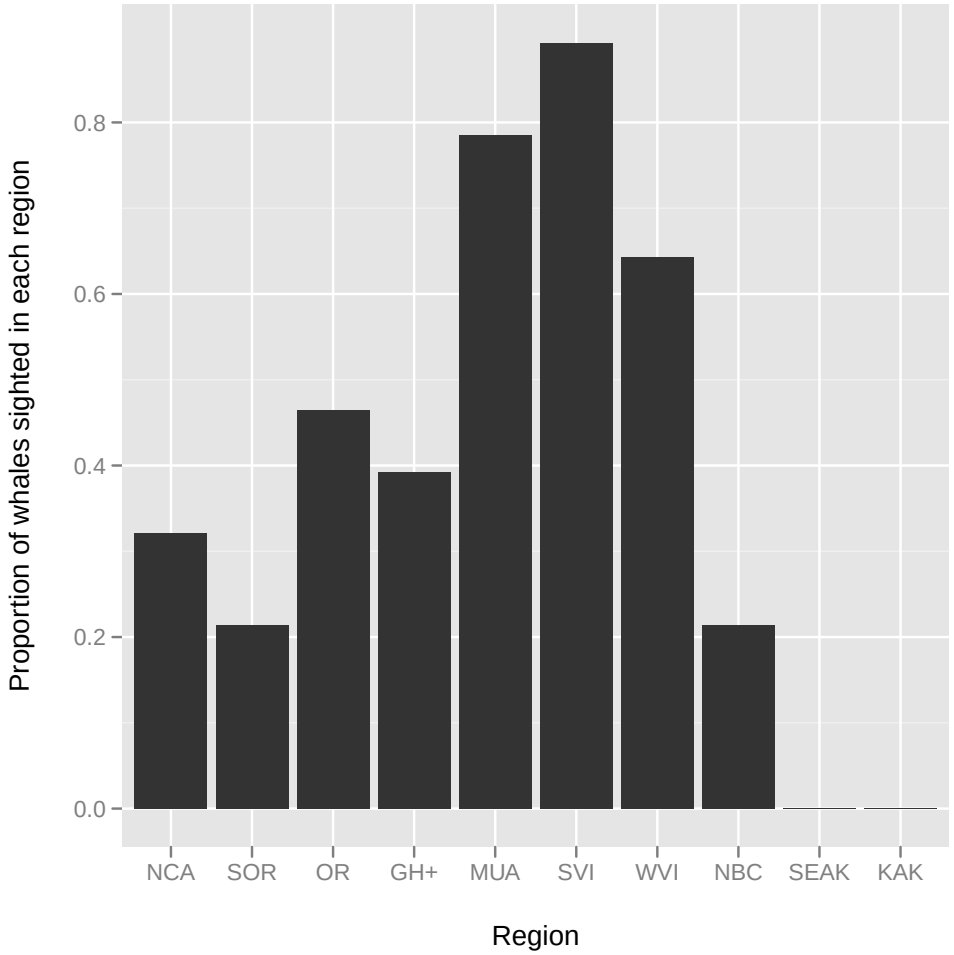

Figure 5: Proportion of the 14 whales seen in NWA during the spring and in the PCFG after 1 June that were seen in each PCFG sub-region after 1 June at least once from 1998-2010.

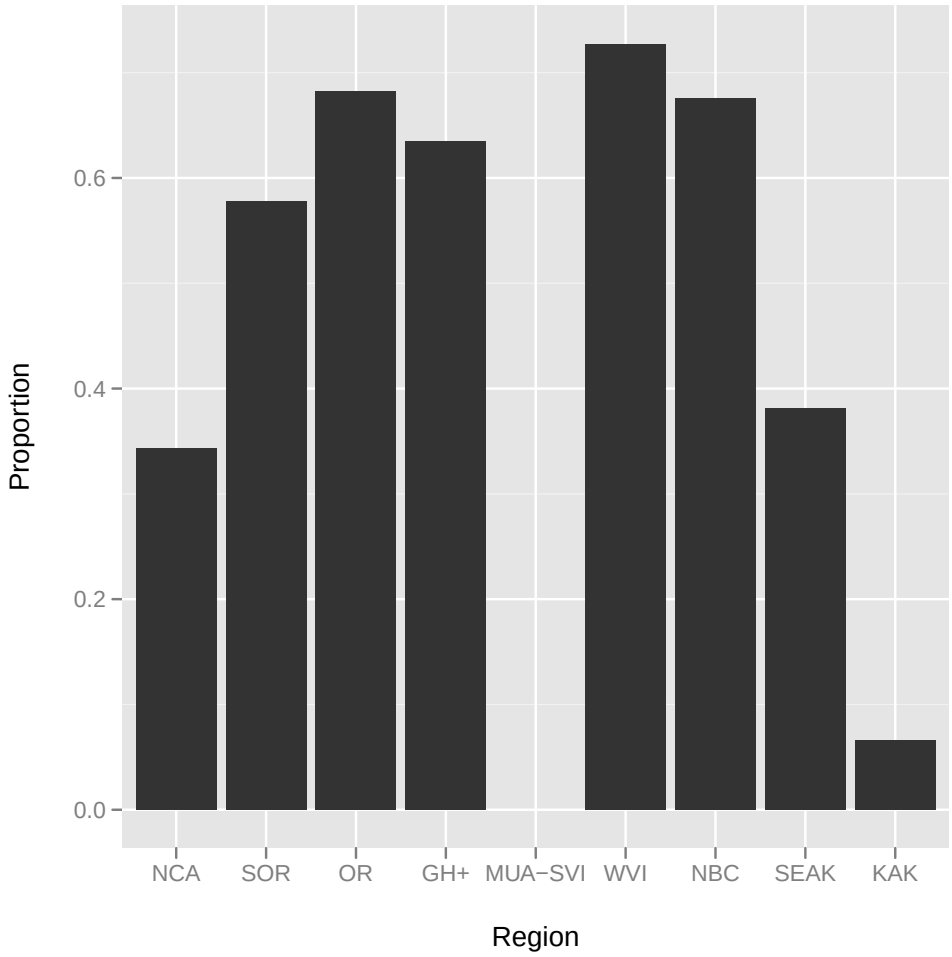

Figure 6: Proportion of whales in PCFG sub-regions that have been seen in the MUA-SVI using sightings after 1 June from 1998-2010.

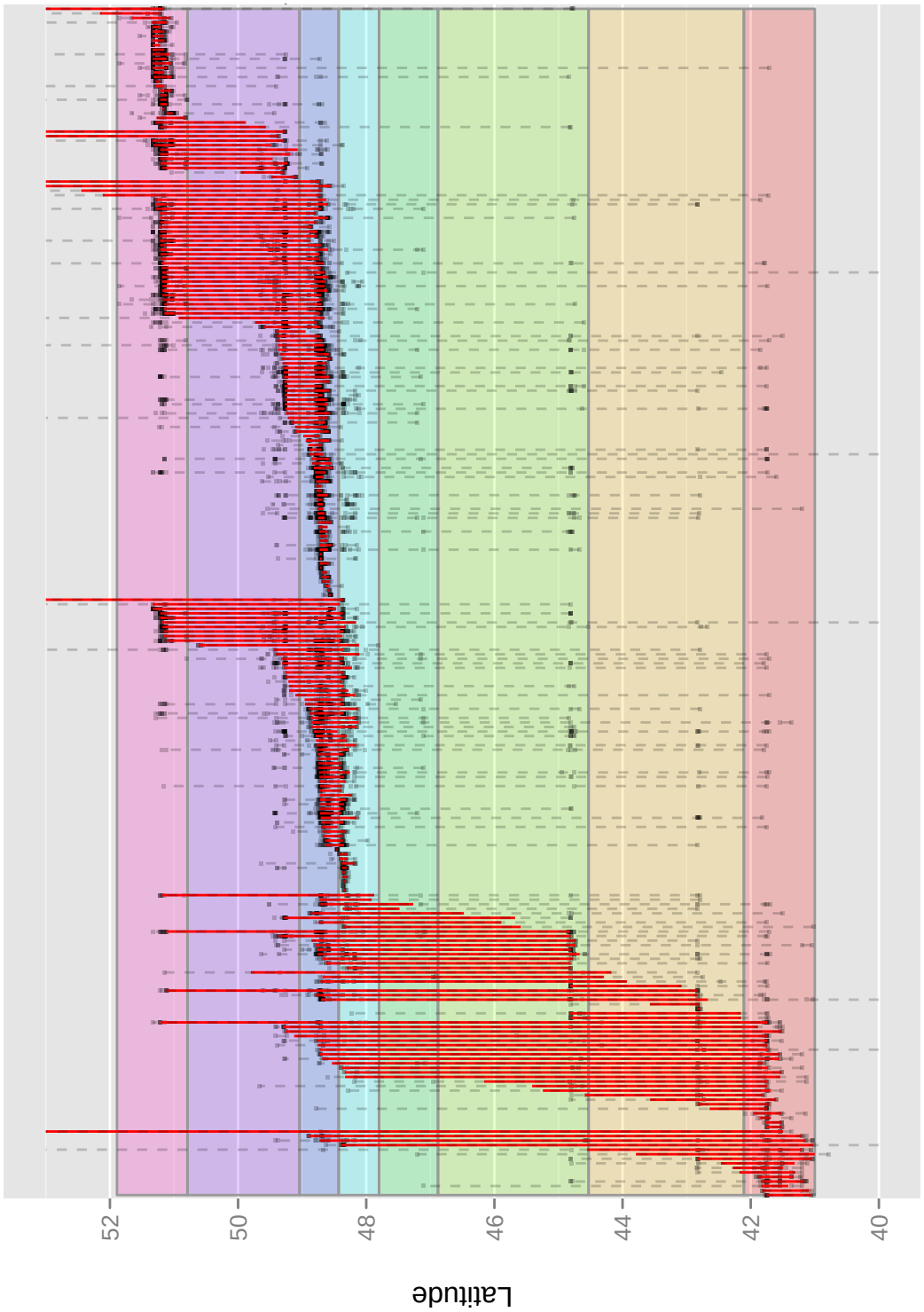

Figure 7: Distribution of latitudes of sightings (points) for whales with 6 or more sightings after 1 June from 1998-2010, the 75% inner quantile (solid thick line), and full range (light dashed line). Each position on the x axis represents an individual whale. Whales have been arranged on the plot by sorting first on the lower bound of the inner quantile (to a half-degree) and then the upper bound of the quantile. This has the effect of sorting from south to north and clusters whales with smaller quantile ranges followed by whales with larger ranges.

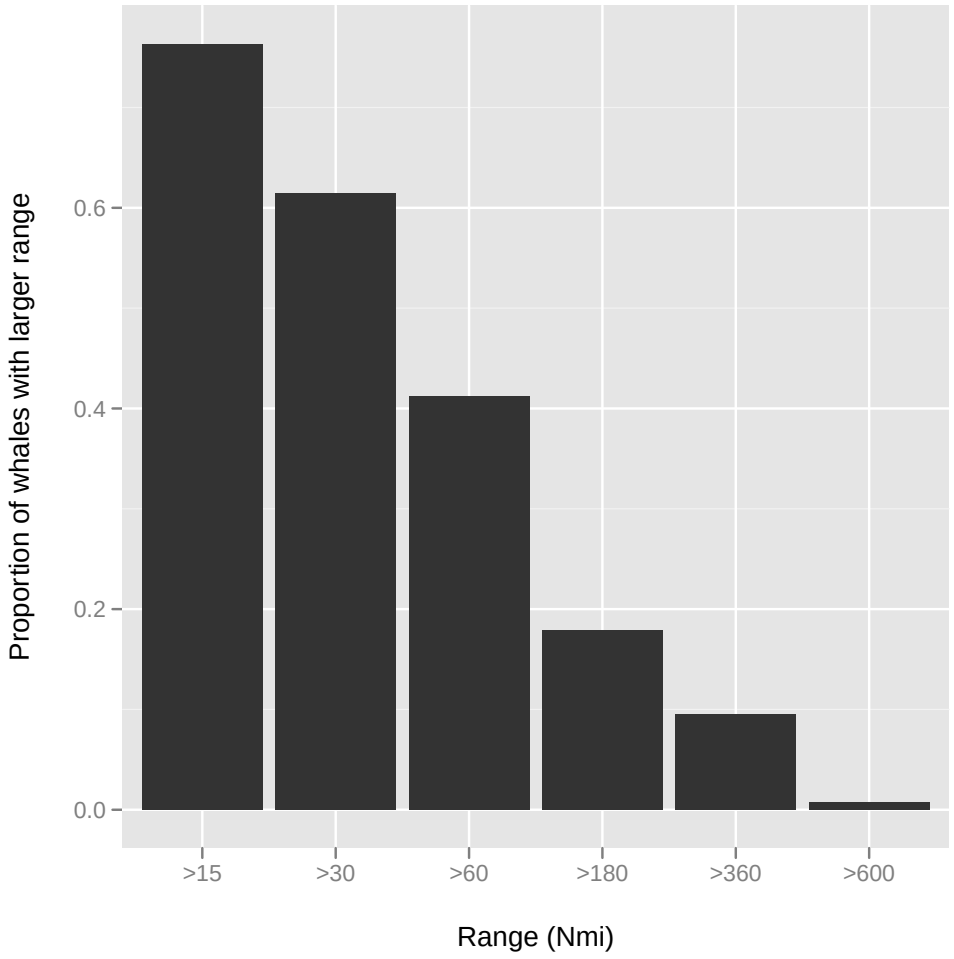

Figure 8: Distribution of ranges of 75% inner quantiles of latitudes expressed in nautical miles for whales sighted on 6 or more days during 1998-2010.

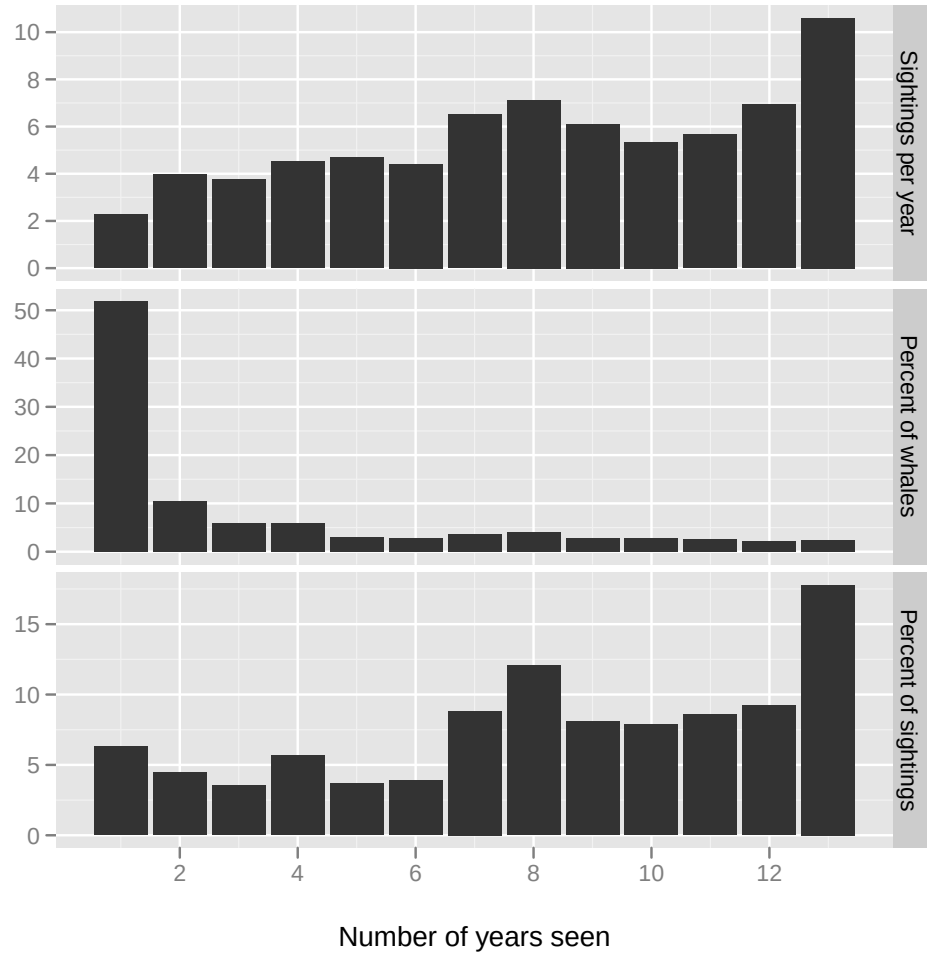

Figure 9: Average number of sightings per year and distribution of whales and numbers of sightings based on numbers of years a whale was seen in NCA-NBC between June-November during 1998-2010.

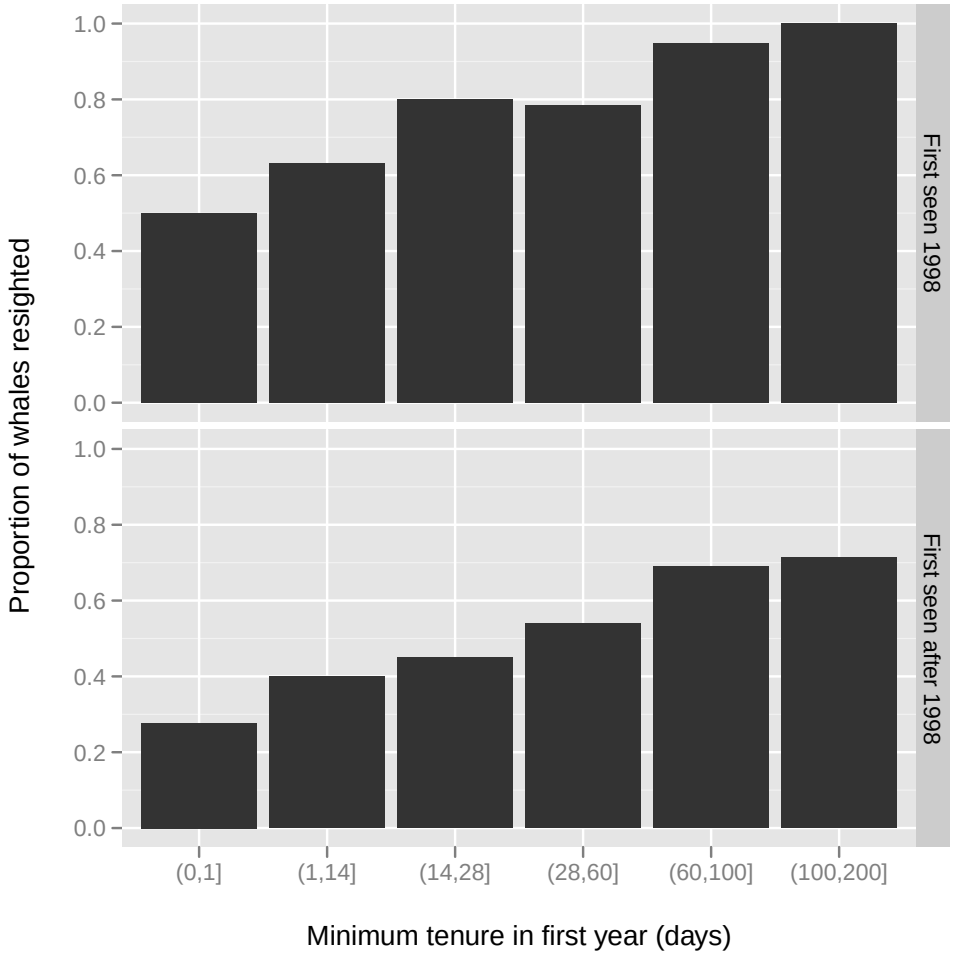

Figure 10: Influence of minimum tenure (MT) in the first year the whale was photographed on the probability it will be re-sighted in one or more following years for whales seen in NCA-NBC for June-November 1998-2010. The bar graphs are divided for 1998 and >1998 because 1998 is the start of the study and it may not be the first year for many of those whales. Re-sightings for 2010 are used but initial sightings for 2010 are excluded because there are no data beyond to evaluate re-sighting probability.

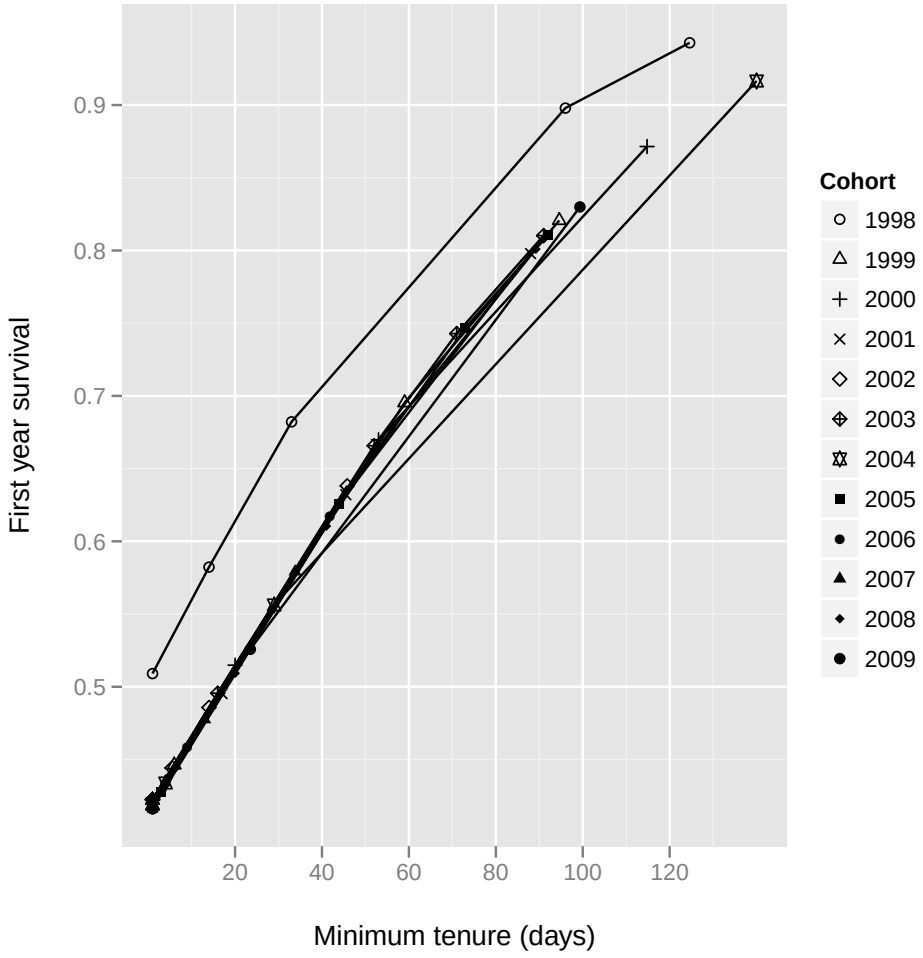

Figure 11: For MUA-SVI analysis of 1998-2010 data, model-averaged estimates of first year survival of non-calves for each cohort at 5%, 25%, 50%, 75%, and 95% quantiles of minimum tenure values for that cohort.

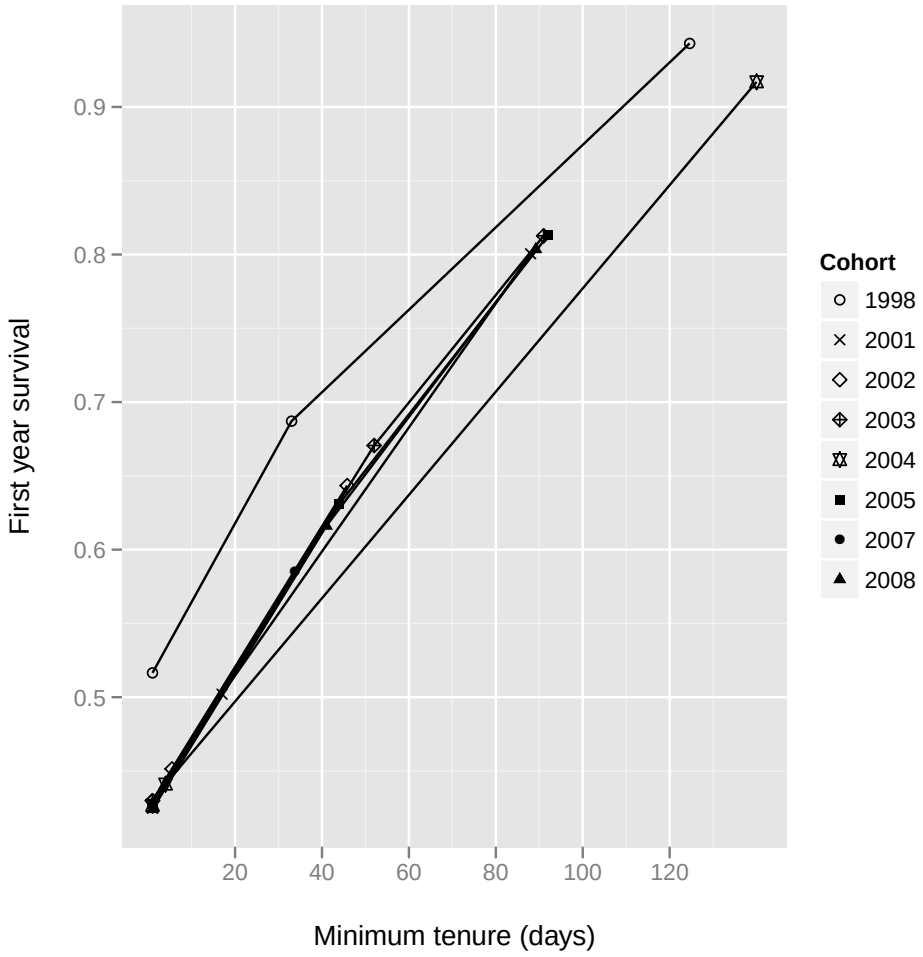

Figure 12: For MUA-SVI analysis of 1998-2010 data, model-averaged estimates of first year survival of calves for each cohort at 5%, 50%, and 95% quantiles of minimum tenure values for that cohort of calves. Cohorts 1999 and 2000 are not shown because no calves were identified in those years.

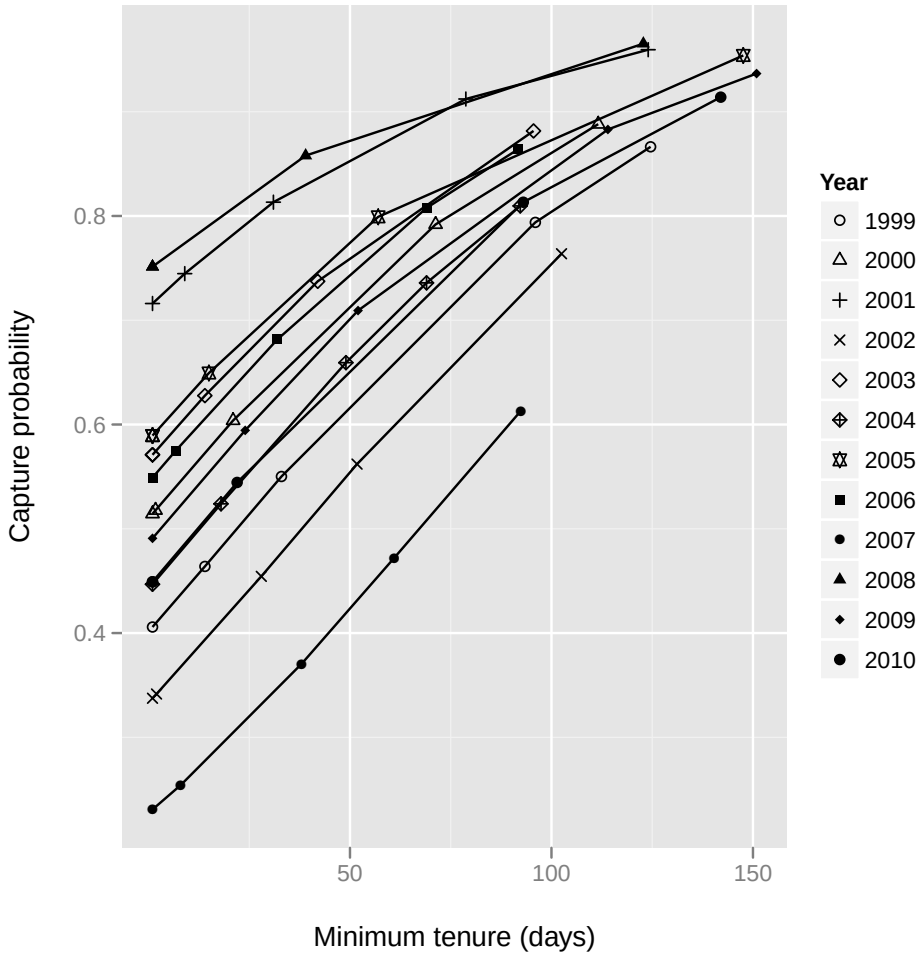

Figure 13: For MUA-SVI analysis of 1998-2010 data, model-averaged estimates of capture probability for each year at 5%, 25%, 50%, 75%, and 95% quantiles of minimum tenure values for whales in the previous year.

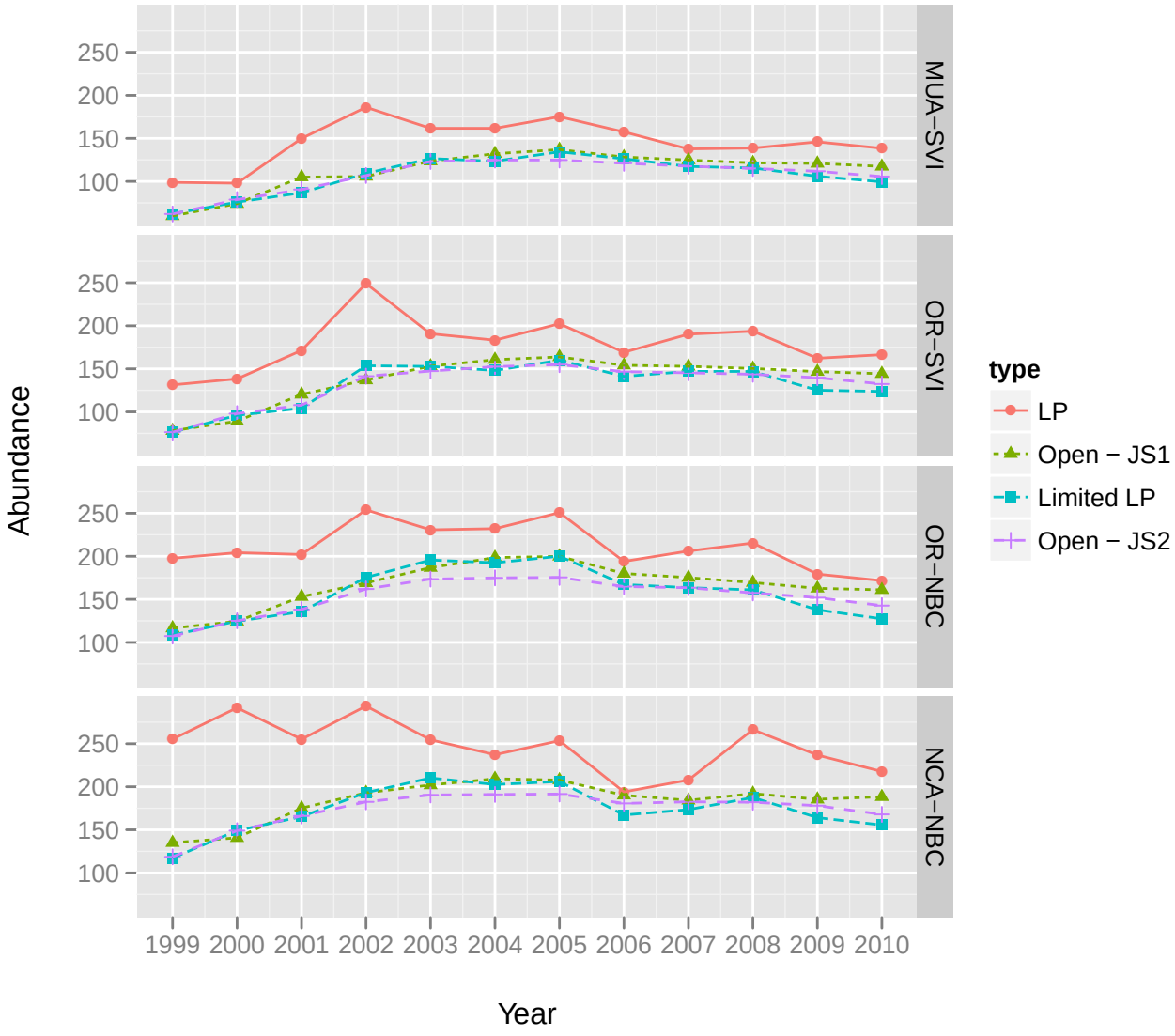

Figure 14: Annual abundance estimates for 1999-2010 in four sub-regions using closed population models, Lincoln-Petersen (LP) and Limited LP and the open (Jolly-Seber; POPAN parametrization) population models using the 2 alternative approaches JS1 and JS2.

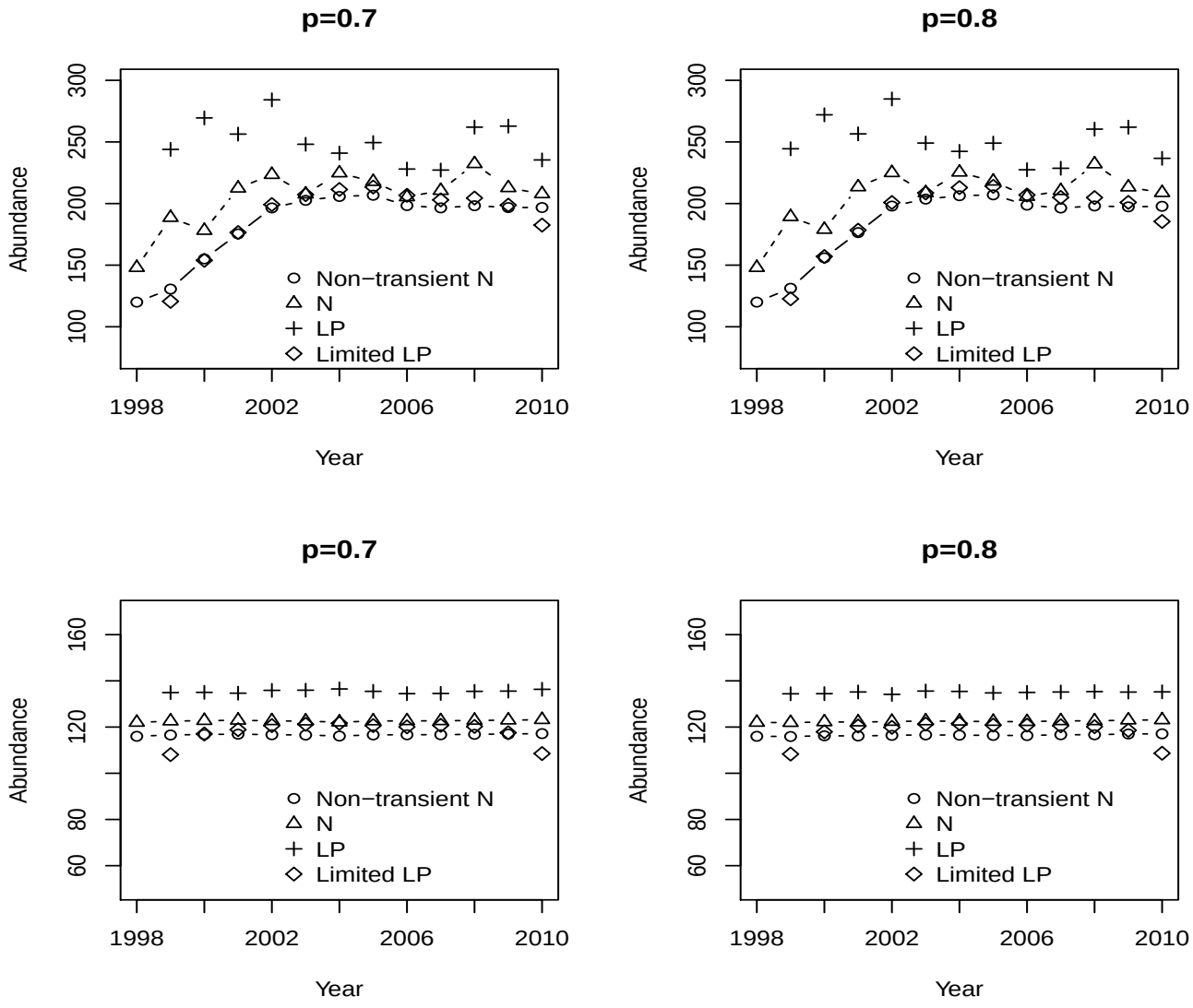

Figure 15: Simulation results for closed estimators with p=0.7 and 0.8 with an increasing trend in non-transients and decreasing trend in transients (upper 2 plots) and no trend (lower 2 plots). The true average simulated non-transient N and total N are shown with lines and the average estimates for LP and limited LP are shown with symbols.

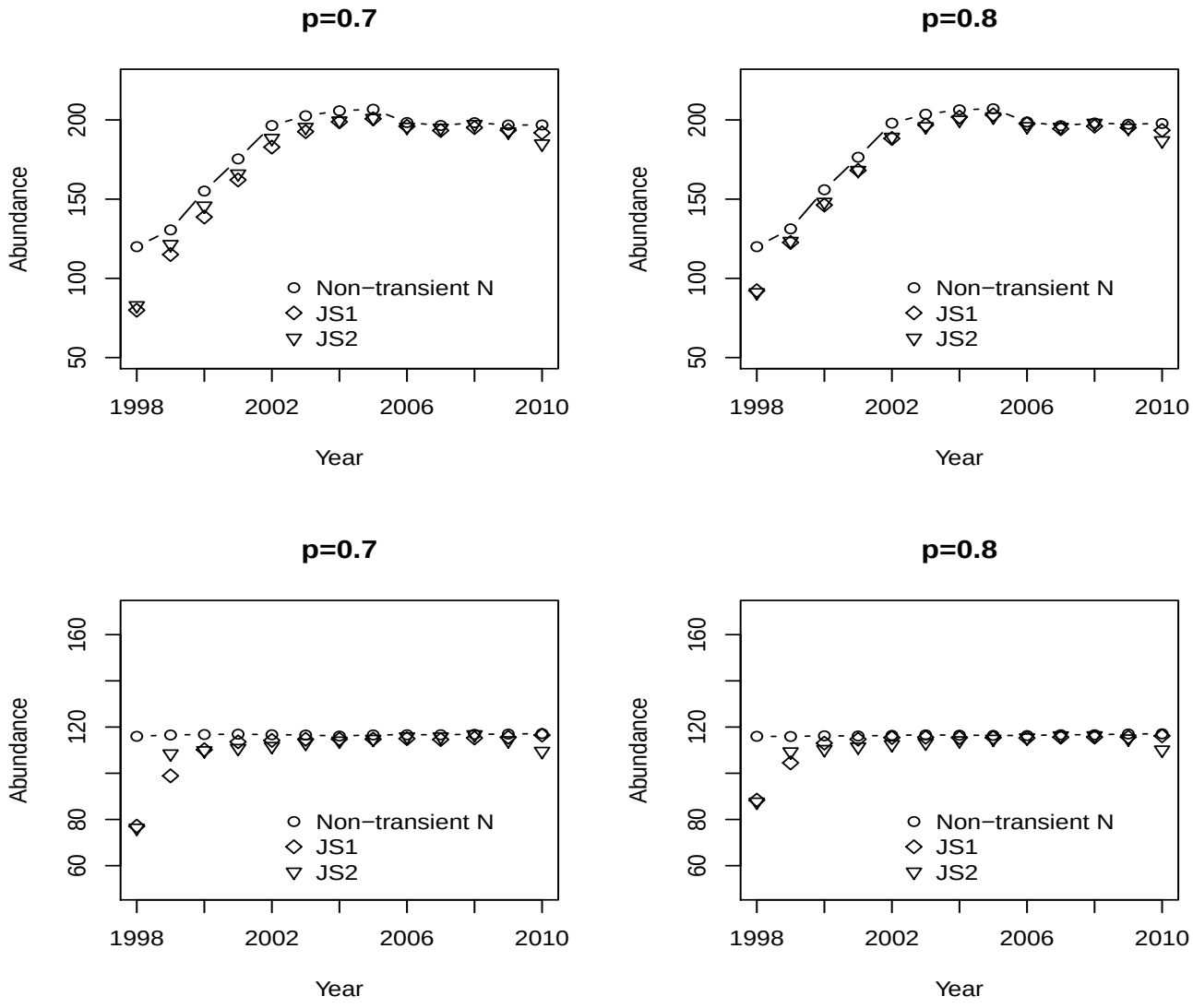

Figure 16: Simulation results for JS estimators with p=0.7 and 0.8 with an increasing trend in non-transients and decreasing trend in transients (upper 2 plots) and no trend (lower 2 plots). The true average simulated non-transient N is shown with the line and the average estimates for JS1 and JS2 are shown with symbols.

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Updated analysis of abundance and population structure of seasonal gray whales in the Pacific Northwest, 1996-2015

0b726579 204c6161 6b652c20 616e6420 416c6965 e

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Updated analysis of abundance and population structure of seasonal gray whales in the Pacific Northwest, 1996-2015

John Calambokidis, Jeffrey Laake, and Alie Pérez

Abstract

We update the results of a 20-year (1996-2015) collaborative study examining the abundance and the population structure of these animals conducted over a number of regions from Northern California to British Columbia using photographic identification. Some 21235 identifications representing 1638 unique gray whales were obtained during 1996-2015 from Southern California to Kodiak, Alaska. Gray whales seen from 1 June - 30 Nov (after the northward and before southward migrations) were more likely to be seen repeatedly and in multiple regions and years;therefore only whales seen during those data were included in the abundance estimates. Gray whales using the Pacific Northwest in summer and fall include two groups: 1) whales that return frequently and account for the majority of the sightings and 2) transients seen in only one year, generally for shorter periods and in more limited areas. A time series of abundance estimates of the non-transient whales for 1996-2015 was constructed for the region from N. California (NCA) to N. Vancouver Island (NBC). The most recent estimate for 2015 was 243 whales (se=18.9). The estimated abundance increased in the late 1990s and early 2000s during the period when the eastern North Pacific gray whale population was experiencing a high mortality event and this created an apparent influx of whales into the area. The earlier estimates for 1996-1997 are biased low because the survey coverage area was much smaller but those data were included to improve estimates later in the time series. The abundance estimates since the early 2000s has been relatively stable but it has increased in 2013-2015.

1 Introduction

Beginning in 1996, a collaborative effort among a number of research groups was initiated to conduct a range-wide photographic identification study of gray whales in the Pacific Northwest (Calambokidis et al. 2000, 2002b). An initial publication of findings from 1998 demonstrated there was considerable movement of individual whales among sub-areas from northern California to southeastern Alaska (which we broadly refer to as the Pacific Northwest) and also provided initial estimates of the abundance of whales within that geographical area (Calambokidis et al. 2002a). The ability to look at movements and employ more sophisticated capture-recapture models, however, was restricted by the lack of multiple

years of data with broad geographic coverage. A subsequent report by Calambokidis et al. (2004) characterized the group of whales feeding in these survey areas during the summer-fall period as a "Pacific Coast Feeding Aggregation" (PCFA). They proposed that a smaller area within the PCFA survey areas – from Oregon to Southern Vancouver Island (OR-SVI) – was the most appropriate area for abundance estimation for managing a Makah gray whale hunt (Calambokidis et al. 2004). Subsequently the IWC has adopted the term PCFG for Pacific Coast Feeding group so we will use PCFG in place of PCFA.

This report updates information through 2015 from a collaborative effort to collect photographic identifications of gray whales from California to Alaska has continued since 1996 and these data now cover 20 years (1996-2015) and span fifteen survey regions along the coast from Southern California to Kodiak, Alaska (Figure 1). We provide estimates of abundance for the summer-fall seasons (1 June to 30 November) during 1996–2015 for survey regions between Northern California and Northern British Columbia (NCA-NBC), the region chosen by the IWC to represent the PCFG. For the National Marine Fisheries Service development of an Environmental Impact Statement, we also provide estimates for the smaller regions between Oregon and Southern Vancouver Island (OR-SVI) and Makah Usual and Accustomed area (MUA) which includes the outer coastal area of the Olympic Peninsula (NWA) and the Strait of Juan de Fuca (SJF), even though this area is quite small relative to the observed movements of whales within the PCFG.

2 Methods

Gray whales were photographed during small boat surveys conducted from California to Alaska by collaborating researchers (Table 1) between 1996 and 2015. Gray whale identifications were divided into the following regions (Figure 1): 1) SCA: Southern California, 2) CCA: Central California, 3) NCA: Northern California, 4) SOR: Southern Oregon, 5) OR: central Oregon, 6) GH+: Gray's Harbor and the surrounding coastal waters, 7) NWA: Northern Washington coast, 8) SJF: Strait of Juan de Fuca, 9) NPS: Northern Puget Sound, 10) PS: which includes southern Puget Sound, Hood Canal (HC), Boundary Bay (BB) and San Juan Islands (SJ), 11) SVI: Southern Vancouver Island, 12) WVI: West Vancouver Island, 13) NBC: Northern Vancouver Island and coastal areas of British Columbia, 14) SEAK: Southeast Alaska, and 15) KAK: Kodiak, Alaska. With some exceptions, research groups work primarily in one or two regions. Details of identifications obtained by the different research groups are are summarized in Tables 1-2.

2.1 Photographic Identification Procedures

Procedures during surveys by different research groups varied somewhat but were similar to one another in identification procedures. When a gray whale was sighted, the time, position, number of animals, and behaviors were recorded. Whales were generally approached to within 40-100 m and followed through several dive sequences until suitable identification photographs and associated field notes could be obtained.

For photographic identification of gray whales, both left and right sides of the dorsal region around the dorsal hump were photographed when possible. Most identification pho-

tographs were obtained with were obtained with 35mm cameras prior to 2004 and primarily with digital SLR after 2004 with both camera types paired with a telephoto lens (generally 200-300 mm). Researchers also photographed the ventral surface of the flukes for further identification when possible. The latter method was not as reliable since gray whales did not always raise their flukes out of the water. Markings used to distinguish whales included pigmentation of the skin, mottling, and scarring, which varied among individuals. These markings have provided a reliable means of identifying gray whales (Darling 1984). We also identified gray whales using the relative spacing between the knuckles along the ridge of the back behind the dorsal hump. The size and spacing of these bumps varies among whales and has not changed throughout the years these whales have been tracked, except with injury. Figure 2 shows typical photographs and features used in making gray whale identifications.

Comparisons of whale photographs were made in a series of steps. All photographs of gray whales were examined and the best photograph of the right and left sides of each whale (for each sighting) were selected. Identification photographs were initially compared within year to identify resightings and compared to the CRC catalog of whales seen in past years. Whale photographs that were deemed of suitable quality but did not match our existing catalog (compared by two independent persons) were considered "unique" identifications and assigned a new identification number and added to the catalog.

2.2 Data Analysis

The abundance of gray whales was estimated with open population models for three nested spatial scales consisting of contiguous survey regions (Figure 1; Table 3) 1) NCA-NBC: the coastal survey regions from Northern California (NCA) through Northern Vancouver Island/British Columbia (NBC) which matches the IWC definition of the PCFG, 2) OR-SVI: survey regions from southern Oregon through Southern Vancouver Island (SVI) identified in the Makah waiver request, and 3) MUA - survey regions NWA and SJF. Inland waters in WA (other than SJF) and in BC are excluded from the abundance estimates because these are used primarily by transient whales in the northward spring migration.

Gray whales photographed and identified anytime during the period between 1 June and 30 November (hereafter referred to as the "sampling period") within the defined region were considered to be "captured" or "recaptured". For each unique gray whale photographed, a capture history was constructed using 20 years of data from 1996-2015. For example, the capture history 00010010010000000000 could represent a gray whale photographed in 1999, 2002 and 2005 in the PCFG. The same gray whale may have had a capture history 00010010000000000000 for a smaller spatial scale such as OR-SVI or may not have been seen at all (00000000000000000000) and would not be used at the smaller spatial scale.

Multiple "detections" of a single whale within the sampling period were not treated differently than a single detection. A "1" in the capture history meant that it was detected on at least one day during the sampling period. However, multiple detections in the same year were used to construct an observed minimum tenure (MT) for each whale. MT was defined as the number of days between the earliest and latest date the whale was photographed with a minimum of one day for any whale seen.

We fitted open population models to the 20 yearly time series of capture history data for each spatial scale to estimate abundance and survival. Open models allow gains due to births/immigration and losses due to deaths/emigration. Using the RMark interface (Laake and Rexstad 2008) to program MARK (White and Burnham 1999), we fitted a range of models to the data using the POPAN model structure. The POPAN model structure (Schwarz and Arnason 1996) provides a robust parametrization of the Jolly-Seber (JS) model structure in terms of a super population size (N), probability of entry parameters (immigration), capture probability (p), and survival/permanent emigration (φ).

It is essential to consider the population structure and its dynamics to build adequate models. In particular, we know from previous analysis of a subset of these data (Calambokidis et al. 2004) that some whales were seen in only one year between 1 June and 30 November and were never seen again. Transient behavior is a well-known problem in capture-recapture models and it is often addressed using a robust design which involves coordinated multiple capture occasions within each year and typically assumes closure within the sampling period (June-November). Region-wide coordinated surveys may be possible but would be difficult with variation in weather conditions. Also, the closure assumption within the year would be suspect due to variable timing of whales arrivals and departures into the PCFG, so it would require nested open models. We know from prior analysis that whales newly seen in year (y) were less likely to return (i.e., seen at some year >y) than previously seen whales but also newly seen whales that stayed longer during their first year (i.e., longer MT) in the PCFG were more likely to return. Likewise, previously seen whales were more likely to be seen in the following year (y+1), if they had a longer MT in year y. Calambokidis et al. (2004) postulated that these observations were consistent with whale behavior that was determined by foraging success.

Transient behavior in which an animal is seen only once can be modeled by including a different "first year" survival (Pradel et al. 1997) for the newly seen animals. Survival in the time interval after being first seen is dominated by permanent emigration rather than true mortality. Survival in subsequent time intervals represents true survival under the assumption that animals do not permanently emigrate except in their first year. Pradel et al. (1997) were working with release-recapture data (Cormack-Jolly-Seber) where modeling this transient effect on survival is straightforward. For a Jolly-Seber type analysis where the first capture event is also modeled, the inclusion of a transient effect is less easily accommodated.

We divided the whales into cohorts based on the year in which they were first seen ("newly seen"). In the model, their first year survival could differ from subsequent annual survival as in Pradel et al. (1997). "Newly seen" is not a particularly useful concept for the first year of the study (1996), because all whales were being seen for the first time. The survey effort and coverage in 1996 and 1997 were not nearly as expansive as 1998 and later. We considered models that had three different first year survivals (1996&97, 1998, and >1998) and we also considered a model that allowed for a different first year survival for each year (cohort) to allow for different transient proportion in each year. The first year survival was also allowed to vary as a function of MT with a model in which the relationship was constant across years and varied for (1996&97, 1998, and >1998). We also considered models that allowed a different first-year survival for whales identified as calves under the presumption that their true survival might be lower but that their probability of returning to

the PCFG might be higher. Discussion at the 2012 intersessional AWMP meeting led to consideration of an additional covariate which split whales into 2 groups for estimation of post-first-year survival. Whales seen initially as calves and any whale newly seen in 1998 or was in the CRC catalog because it had been seen prior to 1998 were put in one group and the remaining whales newly seen in 1999 or later were put in another group. The expectation was that the first group would have higher post-first-year survival because many of the newly seen whales that entered after the stranding event in 1999/2000 might eventually emigrate. When this covariate was included it made such a large improvement that any model without it would have no support. Therefore, it was included in all 10 models for survival (Table 4).

In Calambokidis et al. (2010) we estimated a cohort-specific super-population size for each cohort using the median MT covariate value for unseen whales but during the April 2011 AWMP meeting it became apparent that this may lead to bias in estimating abundance. Therefore, we used the method outlined in the 2011 AWMP report which is similar to the method used by Calambokidis et al. (2004) in that we assume that all whales in the PCFG for the first year are seen so the super-population size for each cohort is the number seen and thus there are no unknown covariate values. We fixed capture probability (p) and probability of entry (pent) to 1 for each cohort in their entry year. We are not interested in the number of transient whales so we used an estimator of abundance for non-transient whales (2011 AWMP report) which is a modification of the Jolly-Seber estimator which for any year can be expressed as:

$$\hat{N} = n/\hat{p} = (u+m)/\hat{p}$$

where $n = u+m$, n is the number seen in a year being composed of new animals (u=unmarked) and previously seen animals (m=marked), and $\hat{p}$ is the capture probability estimate. For the PCFG we are assuming that any new whale is sighted ($p = 1$) and we are only interested in estimating the abundance of whales that will remain part of the PCFG which is the portion of the new whales that do not permanently emigrate from the PCFG. We can modify the estimator for year j as follows:

$$\hat{N_j} = u_j\hat{\phi}_j + m_j/\hat{p_j}$$

where ϕ_j is the first year survival rate of "new" whales. When ϕ and p contain whale specific covariates like minimum tenure (MT) the estimator becomes:

$$\hat{N_j} = \sum_{i=1}^{u_j} \hat{\phi}_{ij} + \sum_{i=1}^{m_j} 1/\hat{p}_{ij}.$$

To obtain an abundance estimate for 2015, we assumed that the parameter for first year survival intercept in that year was the same as in 2014. A variance-covariance matrix for the abundance estimates was constructed using the variance estimator in Borchers et al. (1998) for a Horvitz-Thompson type estimator with an adaptation for the first component of the abundance estimator for prediction of number of new whales that do not permanently emigrate. For the estimated capture probabilities (p) not fixed to 1, we fitted 3 models that varied by time (year) and/or varied by MT in the previous year (Table 4).

We used Test 2 and Test 3 results from the Cormack-Jolly-Seber structure (Lebreton et al. 1992) as a general goodness of fit for the global model and as a measure of possible over-dispersion creating the lack of fit. We fitted each combination of models for S (survival) and p (capture probability) and used AICc (Burnham and Anderson 2002) to select the most parsimonious model of the 30 fitted models. Model averaging was used for all models to compute estimates and unconditional standard errors and confidence intervals.

3 Results

The database contains 25580 records for whales photographed between 1996 to 2015 from California to Kodiak, Alaska; however 4345 are replicate identifications of whales on the same day. We define a sighting as one or more photographs of a whale on a day. The number of sightings varied annually from 131 and 1959 with a total of 21235 sightings of 1638 unique gray whales (Table 1). The average number of sightings/whale was 13 (range: 1-339). Identifications were made throughout the year but with most effort from June to September. Number of sightings were most numerous in NCA, SVI, WVI, and NBC and (Table 2). The number of uniquely identified whales was greatest in NCA, NWA, SVI and WVI (Table 2).

3.1 Seasonal Sighting Patterns

Whales have been photographed in every month of the year (Table 5) but with very few during December-February when most of the whales are in or migrating to Mexico and survey effort is reduced. Previous analysis of these data have always used 1 June - 30 November as the sampling period to describe the whales in the PCFG because whales seen prior to 1 June and after 30 November are more likely to be whales that are migrating through the region. The southbound migration starts in December and the separation between May and June is clearly supported by the data. For example, of the 1638 unique whales sighted from California to Kodiak, Alaska, 666 whales were only seen between 1 Dec - 31 May and 87.2% of those were only sighted once (one day). Of the 972 whales sighted between 1 June -30 November at some time, 38.8% were only sighted once (one day). If sightings in Alaska are excluded, then only 31.7% of the 833 were seen only once (one day).

The break between May and June is apparent in various measures such as proportion of whales sighted more than once, sighted in more than one region, and sighted in more than one year (Figure 3). However, the break is more apparent if we separate out SJF, NPS and SVI from the other survey regions (Figure 4). The difference across months is not as strong for inland waters of Washington and British Columbia (NPS, SJF) because these are whales that have diverted from the migration and are either more likely to remain after 1 June or demonstrate high year-to-year fidelity during spring such as with NPS. Also, even though Southern Vancouver Island (SVI) is in the main migration corridor and not an inland water, the pattern across months is also weaker because the sampling has been focused on the spring herring spawn in Barkley Sound (effectively an inland waterway) and has purposefully undersampled passing migrant whales (Brian Gisborne, pers. comm.).

The break between May and June is much more apparent for NWA and the other areas in the migration corridor which is consistent with the northbound migration of gray whales proceeding past Washington through May. Resighting rates of whales seen after 1 June remained high through November.

A large photo-ID sample of gray whales in the MUA was conducted in 2015 by Makah Tribal biologists. At the time of this report the full comparison of these whales to historical images had not been completed but in the future will provide a better indication of proportion of PCFG whales present prior to 1 June.

Capture (sighting) histories of whales seen at least once in the PCFG from 1 June - 30 November are provided in Appendix Table 1 which show sightings of whales in 1 Mar -31 May only, 1 June - 30 Nov only and in both time periods within a year.

3.2 Regional Sighting Patterns

There is considerable variation in the annual regional distribution of numbers of whales photographed during the sampling period (Table 6) which is in part due to variation in effort. Although not a true measure of effort, the number of days whales were seen (Table 7) does reflect the amount of effort as well as abundance of whales. In particular, in comparison to other regions, the large number of sightings in SVI partly reflects large numbers of sampling days by Brian Gisborne who has routinely sampled SVI from summer through fall on almost a daily basis. On the other hand, the decline in sightings in SVI during 2007 was not due to reduced effort but to the distribution of whales with many of the whales having moved to waters off Oregon and Washington (Calambokidis et al. 2009b). Similarly, there were 40 survey days in SJF in 2010 but only 4 whales were seen on 4 different days (Table 6, Table 7) so this drop relative to other years was not due to lack of effort.

Whales were sighted across various survey regions and the interchange of whales (Table 8) between survey regions during 1 June - 30 November depends on proximity of the regions (Calambokidis et al. 2004). During 1 June-30 November for 1996 to 2015, 793 unique whales were seen in the PCFG range and 68.6% (544 of the 793 whales seen in the PCFG range) were seen within the smaller OR-SVI region and approximately 36.3% (288 of the 793 whales seen in the PCFG range) were seen within the smaller MUA area; however, there is variation in interchange between areas in the PCFG and the MUA. Of the whales sighted in regions from NCA to NBC, from 39.8% to 59.6% of the whales were seen at some point within MUA (Figure 5). If we exclude transients (whales seen in only one year), the interchange rates with MUA are much higher but the pattern is similar (Figure 6) with a range of 47.7% to 77.5%. Appendix Table 2 provides capture histories using data from 1 June - 30 Nov of whales seen in the MUA at least once. For each year, the table shows whether the whale was sighted in PCFG but not in the MUA during that year, only seen in MUA that year, and seen in both MUA and another PCFG area in that year.

Whales seen in the PCFG exhibited a wide range of movement across and within years. The 143 whales seen in 9 or more years provide a useful example. None of those whales was seen exclusively in a single region, and 67.1% were seen in at least 4 of the 9 survey regions from 1996 to 2015. However, whales did regularly visit the same regions across years with 94.4% were seen in at least one of the regions during six or more of the years they were seen and 65.7% were seen in a region two-thirds or more of the years they were

seen. SVI was the region with the maximum number of years seen for 65 of the 143 whales, which in part reflects the larger amount of survey effort in SVI (Calambokidis et al. 2004a, Calambokidis et al. 2013). Thus, some whales regularly visit particular regions more often than others, but they are seen across the other regions as well.

Some of the whales not seen in the PCFG in a year were seen in Kodiak and Southeast Alaska (Table 9). Of the 25 whales identified in Southeast Alaska and the 153 whales identified in Kodiak, Alaska, 14 (56%) and 24 (15.7%), respectively have been seen farther south in the PCFG.

If we look at latitudes of sightings of individual whales across the 20 years using whales that have been sighted on at least 6 different days (Figure 7), we see that sightings of some whales are highly clustered; whereas, sightings of other whales are highly dispersed across several regions. We defined each whales primary range by the 75% inner quantile which is the middle of the range that includes 75% of the locations. The length of the 75% inner quantile in nautical miles exceeded 60 nautical miles (or 1 degree of latitude) for 49.0% of the whales (Figure 8) and it was more than 180 nautical miles for more than 29.6% of the whales. Thus, it makes little sense to compute an estimate of abundance for any region that spans less than a degree of latitude.

3.3 Annual Sighting Patterns

The average number of whales identified in any one year was 156, 104, and 37 for the PCFG, OR-SVI, and MUA, respectively (Table 10). However, those numbers do not represent the total numbers of whales that use each of these areas because not all whales using a region in a year are seen, not all whales return to the same region each year, and not all of the whales return to the PCFG region each year. The annual average number of newly seen whales (excluding 1996-1998 when the photo-id effort expanded to cover all survey regions) was 37.2, 25.8, and 13.6 for PCFG, OR-SVI, and MUA, respectively. The annual average number of newly seen whales that were "recruited" (seen in a subsequent year), excluding 1996-1998 and 2015, was 14.9, 12.6, and 6.4 for PCFG, OR-SVI, MUA respectively. Thus, there were a substantial number of new whales seen each year and 40.6, 49.6, and 47 percent of those were seen again in a subsequent year in the 3 regions respectively. The number of newly seen whales and the number newly seen and recruited (i.e., seen in at least one more year after the initial year it was seen) (Table 11) are displayed as discovery curves in Figures 9 and 10.

Of the whales that were seen during June-November 1996-2015 in the PCFG (NCA to NBC) about half were only seen in one year and the whales that were seen in more years were sighted more often each year and therefore represented a large proportion of the sightings (Figure 11). Of the 750 identified whales first seen before 2015 between 1 June and 30 November in the PCFG range (NCA-NBC), 52% were seen in only one year and only represent about 5% of the sightings (Figure 11). Many of the newly seen whales did not return in subsequent years. Some whales were seen in every year with 9.3% that were seen in every year after their initial identification, including 5 whales first seen in 1996 that were seen in all of 20 subsequent years. The remaining 39% were seen more than once but not in every year.

Likewise, examination of MT in the first sighting year demonstrates that whales who

stay longer in their first year were more likely to be seen in a following year (Figure 12). Whales "first" seen in the first few years of the study (1996-1998) includes some whales that were truly new to the PCFG in those years but many were only "new" because it was the first year of the study or as the surveyed regions expanded over time. This is evident (Figure 12) in the much higher proportions for 1996-1998 than for the other years. These relationships will be important in the capture-recapture models for abundance estimation because whales that do not return after their first year (a large percentage in this analysis) would appeared to have not survived because they have permanently emigrated (with a small fraction that died).

3.4 Open Population Capture-Recapture Models

If the yearly cohorts were pooled, Test2+Test3 statistics indicated a significant lack of fit for the PCFG and subsets (Table 12) primarily resulting from Test 3. This was expected due to the different "survival" rates of previously seen whales (true survival) and newly seen whales of which many never returned (i.e., permanently emigrated) (Table 13) . By separating the cohorts, survival for each cohort was time-varying and thus each cohort has a separate first year survival. The goodness of fit test (Test 2) demonstrated a lack of fit for NCA-NBC and OR-SVI (Table 12). For those regions, we estimated an over-dispersion values of $\hat{c}$=2.29 and $\hat{c}$=1.23 respectively to adjust AICc and estimated standard errors.

For all areas, the best fitted model (Table 14) was model 2 for p with capture probability varying across years and higher when MT was greater in the previous year. Likewise, for φ the best model was model 4 for all areas. Model 9 was the second best model. Both models 4 and 9 included a separate first year survival which depends on MT. Model 9 included a different calf first-year "survival" which gave a higher survival for calves than non-calves the first year seen (redundant for calves) because they are more likely to return. In models 9 and 4, there are 3 intercepts for first year survival (1996&97, 1998, >1998) and in model 9 the slopes for MT differ as well. These results were consistent with Calambokidis et al. (2004) who demonstrated strong support for the effect of MT on first year survival (Figure 13) and capture probability (Figure 15) in the following year. These results differ some from Calambokidis et al. (2010) who used an annual median-centered MT. Use of MT with median centering was necessary to construct open model abundance estimates in the manner described in Calambokidis et al. (2010). However, that was not necessary for JS1 and the use of MT without median-centering resulted in lower AICc values.

There was large year to year variation in capture probability. The values for NCA-NBC ranged from 0.42 to 0.98 depending on the year and value of MT (Figure 15). The lowest values were from 2007 which reflects the temporary emigration of whales from MUA and SVI to waters offshore of Oregon in that year. In contrast, for MUA capture probabilities were much lower ranging from 0.08 to 0.76 depending on the year and value of MT (Figure 16). The lower overall capture probability and weaker relationship between capture probability and MT reflect the transitory behavior of whales in such a small area. The lower estimates of of capture probability in 1999-2004 for MUA was due to decreased effort by NMML which spread their survey effort across MUA to WVI during 1999-2002, lost a vessel in 2002 and had no funding in 2004 (Figure 16).

First year survival estimates were dominated by permanent emigration. For NCA-NBC, the estimates varied from 0.30 to 0.81 for non-calf whales with MT=1 in their first year and from 0.69 to 0.95 for MT>80 in their first year (Figure 13). Calf survival is by definition a first year survival rate and potentially includes permanent emigration from the PCFG. Depending on the value of MT, calf survival estimates ranged from about 0.35 to over 0.90 (Figure 14). The average calf survival estimate was 0.63 (se = 0.090). There was some support for a different first year calf survival with model 9 being the second best model (ϕ in Table 14) because calves are less likely to permanently emigrate. Unfortunately there is no way to separate permanent emigration from mortality with the existing data.

Survival subsequent to the first year was assumed to be constant but was less for non-calf whales that were newly seen in 1999 or later. Post-first-year suvival for calves and whales present in 1998 or earlier presumably represents true survival assuming there was little permanent emigration after the first year. Those estimates were 0.967 (se=0.0062) and 0.967 (se=0.0066) for OR-SVI and NCA-NBC respectively. The post-first-year survival estimates for whales that entered in 1999 or later and not identified as a calf were 0.912 (se=0.0125) and 0.917 (se=0.0142) for OR-SVI and NCA-NBC respectively.

3.5 Abundance and Recruitment

For NCA-NBC, OR-SVI and MUA annual estimates of abundance were constructed with model averaged values for JS1 (Table 15-16). Estimates for NCA-NBC in Figure 17 are only shown for 1998-2015 with the open models $p = 1$ for 1996 so it will certainly be an underestimate and the survey coverage in 1996 and 1997 was not as extensive as the later years.

The value of N_{min} for 2015 is 228 for NCA-NBC (Table 15). To gain a sense for how these values might be relevant to estimating a possible level of removal (e.g., due to harvest) we computed the MMPA's Potential Biological Removal (PBR) (typically reserved for stock-level assessments). Using the PBR formula, with an Rmax of 6.2% and a recovery factor of 0.5 (Caretta et al. 2013), the PBR for NCA-NBC (PCFG) would be 3.5.

New whales that are not identified as calves have appeared annually and many of these new (non-calf) whales have subsequently returned and been re-sighted (Table 13). In NCA-NBC from 1999-2014, an average of 32.1 (range: 8.0, 68.0) new whales not identified as a calf were seen each year. Of these new non-calf whales, on average 11.8 (range: 1.0, 28.0) whales returned and were seen in subsequent years. It is unknown what proportion of the non-calves used the PCFG as a calf but were not seen in that year. Currently recruitment appears to be offset by losses (either mortality or permanent emigration) as the abundance estimates have been fairly stable since 2002 and recently increasing.

4 Discussion

The population structure of gray whales using the Pacific Northwest in summer and fall is complicated and involves two elements. One group of whales return frequently and account for the majority of the sightings in the Pacific Northwest during summer and fall. This

group is certainly not homogeneous and even within this group, there is some degree of preference for certain subareas. Despite widespread movement and interchange among areas, some of these gray whales are more likely to be seen returning to the same areas they were seen before. The second group of whales are transients that are seen in only one year, tend to be seen for shorter periods that year, and in more limited areas.

The existence of these two groups in the study area and their dynamics complicate estimating abundance. While the JS1 estimator may not be optimal, it provides a practical way of handling transients in this open population. Excluding 1996-1997, the JS1 sequence of abundance estimates provides the most reliable assessment of trend for the non-transient abundance and the best estimate of current abundance in 2015.

Despite extensive interchange among subregions in our study area, whales do not move randomly among areas. Abundance estimates were lower when using more limited geographic ranges but these more limited areas do not reflect closed populations. While the use of geographically stratified models can be useful in cases where populations have geographic strata they use (see for example Hilborn 1990), this would be difficult in our case because of the frequent sightings of animals in multiple regions within the same season and these models typically only allow an animal to be sighted in one strata per period. This could be dealt with by assigning animals to only a single region per season but this would be forcing the data into a somewhat inaccurate construct.

Several studies have considered the question of gray whale population structure. There is widespread agreement that at least two populations of gray whales in the North Pacific exist, a western North Pacific population (also called the Korean population) and an eastern North Pacific (ENP) population (sometimes called the California population) (Swartz et al. 2006; Angliss and Outlaw 2008; Rugh et al. 1999). The population structure of the gray whales feeding in the Pacific Northwest has remained in question and only a few studies have examined this. Steeves et al. (2001) did not find mtDNA differences in a preliminary comparison of gray whales from the summer off Vancouver Island and those from the larger ENP population. Ramakrishnan et al. (2001) did not find evidence that the Pacific Northwest whales represented a maternal genetic isolate, although even very low levels of recruitment from the larger overall population would prevent genetic drift. More recently, Frasier et al. (2011) generated mtDNA sequences from a larger sample of gray whales from Vancouver Island than tested by Steeves et al. (2001). They found significant differences in the haplotype frequencies between that sample and mtDNA sequence data reported for ENP gray whales, most of which were animals that stranded along the migratory route. The Frasier et al. (2011) samples were from a relatively small area; however, Lang et al. (2011) evaluated biopsy samples from California to southern Vancouver Island in the PCFG and ENP samples from whales sampled north of the Aleutians and also found significant mtDNA halpotype frequency differences. These two studies provide the strongest evidence to date that the Pacific Northwest whales might be sufficiently isolated to allow maternally inherited mtDNA to differ from the overall ENP population.

Population structure in other large whales has been the subject of recent inquiry and has revealed diverse results for different species. Clapham et al. (2008) examined 11 subpopulations of whales subjected to whaling that were extirpated possibly due to the loss of the cultural memory of that habitat and concluded subpopulations often exist on a smaller spatial scale than had been recognized. Studies of other baleen whales, particularly

humpback whales, have shown evidence of maternally directed site fidelity to specific feeding grounds based on photographic identification studies (Calambokidis et al. 1996, 2001, 2008). This high degree of fidelity to specific feeding areas is often discernible genetically. In the North Pacific strong mtDNA differences were found among feeding areas even when there was evidence of low level of interchange from photo-ID (Baker et al. 2008). Similar findings were documented for humpback whales in the North Atlantic which feed in different areas but interbreed primarily on a single breeding ground (Palsboll et al. 1995) like ENP gray whales. In the North Pacific the differences for humpback whales were often dramatic. For example, humpback whales that feed off California have almost no overlap in mtDNA haplotypes with humpback whales feeding in Southeast Alaska (Baker et al. 1990, 1998, 2008). One difference between humpback and gray whales is the coastal migration route of gray whales which means gray whales going to arctic waters to feed would migrate right through the feeding areas to the south. Other species of large whales have not shown as strong site fidelity to specific feeding grounds. Blue whales have undergone an apparent shift in their feeding distribution in the North Pacific apparently due to shifting oceanographic conditions (Calambokidis et al. 2009a). Fin whales in the North Pacific have long migrations and while there do not appear to be multiple distinct feeding areas as was the case for humpback whales, there were some distinct and isolated apparently non-migratory populations (Mizroch et al. 2009; Berube et al. 2004).

Even though the population structure of gray whales off the Pacific Northwest remains unresolved, there is a consistent group of animals that use this area and we provide several estimates of their abundance. Different abundance methods and geographic scopes yield varied results but all suggest the annual abundance of animals using the Pacific Northwest for feeding through the summer is at most a couple hundred animals depending on the estimating method and how broadly the region is defined geographically.

The rapid increase in the abundance estimates at the start of this study is in part due to the smaller area of coverage during 1996 and 1997. We included those years to improve the estimate in 1998-1999 and the estimate for 1998 did increase by 7% from previous analysis. The increase from 1998-2000 occurred during a period the overall eastern North Pacific gray whale population was experiencing a high mortality event that included unusually high numbers of gray whales showing up in areas they were not common. The high rate of increase in the late 1990s and early 2000s should be verified with additional data such as compiling photographic identifications for this area from multiple sources to attempt to verify if the abundance of animals prior to the start of our study was as low as suggested by these trends. Even though the rate of increase may be too high, we believe the abundance did increase and now appears to be relatively stable since 2002.

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Table 1: Contributions of numbers of sightings (one or more photographs of a whale per day) by reseach group for 1996-2015 and resulting number of uniquely identified whales. Totals for whales are unique whales across all research groups.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Whales
Brian Gisborne	0	4	342	305	634	505	363	786	288	393	406	101	484	297	556	540	521	695	638	472	505
Canada Fisheries/Oceans	0	0	0	0	0	0	0	0	0	0	0	0	0	1	14	8	0	0	0	0	22
Carrie Newell	0	0	0	0	0	0	0	0	0	0	12	72	0	18	2	0	138	190	127	0	129
CERF	13	260	101	124	203	346	271	125	761	11	33	11	38	4	7	40	26	50	7	0	137
CRC	54	36	127	179	91	60	89	85	135	31	61	92	69	58	50	56	83	61	22	41	457
Dawn Goley-HSU	0	0	21	74	56	60	63	0	0	0	0	0	42	19	50	227	228	73	78	28	333
Jan Straley-UASE	0	0	0	0	0	0	0	7	0	0	1	1	0	0	0	0	0	0	0	0	7
Jeff Jacobsen-HSU	0	0	0	0	0	0	0	0	0	0	1	1	0	5	127	327	124	229	141	88	332
Jim Darling	18	0	48	0	0	34	13	0	0	0	0	0	0	0	0	23	0	0	0	0	80
MAKAH	0	0	0	0	0	0	0	0	30	45	129	62	247	102	45	66	145	196	150	202	284
MAKAH-NMML	0	0	0	0	0	0	0	0	0	0	0	0	0	71	24	45	116	53	43	9	137
NMML	34	110	125	159	121	115	71	64	13	99	46	37	65	25	6	11	19	13	25	28	377
North Slope Borough	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Opportunistic	12	3	8	14	1	1	0	0	0	1	28	46	66	82	70	196	43	183	70	38	314
OSU	0	0	0	0	0	0	0	0	0	0	0	0	0	212	68	0	91	45	0	34	119
SWFSC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	131	118
UAF	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	23
UVIC	0	0	308	125	128	0	113	0	0	0	0	1	0	0	0	0	0	0	58	100	177
Volker Deecke	0	0	39	40	26	2	0	0	0	0	11	0	0	0	0	0	0	0	0	0	73
Wendy Szaniszlo	0	0	0	0	0	0	0	0	0	87	50	58	117	4	23	90	136	171	52	32	150
Photo Totals	131	413	1119	1020	1260	1123	983	1067	1227	667	777	482	1152	898	1042	1629	1670	1959	1411	1203	
Whale Totals	70	77	158	247	179	196	251	178	196	202	182	159	225	242	234	284	330	384	295	266	1638

Table 2: Regional distribution of numbers of sightings (one or more photographs of a whale per day) and resulting number of uniquely identified whales by reseach group for 1996-2015. Totals for whales are unique whales across all research groups. NPS is northern Puget Sound and PS includes southern Puget Sound, San Juan Islands, Hood Canal and Boundary Bay.

	CA	NCA	SOR	OR	GH+	NWA	SJF	PS	NPS	SVI	WVI	NBC	SEAK	KAK
Brian Gisborne	0	0	0	0	0	0	0	1	0	8073	254	2	0	0
Canada Fisheries/Oceans	0	0	0	0	0	0	0	0	0	18	5	0	0	0
Carrie Newell	0	0	0	559	0	0	0	0	0	0	0	0	0	0
CERF	0	0	0	0	0	0	0	0	0	0	48	2383	0	0
CRC	23	98	117	100	254	112	40	68	521	38	0	95	14	0
Dawn Goley-HSU	0	919	64	36	0	0	0	0	0	0	0	0	0	0
Jan Straley-UASE	0	0	0	0	0	0	0	0	0	0	0	0	9	0
Jeff Jacobsen-HSU	13	992	31	6	0	0	0	0	0	0	0	0	0	0
Jim Darling	0	0	0	0	0	0	0	0	0	9	127	0	0	0
MAKAH	0	0	0	19	0	618	782	0	0	0	0	0	0	0
MAKAH-NMML	0	0	0	0	0	258	102	0	0	0	1	0	0	0
NMML	0	13	65	0	0	314	307	0	18	182	150	10	0	127
North Slope Borough	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Opportunistic	106	2	5	67	0	1	22	35	106	213	255	13	7	25
OSU	0	331	3	111	5	0	0	0	0	0	0	0	0	0
SWFSC	0	0	12	0	0	0	0	0	0	41	9	33	0	36
UAF	0	0	0	0	0	0	0	0	0	0	0	0	0	24
UVIC	0	0	0	0	0	0	0	0	0	1	832	0	0	0
Volker Deecke	0	0	0	0	0	0	0	1	0	71	0	42	4	0
Wendy Szaniszlo	0	0	0	0	0	0	0	0	0	467	353	0	0	0
Photo Totals	142	2355	297	898	259	1303	1253	105	645	9113	2034	2578	34	212
Whale Totals	121	526	122	188	146	357	210	44	51	489	338	138	25	155

Table 3: Survey regions and region subsets used for abundance estimation. Numbers refer to locations on the map in Figure 1.

Survey Region	Region Description	NCA-NBC	OR-SVI	MUA
(1) SCA = Southern California				
(2) CCA = Central California				
(3) NCA = Northern California	Eureka to Oregon border; mostly from Patricks Pt. and Pt. St George	x		
(4) SOR = Southern Oregon		x	x	
(5) OR = Oregon Coast	Primarily central coast near Depoe Bay and Newport, OR	x	x	
(6) GH+ = Gray's Harbor	Waters inside Grays Harbor and coastal waters along the S Washington coast	x	x	
(7) NWA = Northern Washington	Northern outer coast waters with most effort from Cape Alava (Sea Lion Rock) to Cape Flattery	x	x	x
(8) SJF = Strait of Juan de Fuca	US waters east of Cape Flattery extending to Admiralty Inlet (entrance to Puget Sound) with most effort ending at Sekiu Point	x	x	x
(9) NPS = Northern Puget Sound	Inside waters and embayments from Edmonds to the Canadian border			
(10) PS = Puget Sound	Central and southern Puget Sound (S of Edmonds), including Hood Canal, Boundary Bay, and the San Juan Islands			
(11) SVI = Southern Vancouver Island	Canadian waters of the Strait of Juan de Fuca along Vancouver Island from Victoria to Barkley Sound, along West Coast Trail	x	x	
(12) WVI = West Vancouver Island		x		
(13) NBC = Northern British Columbia	British Columbia waters north of Vancouver Island, with principal effort around Cape Caution	x		
(14) SEAK = Southeast Alaska	Waters of southeastern Alaska with the only effort in the vicinity of Sitka			
(15) KAK = Kodiak, Alaska				

Table 4: Model specifications for survival (φ) and capture probability (p) parameters in POPAN models for gray whale photo-identification data. For survival models, β_0 is the baseline intercept for non-transient survival. Fy is 1 if it is year the whale was first seen and 0 otherwise. A subscript for Fy means that it applies only for that cohort except that Fy_{99}applies to cohorts 1999 and beyond and Fy_c represents each of the cohorts from 1996 to 2015. C is 1 if identified as a calf in its first year and 0 otherwise. R is 1 for calves or any whale seen in 1998 or was already in the catalog prior to 1998 and 0 otherwise. β_r is an adjustment to post-first-year survival. MT is minimum tenure value of a whale and β_M is the estimated slope parameter for φ or p. $\beta_{M,96-97}$ applies to 1996-97, $\beta_{M,98}$ to 1998 and $\beta_{M,99}$ applies to 1999-2014. $\beta_{Fy,96-97}$, $\beta_{Fy,98}$ and $\beta_{Fy,99}$ are the first-year survival intercept adjustments for 1996-97, 1998 and cohorts 1999-2014 respectively and $\beta_{Fy,c}$ represents 19 cohort-specific first year survival parameters for 1996-2014. β_{CF} is an adjustment for calf first year survival and β_{CM} is an adjustment for calves to the slope of MT for survival. For the capture probability models, β_t has 18 levels for t=1998,...2015 and β_0 represents the 1997 value. For 1996 p=1.

Model	Parameter Logit Formula	Number of parameters
φ		
1	$\beta_0 + \beta_{Fy} Fy + \beta_r R(1 - Fy)$	3
2	$\beta_0 + \beta_{Fy} Fy + \beta_M MT\, Fy + \beta_r R(1 - Fy)$	4
3	$\beta_0 + \beta_{Fy,96-97} Fy_{96-97} + \beta_{Fy,98} Fy_{98} + \beta_{Fy,99} Fy_{99} + \beta R(1 - Fy)$	5
4	$\beta_0 + \beta_{Fy,96-97} Fy_{96-97} + \beta_{Fy,98} Fy_{98} + \beta_{Fy,99} Fy_{99} + \beta_M MT\, Fy + \beta_r R(1 - Fy)$	6
5	$\beta_0 + (\beta_{Fy,96-97} + \beta_{M,96-97} MT) Fy_{96-97} + (\beta_{Fy,98} + \beta_{M,98} MT) Fy_{98} + (\beta_{Fy,99} + \beta_{M,99} MT) Fy_{99} + \beta_r R(1 - Fy)$	8
6	$\beta_0 + \beta_{Fy,c} Fy_c + \beta_M MT\, Fy + \beta_r R(1 - Fy)$	22
7	$\beta_0 + \beta_{Fy,c} Fy_c + \beta_M MT\, Fy + \beta_{CF} C\, F_y + \beta_r R(1 - Fy)$	23
8	$\beta_0 + \beta_{Fy,c} Fy_c + \beta_M MT\, Fy + \beta_{CF} C\, F_y + \beta_{CM} C\, MT + \beta_r R(1 - Fy)$	24
9	$\beta_0 + (\beta_{Fy,96-97} + \beta_{M,96-97} MT) Fy_{96-97} + (\beta_{Fy,98} + \beta_{M,98} MT) Fy_{98} + (\beta_{Fy,99} + \beta_{M,99} MT) Fy_{99} + \beta_{CF} C\, F_y + \beta_r R(1 - Fy)$	9
10	$\beta_0 + (\beta_{Fy,96-97} + \beta_{M,96-97} MT) Fy_{96-97} + (\beta_{Fy,98} + \beta_{M,98} MT) Fy_{98} + (\beta_{Fy,99} + \beta_{M,99} MT) Fy_{99} + \beta_{CF} C\, F_y + \beta_{CM} C\, MT + \beta_r R(1 - Fy)$	10
p		
1	$\beta_0 + \beta_t$	19
2	$\beta_0 + \beta_t + \beta_M MT$	20
3	$\beta_0 + \beta_M MT$	2

Table 5: Regional distribution of numbers of whales seen by month for 1996-2015.

	1	2	3	4	5	6	7	8	9	10	11	12
CA	7	16	18	17	14	3	6	7	13	1	1	28
NCA	154	50	8	67	68	127	139	57	49	100	114	139
SOR	0	3	0	2	5	7	36	45	69	43	0	0
OR	0	1	4	4	30	28	53	83	93	64	2	0
GH+	6	2	30	60	29	17	3	0	27	1	0	0
NWA	7	5	26	61	110	79	78	102	103	73	13	1
SJF	0	0	3	15	32	47	60	62	83	105	79	21
PS-HC-BB-SJ	0	1	6	21	8	10	5	2	1	1	4	1
NPS	1	3	17	28	32	11	1	0	0	0	0	0
SVI	5	8	77	101	129	224	263	216	186	94	37	6
WVI	0	1	14	35	31	116	194	186	113	27	0	0
NBC	1	0	0	0	3	26	84	113	83	28	0	1
SEAK	0	0	0	0	0	17	4	1	3	0	5	0
KAK	0	0	0	0	2	19	34	57	60	0	0	0

Table 6: Regional distribution of numbers of whales seen during June-November for 1996-2015.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CA	0	0	0	1	0	5	0	0	4	0	3	0	0	3	7	1	7	0	0	2
NCA	0	0	16	38	27	32	37	15	3	0	0	1	47	62	62	82	95	81	53	8
SOR	0	0	0	0	0	2	46	24	16	1	0	23	15	2	15	10	11	5	26	30
OR	0	0	17	31	8	15	0	0	16	4	9	39	6	38	20	7	42	40	35	21
GH+	1	0	0	1	1	1	0	0	1	0	0	38	0	2	0	0	0	0	0	0
NWA	13	15	22	7	9	31	7	19	3	19	44	13	35	30	22	36	62	47	32	31
SJF	9	22	18	4	5	2	1	9	24	17	21	14	54	37	4	11	11	36	45	23
PS-HC-BB-SJ	0	0	3	8	4	0	0	0	0	1	0	0	0	4	0	0	1	0	0	1
NPS	0	0	0	0	10	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
SVI	13	17	60	45	55	101	66	90	86	89	67	37	78	75	62	62	73	99	84	98
WVI	8	0	57	66	53	29	85	9	0	52	40	13	23	23	9	53	28	114	50	46
NBC	13	33	23	25	23	40	43	51	88	12	21	5	21	3	4	2	15	31	7	28
SEAK	0	0	5	6	0	1	0	6	0	1	2	3	0	5	0	0	0	0	0	0
KAK	0	0	0	0	0	0	42	4	0	48	0	0	23	0	17	0	2	0	0	35

Table 7: Number of days in which whales were seen for each region and year from 1996-2015 from 1 June - 30 November.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CA	0	0	0	1	0	2	0	0	2	0	1	0	0	2	4	1	2	0	0	2
NCA	0	0	8	8	20	13	20	2	2	0	0	2	9	19	21	32	28	20	14	4
SOR	0	0	0	0	0	1	4	1	2	1	0	3	1	1	7	6	3	4	6	5
OR	0	0	6	9	5	7	0	0	1	1	7	38	1	22	8	11	70	54	18	13
GH+	1	0	0	1	1	1	0	0	1	0	0	3	0	1	0	0	0	0	0	0
NWA	9	12	22	10	7	11	3	9	1	12	13	7	8	7	14	23	20	16	17	16
SJF	9	42	16	9	9	4	2	15	7	13	18	26	36	30	4	11	17	25	31	33
PS-HC-BB-SJ	0	0	3	11	4	0	0	0	0	2	0	0	0	4	0	0	1	0	0	1
NPS	0	0	0	0	1	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0
SVI	9	10	91	87	82	55	68	66	48	73	59	39	82	71	80	106	75	64	77	28
WVI	10	0	54	46	28	7	10	3	0	6	14	27	31	5	1	22	7	46	25	28
NBC	7	53	39	50	53	43	34	29	53	11	16	9	13	2	8	1	3	6	1	5
SEAK	0	0	2	3	0	1	0	3	0	1	2	2	0	2	0	0	0	0	0	0
KAK	0	0	0	0	0	0	4	2	0	7	0	0	5	0	2	0	1	0	0	10

Table 8: Interchange of whales across regions for all years (1996-2015) for June-November. The diagonal is the number of unique whales seen in that region over the 20 year time span. Many of those whales were only seen once. Here PS includes NPS and CA represents SCA and CCA.

	CA	NCA	SOR	OR	GH+	NWA	SJF	PS	SVI	WVI	NBC	SEAK	KAK
CA	28												
NCA	10	301											
SOR	6	73	112										
OR	8	103	69	166									
GH+	1	19	11	21	43								
NWA	9	83	54	87	27	203							
SJF	6	49	27	48	17	97	182						
PS	0	0	0	0	0	1	1	32					
SVI	10	101	56	96	30	148	118	2	343				
WVI	7	87	45	81	30	120	99	2	200	295			
NBC	3	23	13	33	15	42	38	2	84	82	133		
SEAK	0	3	1	3	2	6	7	0	9	10	12	25	
KAK	1	10	1	6	0	3	2	1	13	12	8	1	153

Table 9: Sighting histories of whales seen in the PCFG during 1 June - 30 November in at least one year and also in Southeast Alaska (SEAK) or Kodiak (KAK) in one year. 1: whale sighted in PCFG but not SEAK or KAK that year, 2: only seen in SEAK or KAK that year, and 3: seen in both PCFG and in SEAK and KAK in that year.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
68	1	2	2																
187	1	1	1	1	1	1	1	1				1		1					2
126	1	1			1			1	2			1				1			
130	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
140	1	1	3	1	1	1	1	1		1		1	1	1	1	1	1	1	1
141	1	1	1		1	1	1	1	1	1	3	1	1			1	1		1
152	1		1			2			2					2					
229	1	1	1	1	1	1	1	1	1	2									
323	1	1				1	1	1	2	1		2							
325	1	1			1	1	1	1	3	1							1	1	
328	1	1	1	1	1	1	1	1	1	1		1	3		1	1	1	1	1
899	1							1	2										
227		1	2	1	1	1	1	1	1	1	1		1		1	1	1	1	1
232		1		1	1	2	1								1			1	1
261		2				1		1							1		1	1	
316		1					2		2										
628			2	1	1	1	1	1				1					1		1
538				1	1	1		1	2										
555				1		1	1			1		2	1	1	1	1	1		
566				1		2		1	2					1					
601				1	1		1	1	1	1						2			
612				1	1	1	3	1	1	2						1	1	1	1
581					1		1	1	2	1	1					2	1	1	1
604					1		1		2					2	1				
639					1	2					1		1						
684						1	2				1								
687						1			1	1	1	1	3	1					
691						1	3	1	2			1							
723						2													1
760						1	1	1	3							1			2
800							3	1	1										
815								1				2						1	
900								1					2			1			1
834									2				1				1	1	
893									2							1		1	
918									2							1			
993											1			1	1				3
1778																		1	2

Table 10: Number of unique whales seen by year for MUA, OR-SVI, and PCFG (NCA-NBC) during 1996-2015.

Region	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
MUA	19	27	37	11	14	32	8	22	26	33	58	20	75	57	26	41	67	66	63	45	37
OR-SVI	30	36	86	71	70	128	103	110	118	107	96	114	123	118	93	91	127	145	151	161	104
PCFG	45	69	132	151	140	173	203	157	179	135	126	120	174	152	144	164	208	232	200	211	156

Table 11: Discovery of new unique whales over years 1996-2015 for PCFG,OR-SVI and MUA. Recruited only means that the whale was seen in at least one more year after the initial year it was seen. The number 'recruited' will usually be greater than the abundance estimate because some whales die and others may permanently emigrate and do not return.

Region	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PCFG	45	90	161	229	283	345	398	418	448	466	474	494	544	566	581	600	653	711	750	793
ORSVI	30	50	105	128	155	211	249	275	306	323	333	355	377	394	402	411	439	476	512	544
MUA	19	34	57	58	69	88	89	100	114	123	146	148	177	190	194	205	227	249	273	288
PCFG-recruited	40	76	123	135	163	189	219	234	247	257	258	267	285	292	304	309	328	350	362	
ORSVI-recruited	26	39	76	85	100	122	149	169	185	195	198	205	216	222	229	234	248	266	278	
MUA-recruited	17	28	36	36	44	51	52	58	68	74	91	93	109	111	113	119	126	133	138	

Table 12: RELEASE goodness of fit results for each region using pooled and separate cohorts. When cohorts are separated as groups, Test 3 is always 0 because there are no sub-cohorts.

Region	Cohort	Test	χ^2	df	P
MUA	Pooled				
		Test 2	75.1301	35	1e-04
		Test 3	73.6519	34	1e-04
		Total	148.782	69	0
	Separate				
		Test 2	17.4696	79	1
OR-SVI	Pooled				
		Test 2	207.9702	47	0
		Test 3	358.0037	35	0
		Total	565.974	82	0
	Separate				
		Test 2	172.5884	140	0.0319
NCA-NBC	Pooled				
		Test 2	381.7309	47	0
		Test 3	738.8561	35	0
		Total	1120.587	82	0
	Separate				
		Test 2	302.1301	132	0

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Table 13: Number of whales seen each year, number that were new that year in that region, and number that were new and were seen in a subsequent year for whales seen between June-November 1996-2015 in each region. The year a whale was seen as new can vary across regions and if it differs will be later in the smaller region.

Region		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
MUA	Seen	19	27	37	11	14	32	8	22	26	33	58	20	75	57	26	41	67	66	63	45
	Non-calf: New	19	15	22	1	11	18	1	10	12	9	23	2	28	13	4	9	20	17	21	12
	Non-calf: New/Resighted	17	11	7	0	8	7	1	5	8	6	17	2	15	2	2	4	6	4	5	0
	Calf: New	0	0	1	0	0	1	0	1	2	0	0	0	1	0	0	2	2	5	3	3
	Calf: New/Resighted	0	0	1	0	0	0	0	1	2	0	0	0	1	0	0	2	1	3	0	0
OR-SVI	Seen	30	36	86	71	70	128	103	110	118	107	96	114	123	118	93	91	127	145	151	161
	Non-calf: New	30	20	54	23	27	51	31	23	26	14	10	20	20	16	7	4	21	26	25	26
	Non-calf: New/Resighted	26	13	36	9	15	19	22	17	13	9	3	6	10	6	6	2	8	9	7	0
	Calf: New	0	0	1	0	0	5	7	3	5	3	0	2	2	1	1	5	7	11	11	6
	Calf: New/Resighted	0	0	1	0	0	3	5	3	3	1	0	1	1	0	1	3	6	9	5	0
NCA-NBC	Seen	45	69	132	151	140	173	203	157	179	135	126	120	174	152	144	164	208	232	200	211
	Non-calf: New	45	45	68	68	54	57	44	17	25	15	8	17	48	21	12	13	44	47	24	32
	Non-calf: New/Resighted	40	36	45	12	28	23	23	12	10	9	1	8	17	7	9	1	12	12	5	0
	Calf: New	0	0	3	0	0	5	9	3	5	3	0	3	2	1	3	6	9	11	15	11
	Calf: New/Resighted	0	0	2	0	0	3	7	3	3	1	0	1	1	0	3	4	7	10	7	0

Table 14: Delta AICc and QAICc (for OR-NBC and NCA-NBC models) for 30 models fitted to each set of data.

		φ Model									
Region	p model	1	2	3	4	5	6	7	8	9	10
MUA	1	20.1	11.2	11.8	1.4	4.5	7.9	5.0	7.1	4.2	5.6
	2	17.2	9.5	9.2	0.0	3.2	7.4	4.3	6.4	2.6	4.0
	3	98.1	91.2	88.1	80.6	82.9	86.8	84.4	86.2	82.5	83.5
OR-SVI	1	223.1	181.7	214.9	170.4	173.4	176.2	174.5	173.4	172.8	173.3
	2	42.1	10.0	35.7	0.0	3.1	6.5	4.8	4.8	2.0	2.9
	3	42.9	11.4	36.9	1.7	4.9	9.3	7.9	8.4	3.4	4.3
NCA-NBC	1	185.3	149.8	159.4	120.1	123.6	129.3	127.3	129.3	121.3	123.4
	2	58.9	28.8	33.9	0.0	3.6	10.0	8.6	9.9	0.6	3.5
	3	62.8	33.4	39.5	5.4	8.7	16.6	13.0	NA	6.2	7.7

Table 15: JS1 abundance estimates ($\widehat{N}$), standard errors and minimum population estimate $N_{min} = \widehat{N}e^{-0.842\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ using data from 1996-2015 in OR-SVI and NCA-NBC regions.

Region	Year	$\widehat{N}$	$se(\widehat{N})$	N_{min}
OR-SVI	1996	24	2.2	22
	1997	42	6.2	38
	1998	81	9.1	74
	1999	84	10.3	76
	2000	91	13.3	81
	2001	132	14.3	121
	2002	134	16.1	121
	2003	158	14.2	146
	2004	163	16.6	150
	2005	169	17.2	155
	2006	155	17.1	141
	2007	162	14.6	150
	2008	170	17.4	156
	2009	161	13.6	150
	2010	150	17.7	135
	2011	146	16.0	133
	2012	163	13.6	152
	2013	177	13.2	167
	2014	189	16.5	175
	2015	196	19.3	180
NCA-NBC	1996	38	2.8	36
	1997	80	10.5	72
	1998	126	11.0	117
	1999	145	14.6	133
	2000	146	14.4	135
	2001	178	13.5	167
	2002	197	14.1	185
	2003	207	17.5	193
	2004	216	16.6	202
	2005	215	26.7	194
	2006	197	21.4	180
	2007	192	26.0	171
	2008	210	18.6	195
	2009	208	21.2	191
	2010	200	19.1	184
	2011	205	15.9	192
	2012	217	11.3	208
	2013	235	14.0	224
	2014	238	19.0	222
	2015	243	18.9	228

Table 16: JS1 abundance estimates ($\widehat{N}$), standard errors and minimum population estimate $N_{min} = \widehat{N}e^{-0.842\sqrt{log(1+(se(\widehat{N})/\widehat{N})^2}}$ using data from 1996-2015 in MUA region.

Year	$\widehat{N}$	$se(\widehat{N})$	N_{min}
1996	18	1.5	16
1997	32	4.6	28
1998	40	9.3	33
1999	38	14.8	28
2000	41	26.4	25
2001	53	14.1	43
2002	48	23.7	33
2003	53	17.6	41
2004	58	17.7	45
2005	62	12.5	52
2006	70	8.8	63
2007	71	20.1	56
2008	84	7.6	78
2009	86	11.8	77
2010	80	20.3	65
2011	79	14.6	68
2012	88	10.8	80
2013	91	11.8	82
2014	100	15.2	88
2015	105	21.5	88

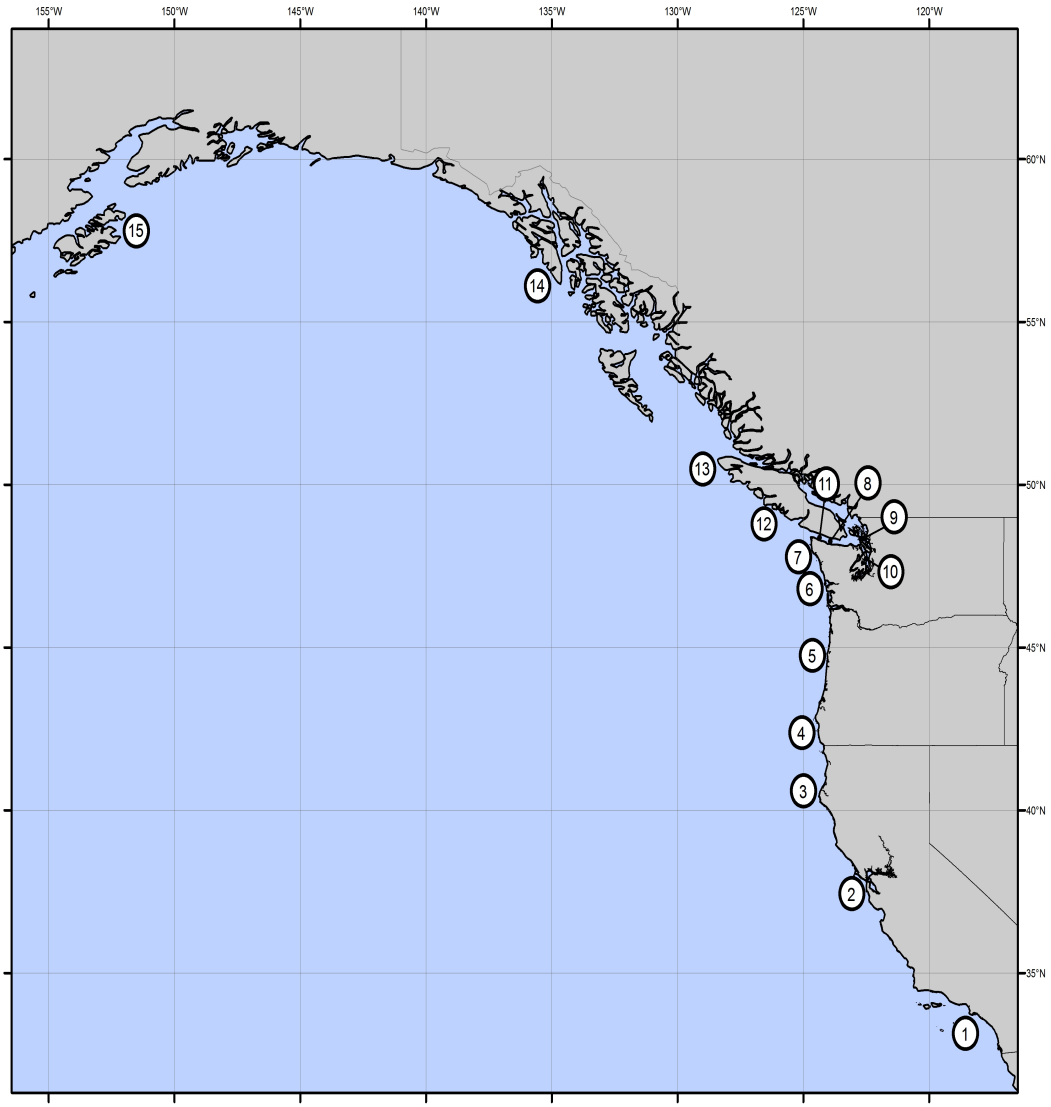

Figure 1: Locations for photo-identifications of gray whales. Numbers refer to values in Table 3.

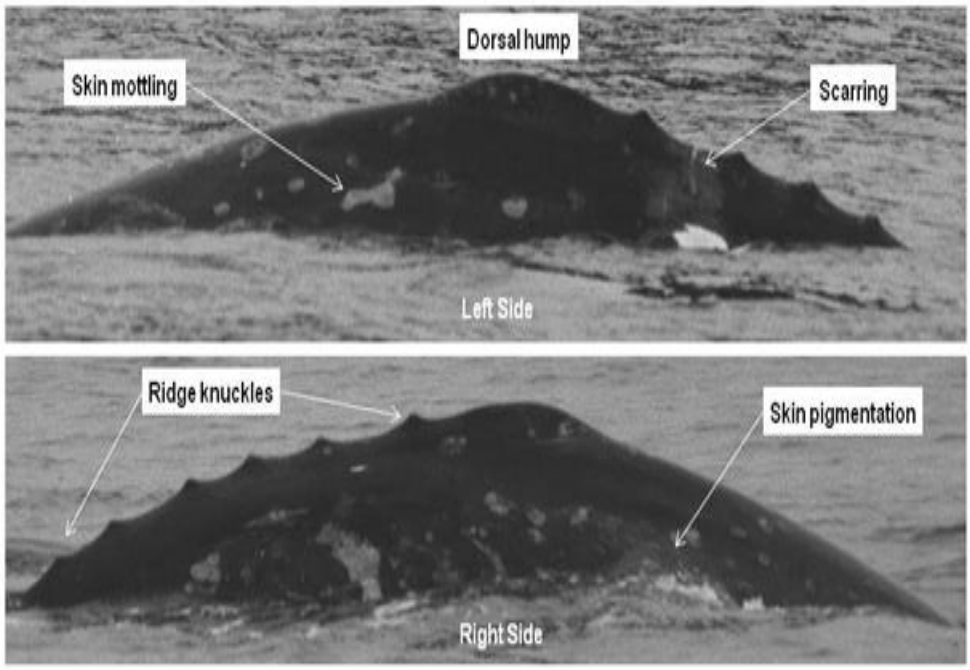

Figure 2: Characteristics used for gray whale photo-identification.

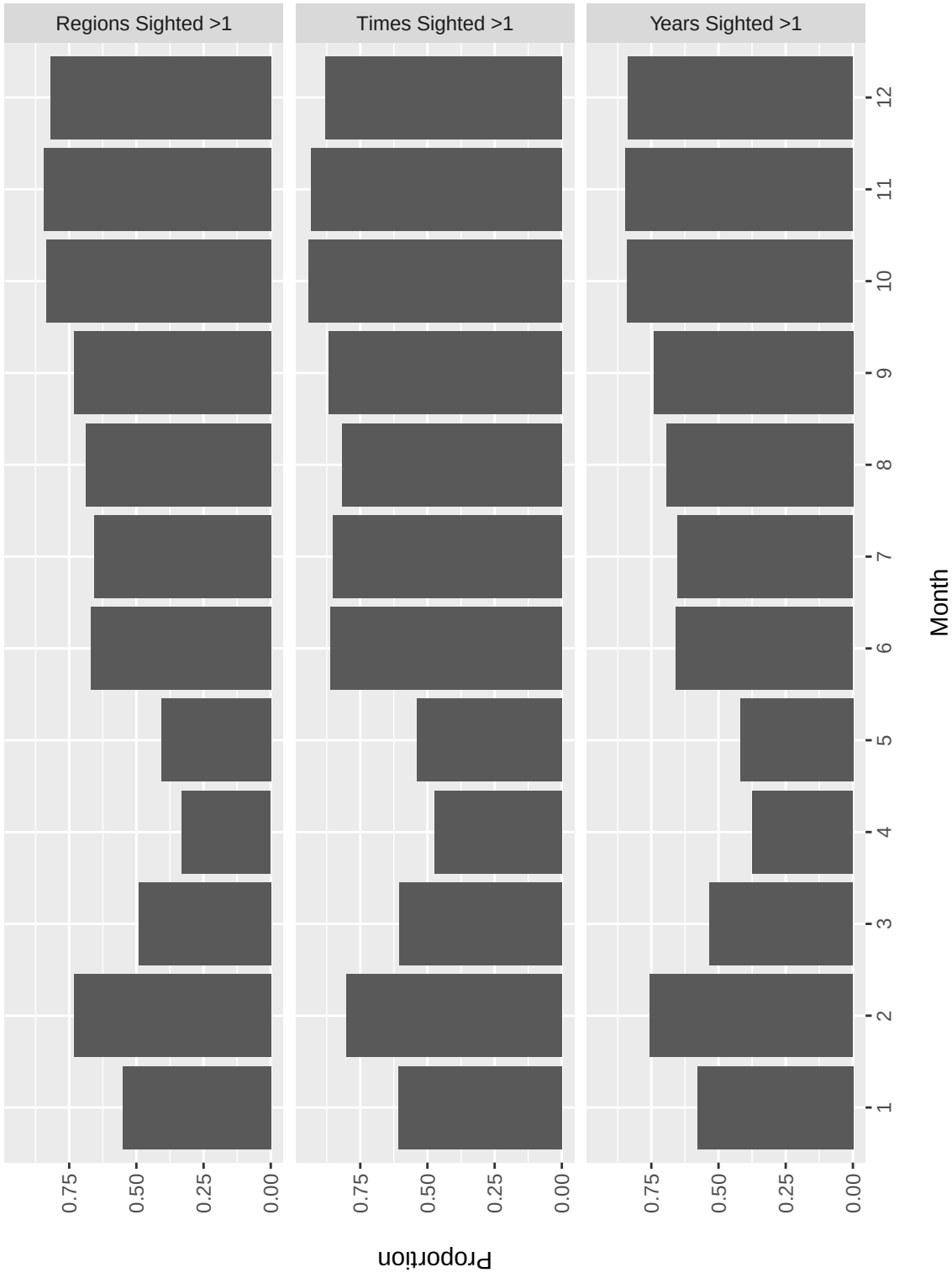

Figure 3: Monthly measures of proportion of whales that were seen in more than one region, seen on more than one day and seen in more than one year. The values include sightings from 1996-2015 in all regions from California to Alaska. Lower values imply whales were simply migrating through the area in a short time frame and were thus less likely to be seen at other times and in other regions. Values are not shown for months with fewer than 20 sightings. Whales seen more often are over-represented because they are used in each month they were seen. For example a whale seen in June, July and August will be in each summary. Thus, these values may be larger than values computed without splitting by month (e.g., overall proportion of whales seen in more than one year).

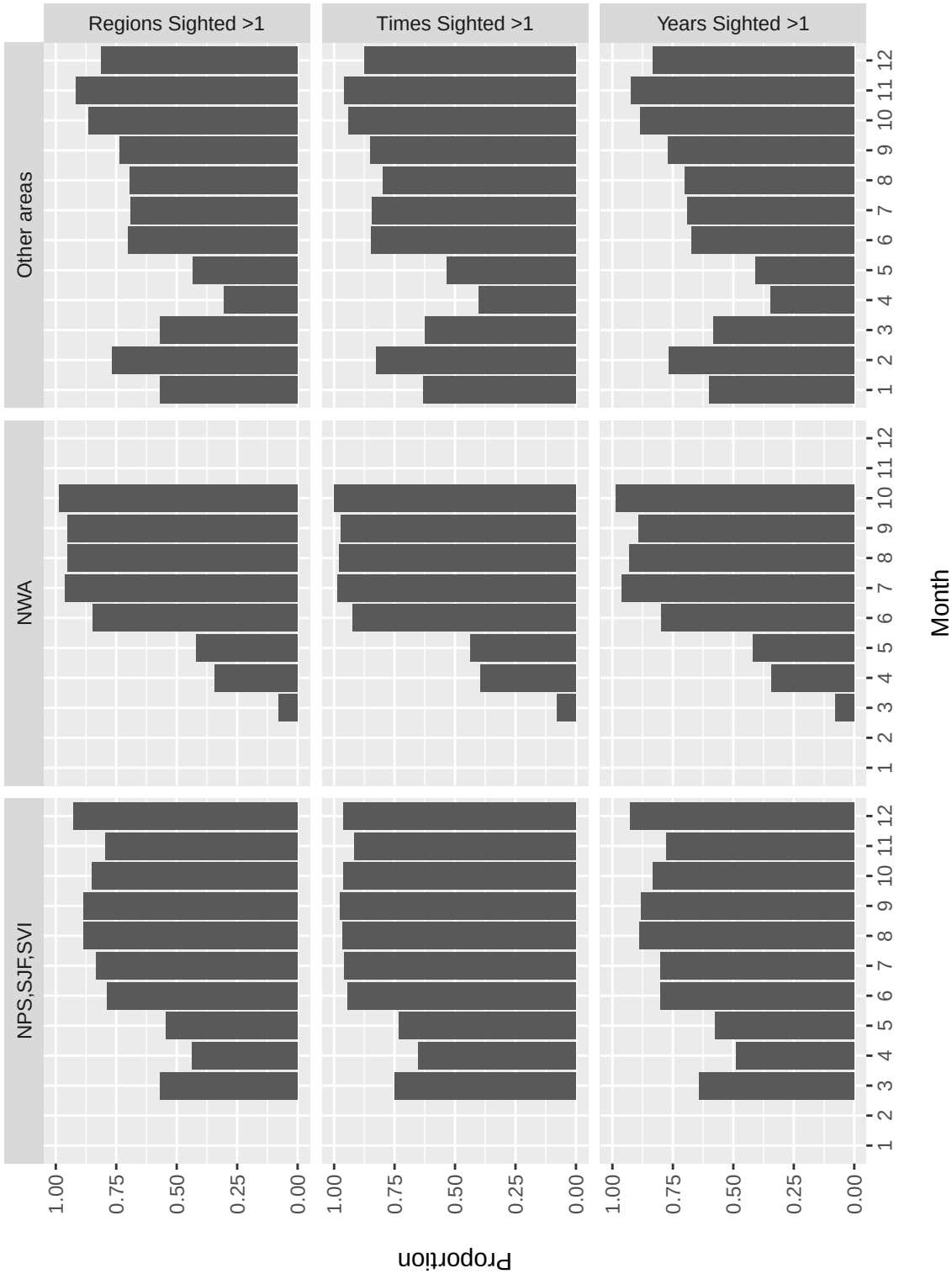

Figure 4: Region and monthly measures of proportion of whales that were seen in more than one region, seen on more than one day and seen in more than one year. The values include sightings from 1996-2015 in all regions from California to Alaska. Lower values imply whales were simply migrating through the area in a short time frame and were thus less likely to be seen at other times and in other regions. Values are not shown for months with fewer than 20 sightings. Whales seen more often are over-represented because they are used in each month they were seen. For example a whale seen in June, July and August will be in each summary. Thus, these values may be larger than values computed without splitting by month (e.g., overall proportion of whales seen in more than one year).

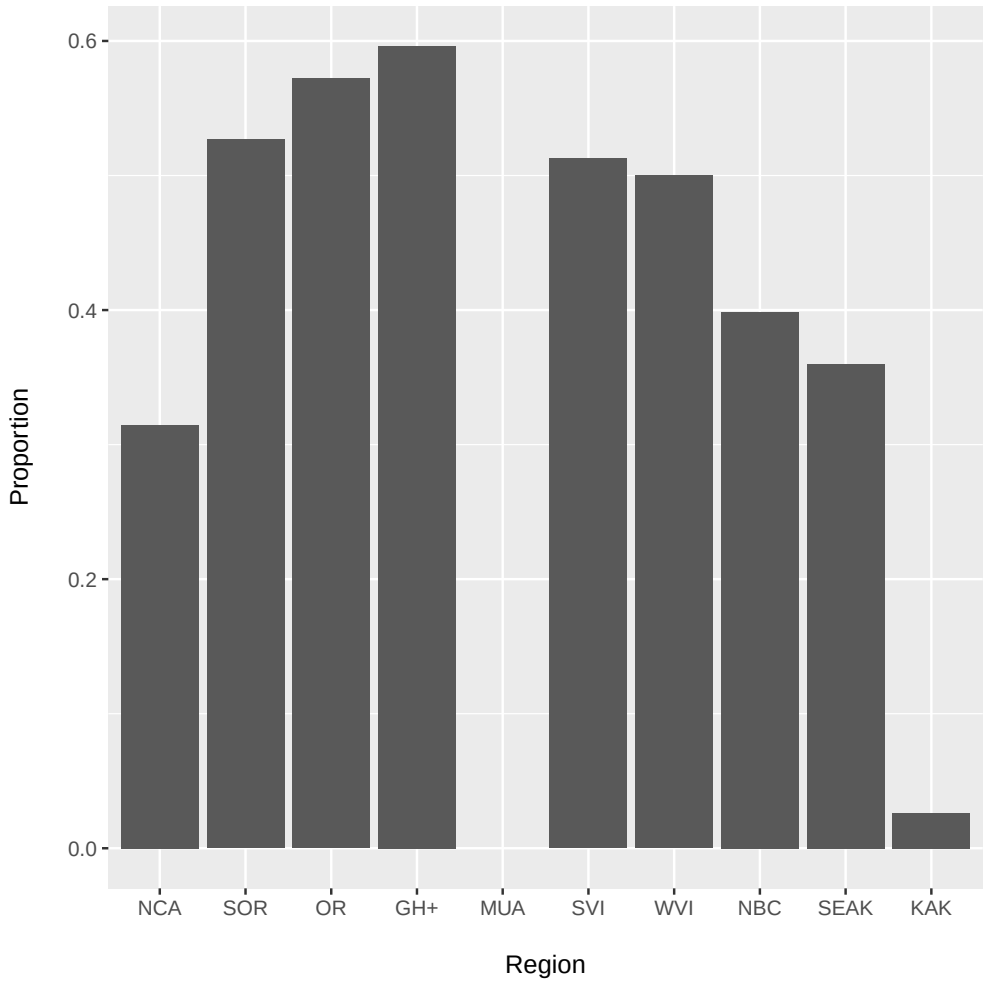

Figure 5: Proportion of whales in sub-regions from NCA to KAK that have been seen in the MUA using sightings after 1 June from 1996-2015.

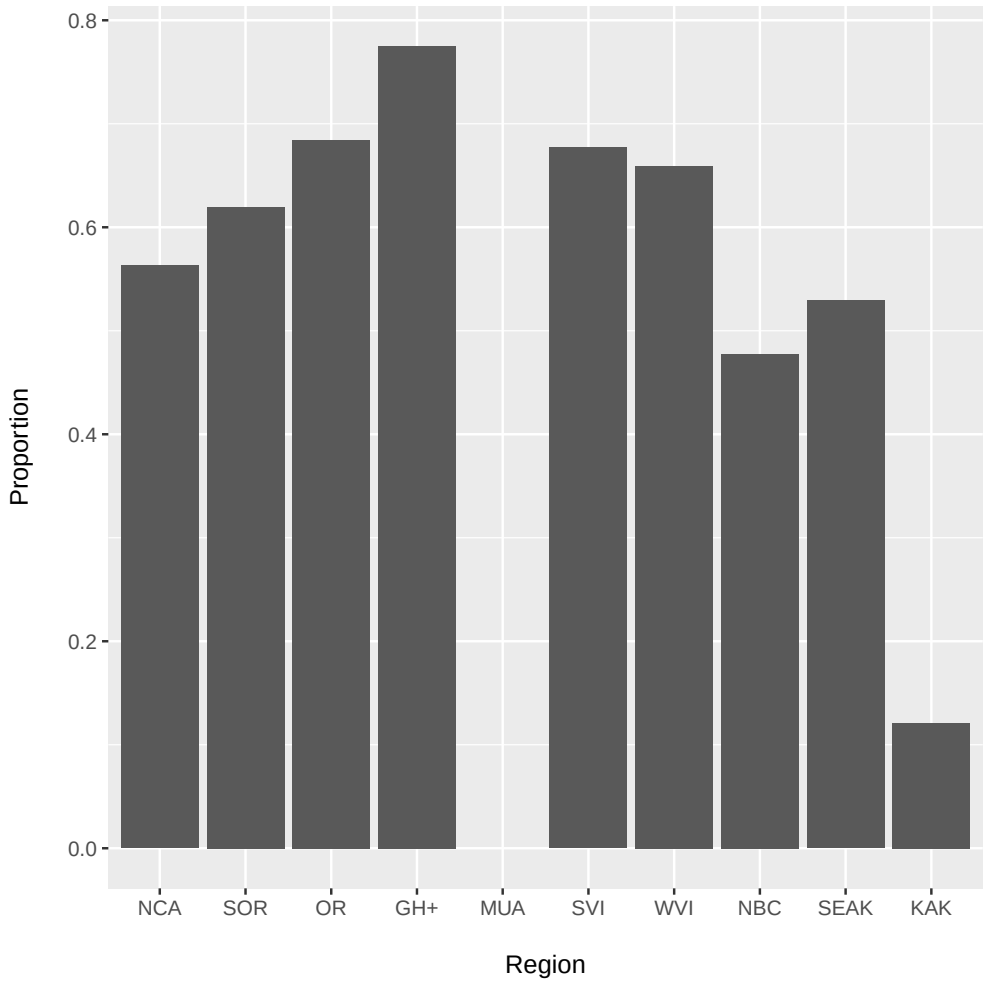

Figure 6: Proportion of whales seen in at least 2 years in sub-regions from NCA to KAK that have been seen in the MUA using sightings after 1 June from 1996-2015.

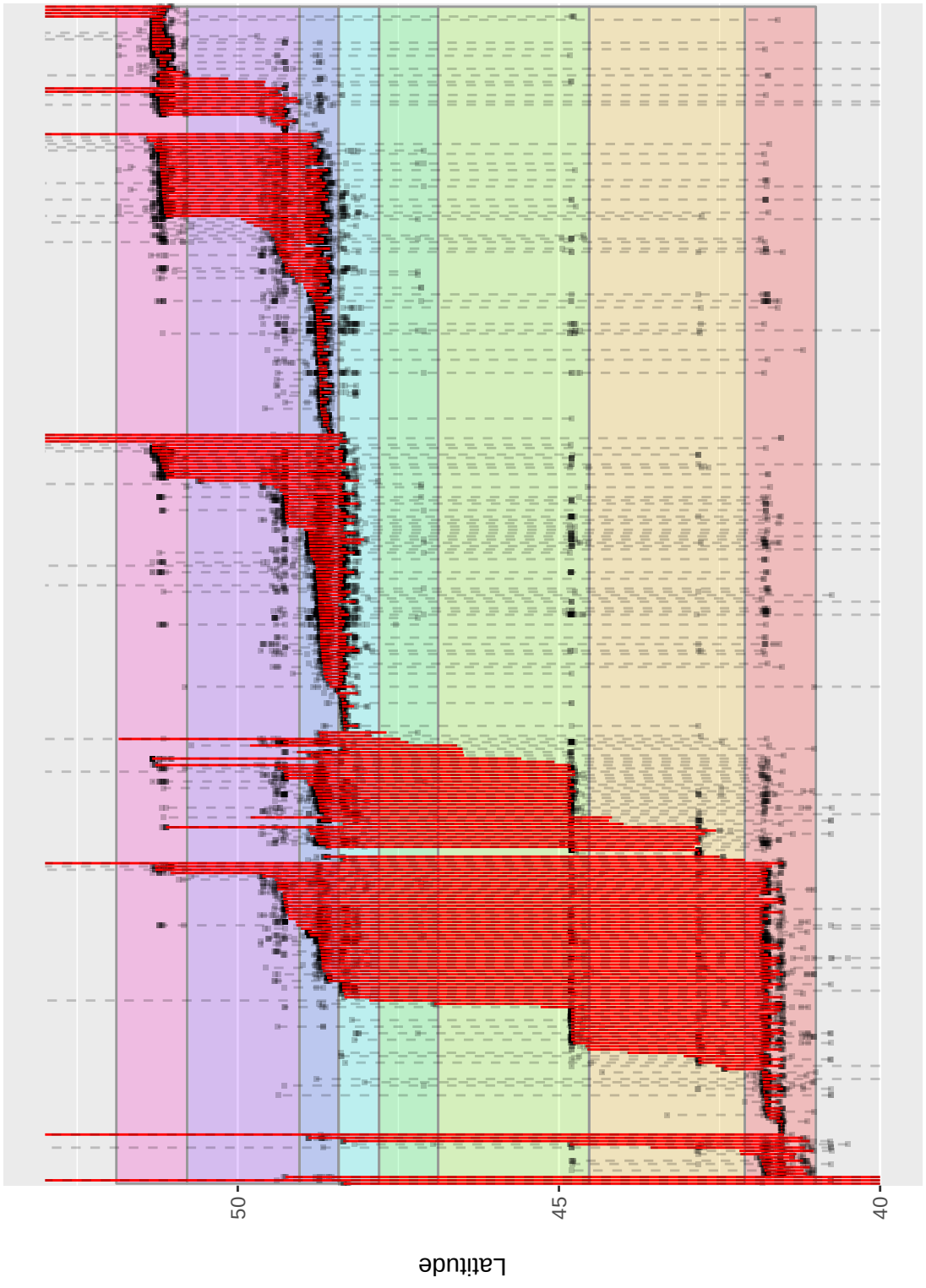

Figure 7: Distribution of latitudes of sightings (points) for whales with 6 or more sightings after 1 June from 1996-2015, the 75% inner quantile (solid thick line), and full range (light dashed line). Each position on the x axis represents an individual whale. Whales have been arranged on the plot by sorting first on the lower bound of the inner quantile (to a half-degree) and then the upper bound of the quantile. This has the effect of sorting from south to north and clusters whales with smaller quantile ranges followed by whales with larger ranges.

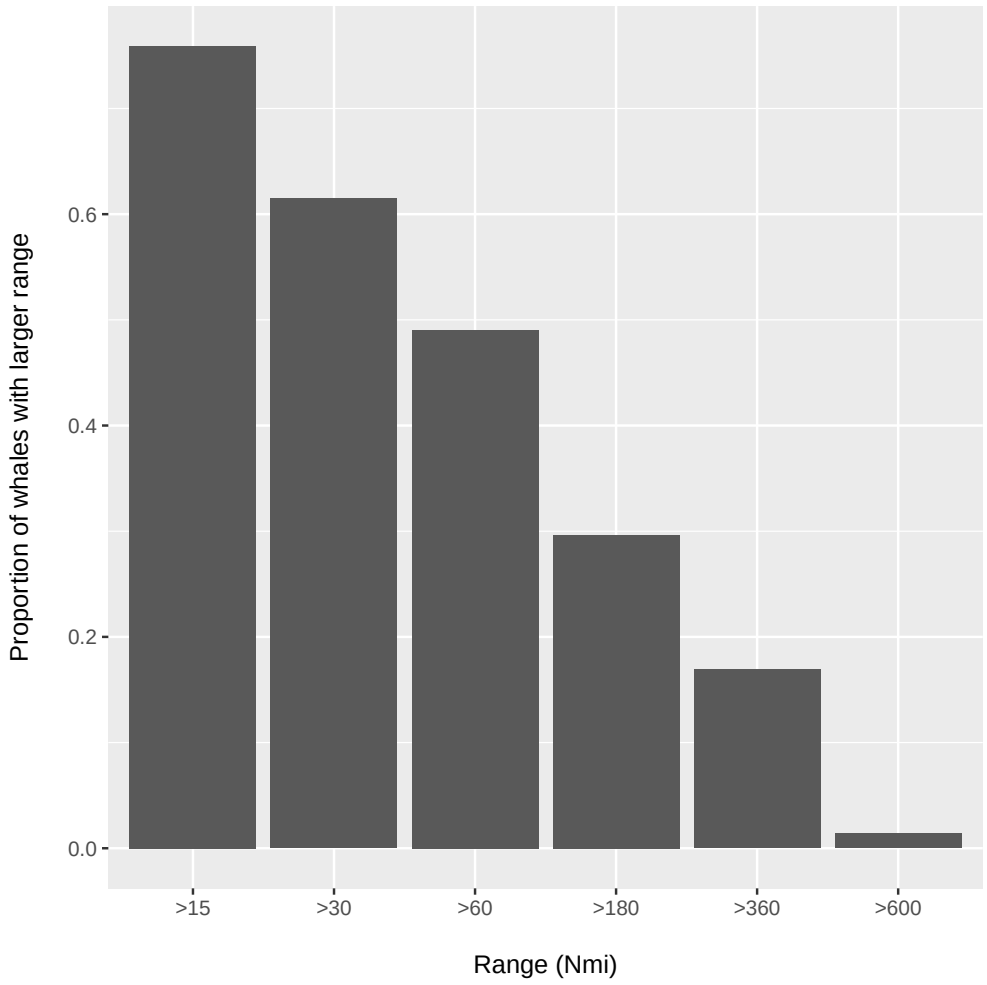

Figure 8: Distribution of ranges of 75% inner quantiles of latitudes expressed in nautical miles for whales sighted on 6 or more days during 1996-2015.

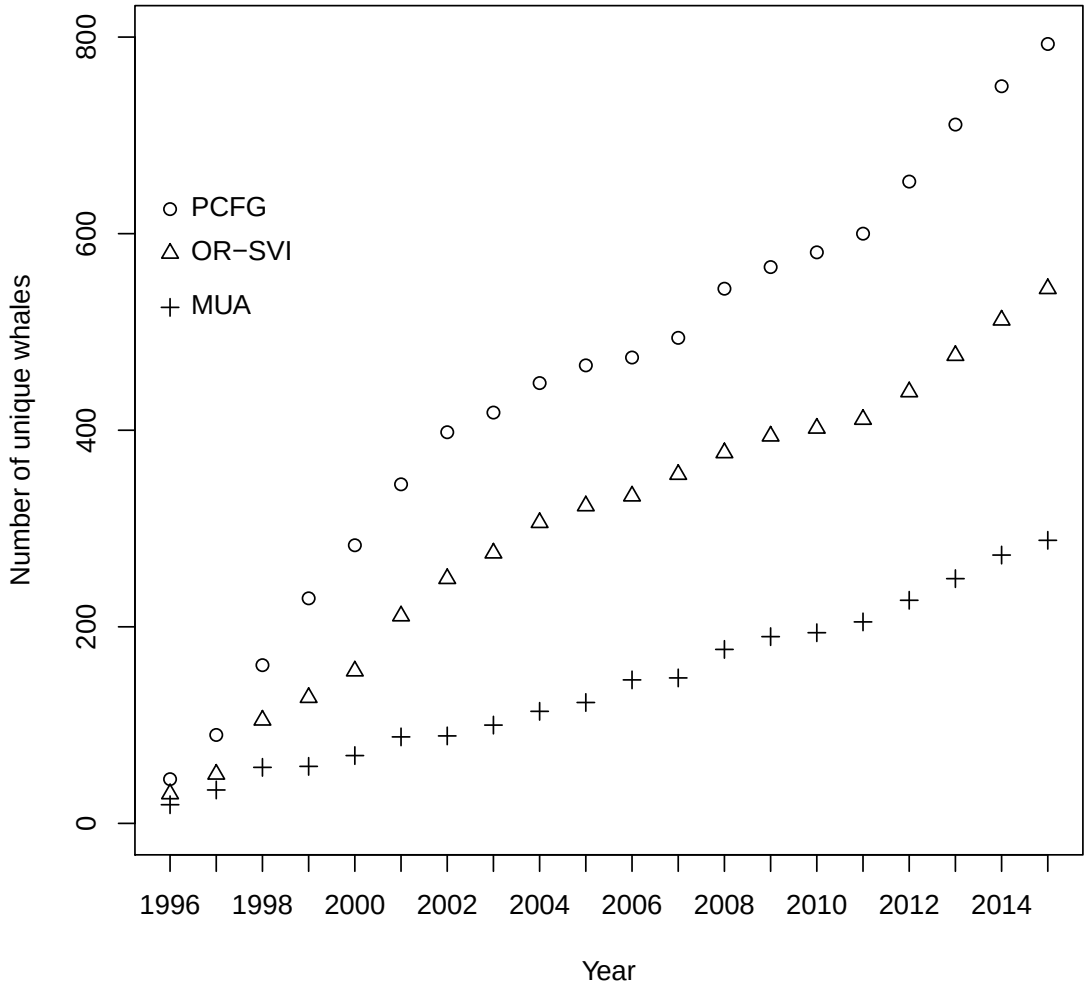

Figure 9: Discovery curves for unique whales seen in PCFG, OR-SVI and MUA for 1996-2015.

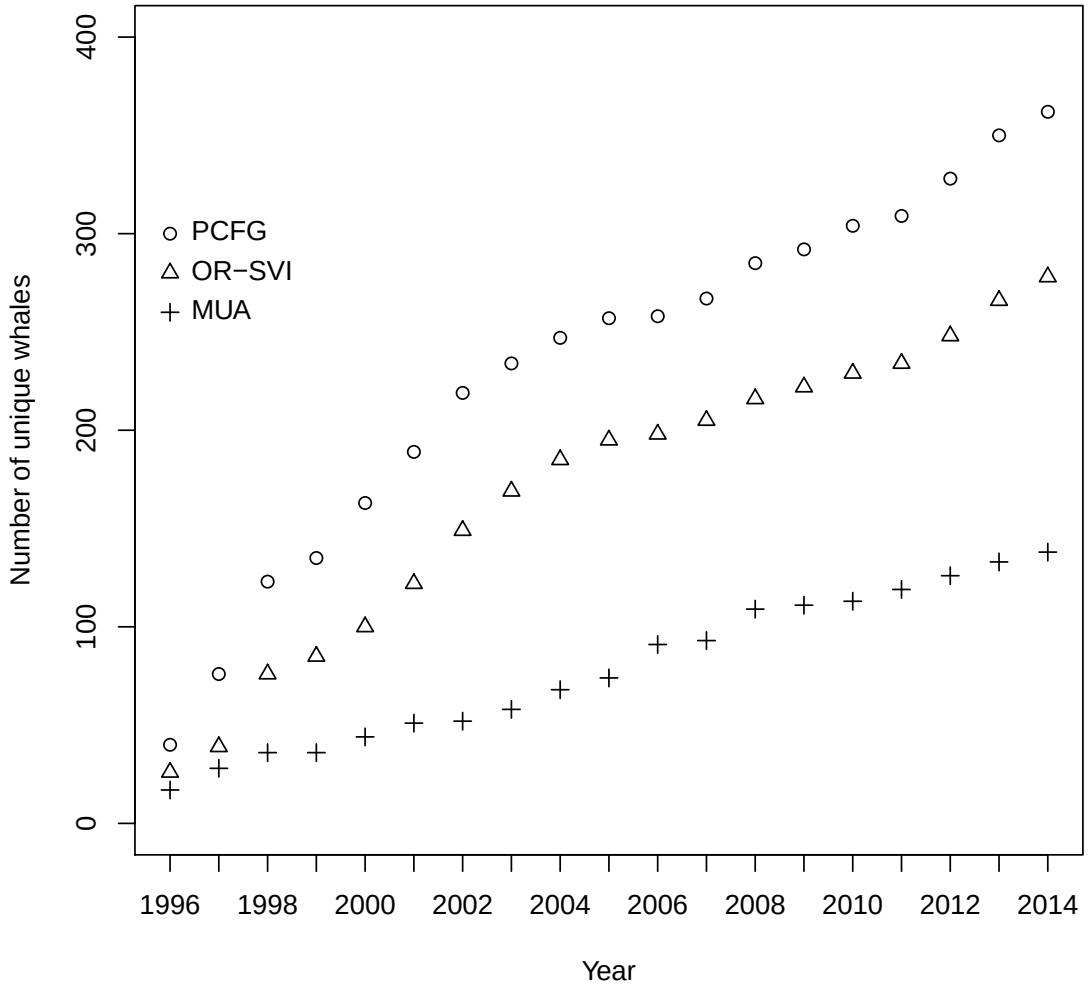

Figure 10: Discovery curves for unique recruited whales seen in PCFG, OR-SVI and MUA for 1996-2015.

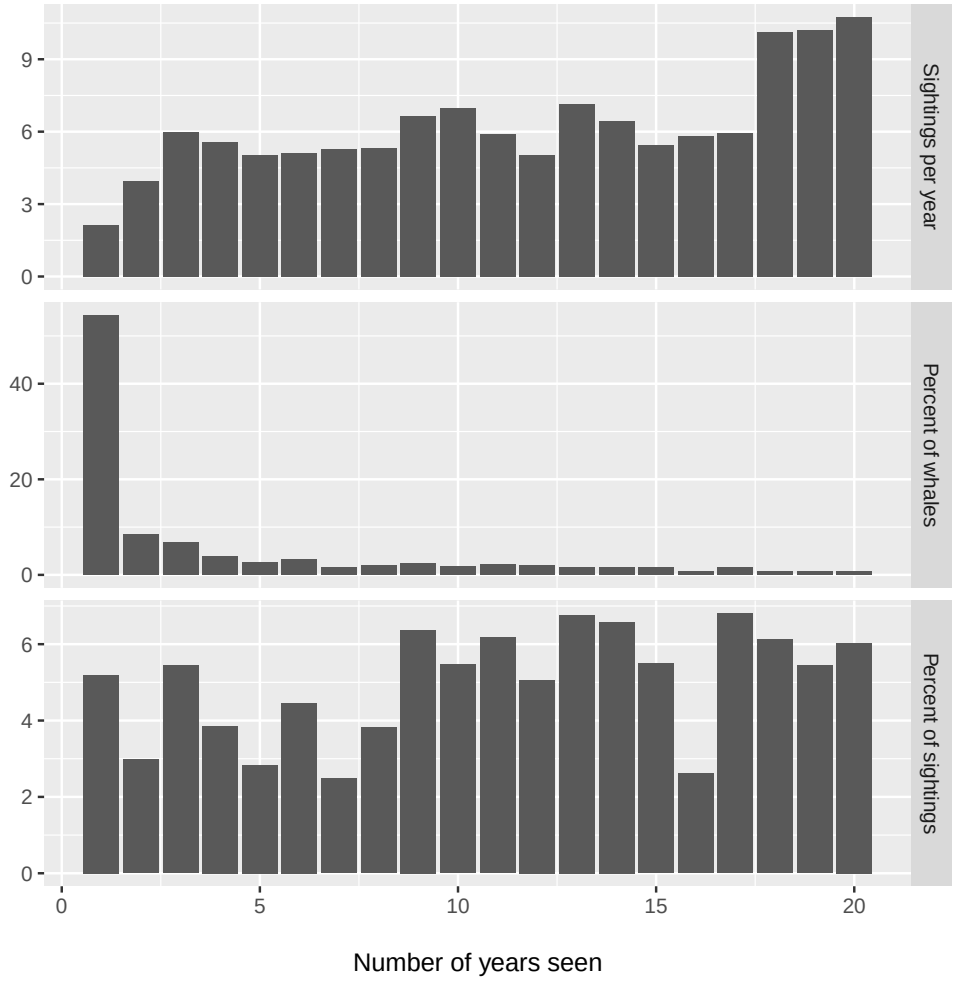

Figure 11: Average number of sightings per year and distribution of whales and numbers of sightings based on numbers of years a whale was seen in NCA-NBC between June-November during 1996-2015.

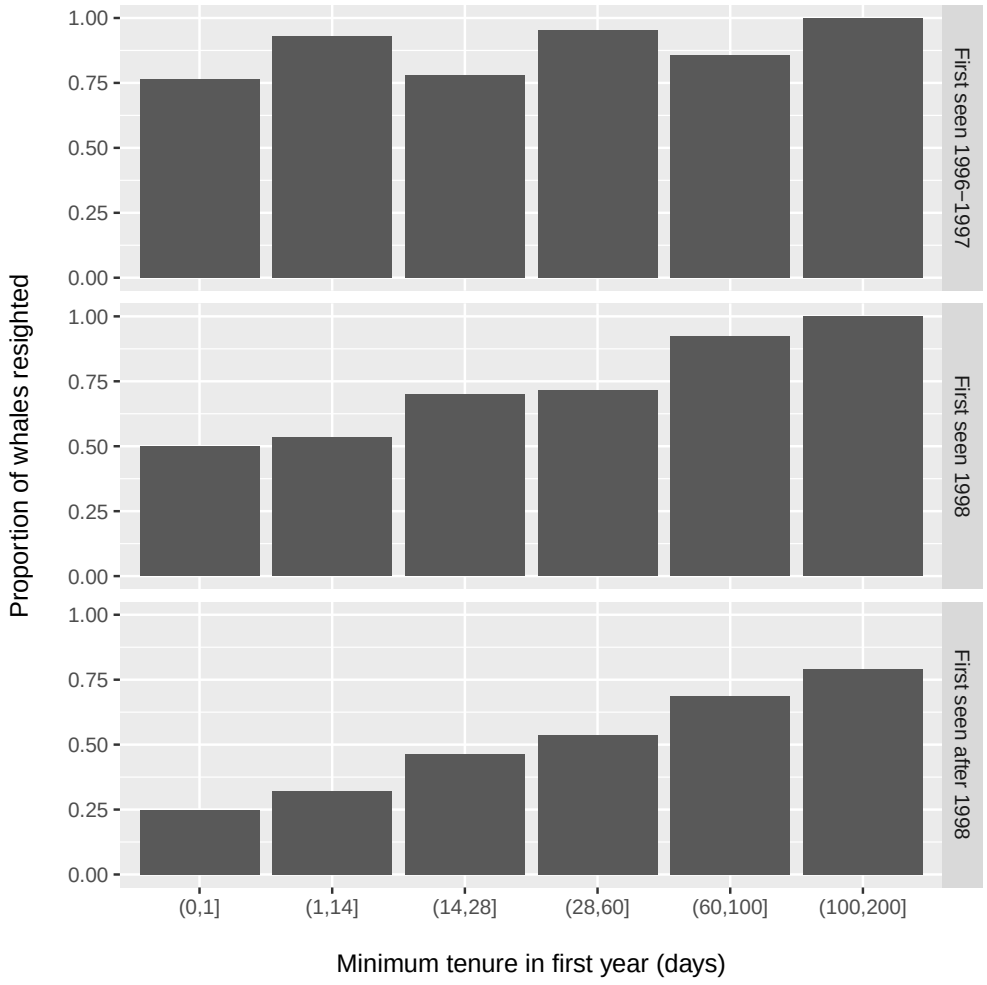

Figure 12: Influence of minimum tenure (MT) in the first year the whale was photographed on the probability it will be re-sighted in one or more following years for whales seen in NCA-NBC for June-November 1996-2015. The bar graphs are divided based on first year in 1996-1997, 1998 and after 1998. Re-sightings for 2015 are used but initial sightings for 2015 are excluded because there are no data beyond to evaluate re-sighting probability.

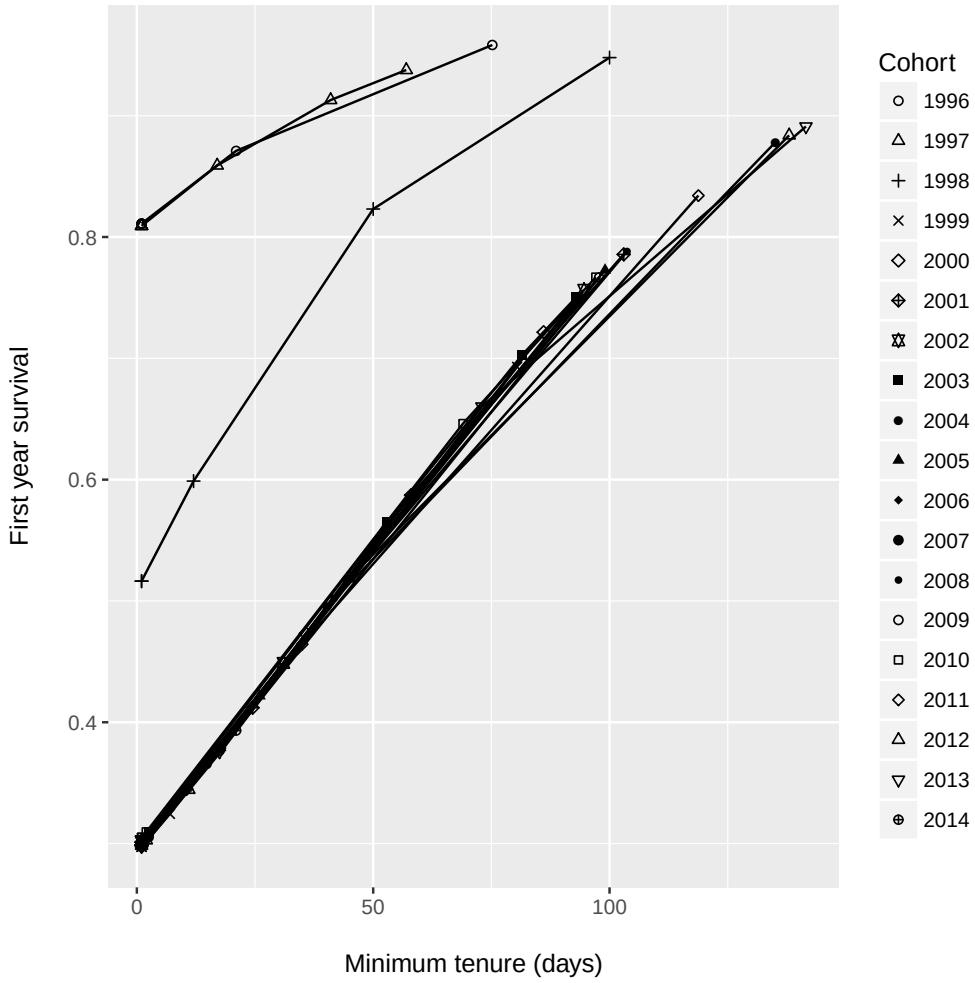

Figure 13: For NCA-NBC analysis of 1996-2015 data, model-averaged estimates of first year survival of non-calves for each cohort at 5%, 25%, 50%, 75%, and 95% quantiles of minimum tenure values for that cohort.

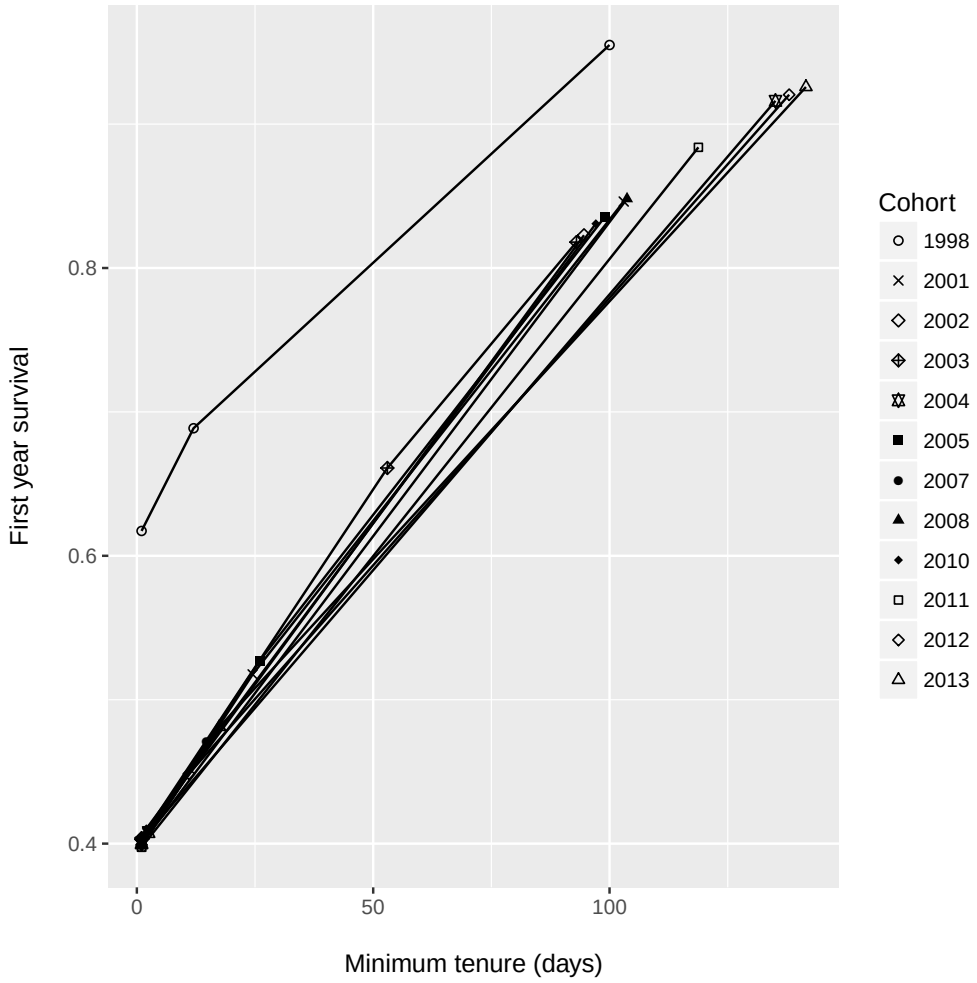

Figure 14: For NCA-NBC analysis of 1996-2015 data, model-averaged estimates of first year survival of calves for each cohort at 5%, 25%, 50%, 75%, and 95% quantiles of minimum tenure values for that cohort.

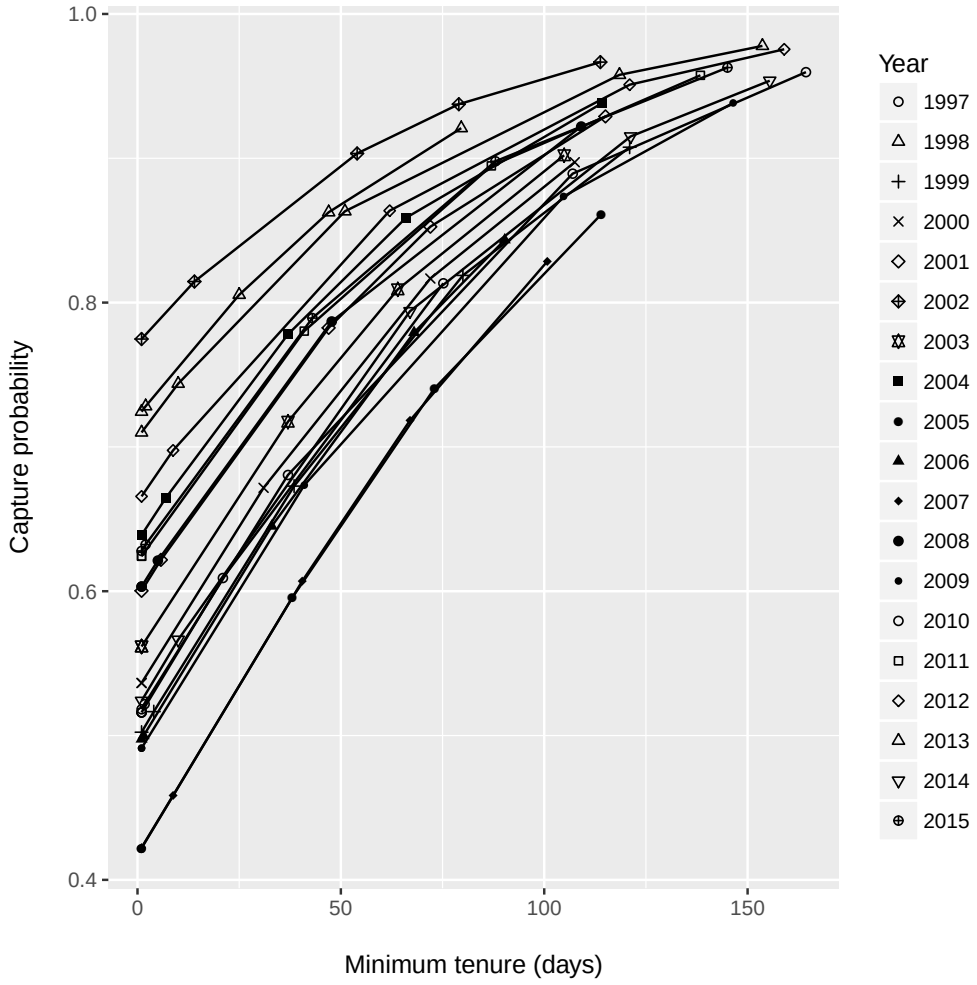

Figure 15: For NCA-NBC analysis of 1996-2015 data, model-averaged estimates of capture probability for each year at 5%, 25%, 50%, 75%, and 95% quantiles of minimum tenure values for whales in the previous year.

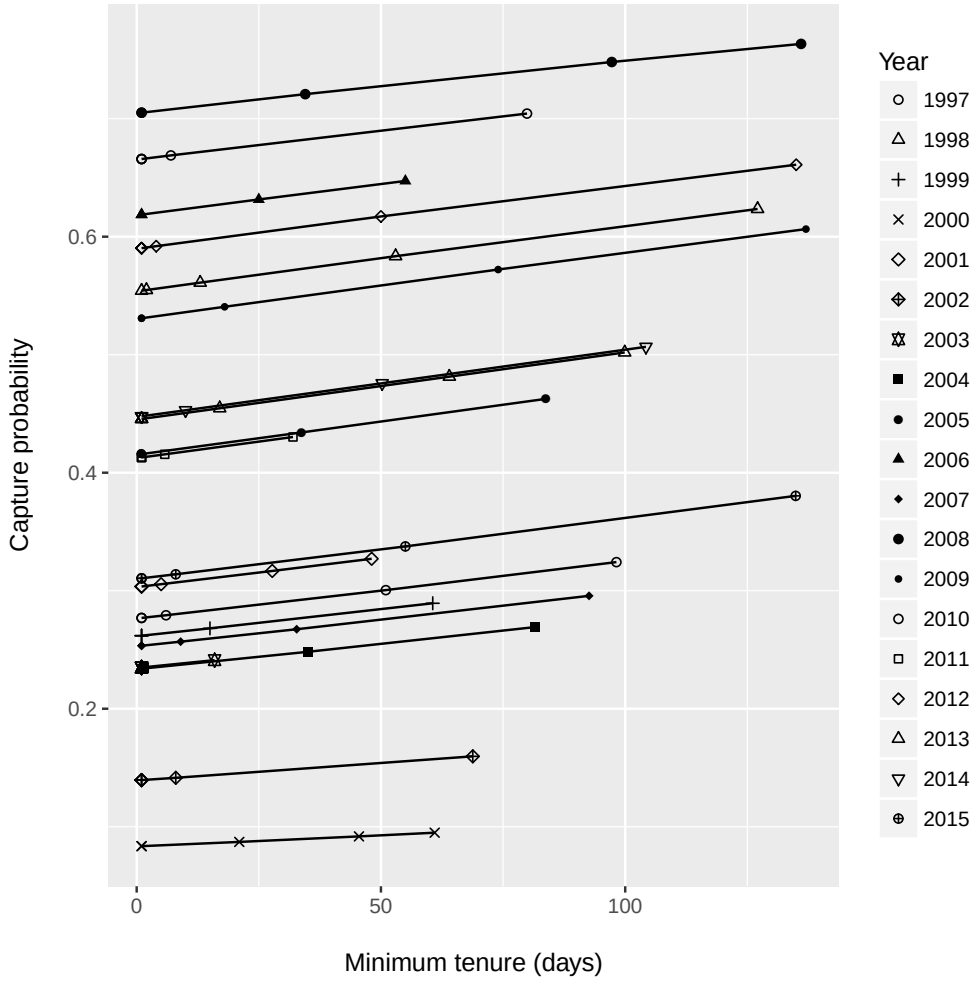

Figure 16: For MUA analysis of 1996-2015 data, model-averaged estimates of capture probability for each year at 5%, 25%, 50%, 75%, and 95% quantiles of minimum tenure values for whales in the previous year.

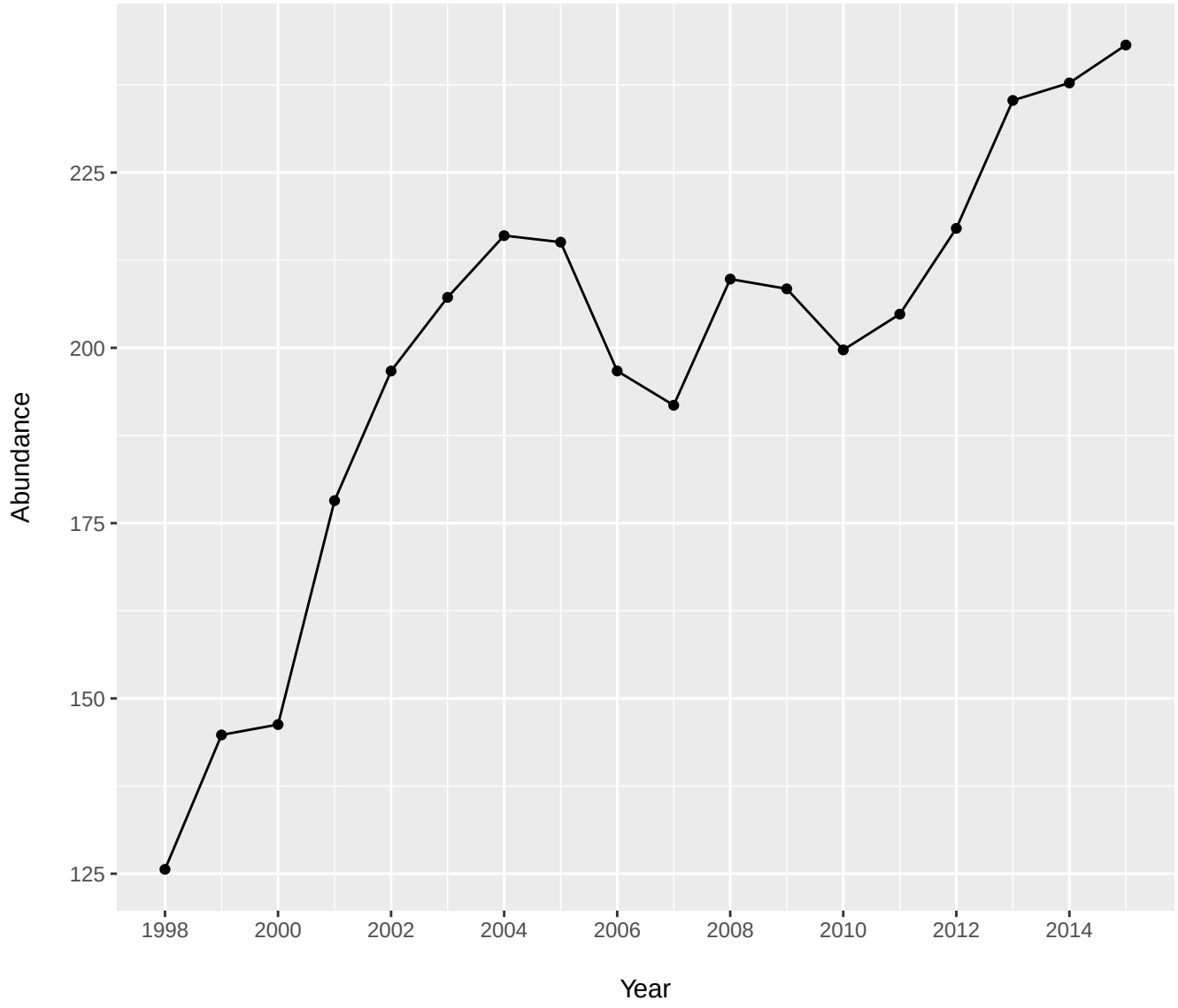

Figure 17: Annual abundance estimates for 1998-2015 in NCA-NBC using the open (Jolly-Seber; POPAN parametrization) population model approach JS1.

Appendix

Table 1 provides capture histories of whales seen in the PCFG at least once from 1 June - 30 November and displays by year, when they were seen only in spring (March-May), only from 1 June - 30 Nov and when they were seen in both time periods. Table 2 provides capture histories using data from 1 June - 30 Nov of whales seen in the MUA at least once. It shows when whales were seen only outside of the MUA but in the PCFG, only in the MUA and both inside the MUA and in the PCFG outside of the MUA

Table 1: Sighting histories of whales seen in the PCFG in at least one year. In year columns, a 1 means the whale was only sighted in the spring (March-May), 2 means it was only seen in June-Nov, and 3 means it was seen in both March-May and June-Nov. The region value is the nunber of years the whale was seen in that region.

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+	NWA	SJF	SVI	WVI	NBC	#areas
							2	2	2	2			2	2	2		2	2	2		2	2	2	2		2	2	2	2	2	20					1		4	15	9	4
							2	2	2	2	3			2								2	2	2							9				1				9		2
																															1					1					1
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				2	2						2	2	2	2	2	2	2		2	2	2										13				2	1	10	5	1	5
					2			2	2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2						18	1			1		6	15	7	4	6
					2		2	2	2	2	2	2	2	2	2	2	2	2	2												15		1	1		5	1	11	3	1	7
								2					2	2																	4			1		2		3	2		4
								2			2	2	2	2	2	2	2	2	2		2		2	2		2	2	2	2	2	19	3			5		5		12	7	4	6
			2				2		2	2	2		2	2	2	2	2	2	2	2	2	2	3	2	3	2	3	3	2		24	1			1	5	3	19	11	2	7
2										2			2	2			2	2	2				1					2			9							2		7	2
	3																														1					1					1
	3																														1					1	1				2
	2																														1					1					1
	2									2				2		3	2		2		1	2	2	2	2	2	2	2	2	15	7	5	4	3	1	1				6
	2											2	2	2	2	2	2	2		2		2		2	3	3	2	2	2	2	17	8	2	5		1	1	4	1		7
		2																													1							1			1
			2					2				2		2	2	2	2	2	2	2	2	2		2		2	3	2	3	2		18					1	2	9	10	3	5
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								2			3		2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	20	5	2	2	1	5		14	6		7

Cont.

Table 1: Sighting histories of whales seen in the PCFG in at least one year. In year columns, a 1 means the whale was only sighted in the spring (March-May), 2 means it was only seen in June-Nov, and 3 means it was seen in both March-May and June-Nov. The region value is the nunber of years the whale was seen in that region.

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+N	WA	SJF	SVI	WVI	NBC	#areas
								2					2	3	3	3	2	2	2	2	2	2	3	2	2	2	2	2	3	2	19	6	5	6		8		16	6		6
								2																							1					1					1
								2			2	2	2		2	2	2	2		2		2		2	2		2			2	2	14		2	1		3	2	7	2	9	7
								2			2	2	3	2	2	2	2	2	2	2	2	2	3	3	2	3	3	2	3	3	21				1	12	7	19	4		5
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									2				2	2	2	2	2	2	2	2	2	2									11			1		1	2	7	3	5	6
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									2			2	2			2			2				2				2				7	2		1				1		5	4
									2	2		2	2		2	2	2	2		2	2	2	2	2	2	2	2	2		2	19		1			2	3	15	4	5	6
									2			2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	1	2	20							12	12	12	3
									2	2	1																			3				1	1	1				3
									2		2	2	2	2	2	2	2	2	2	3	2	3	2	2	2	3	3	2	2	21	1		5	1	1	1	18	10	2	8
									2		2	1	2				2	2	2	2	2			2	2		3	2	2	3	16				1			11	6	5	4
									2			2	2	2	2	2	2	2	2	2											10							4	2	7	3
									2			2			2			2	2		2										6							1		6	2
										2																					1					1					1
										3	1																				2				2						1
										3	1																				2				2						1
										2			2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	3	2	19				1		1	15	11	5	5
										2	2		2	2	2	2	2	2		2	2		2	2	2	2	2	3	2	18	4		1		1		12	8		5
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										2		2		2												1					4							1	1	2	3
										2		2		2	2	2	2														6									6	1
										3																					1				1						1
										2	2	2	2	2	3	3	2	2	2	2	3			2	2	2				2	2	17	1		3	1	5	3	12	1	1	8
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										2																					1					1					1
										2	2	2	2																		4					3	2	1	1		4
										2	2	2	3	2	3	2	2	3	2	2	2	2									13	1		1		5	5	9	7		6
										2		2	2	3																	4					3	2	2	1		4
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										2		2																			2						2				1
										2																					1						1				1
										2																					1						1				1
										2																					1						1				1
										2																					1						1				1
										2	2	2	3	2		3	2		2								1				9					1	2	5	3		4
										2		3	3	2	3	3	3	2	2	3	3	3	2	3	2	3	3	3	2	3	20			4	1	3	5	19	1		6
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										2		2	2				2	2	2		2										7								1	7	2
										2		2	2	2	3		2	2	2	2			2		2	2	1		2	2	15						1	1	2	13	4
										2		2	2	2																	4								4	1
										2		2	2		2	2		2	2	2	2			2			2	2		2	13					1	1		3	12	4
										2		2	2	2	2	2	2	2	2	2	3	1	2	2	1	2	2	2	2	2	20						1	6	5	13	4
										2							2	2	2				2					1			6								1	5	2
										2		2					2	2	2			2					2	2			8									8	1
										2		2			2		2	2	2						1	2					8	1				1				6	3
										2									2												2									2	1
										2																					1							1			1
										2																					1							1			1
											2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	20	5		2	1			18	5	2	6
											1	2	2	3	3	2	2	2		2	3	3	2	2	1	2	3	3	2	3	19							16	12	3	3

Cont.

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1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+	NWA	SJF	SVI	WVI	NBC	#areas
											2	2	2	2	3	3	2	3	2	2	2	2	3	2	3	3	3	2	3	2	20	1		1	1	8	4	16	10	1	8
											2	2	2	2	3	3	2	2	2				2		2						11					3	3	10	2		4
											2		1																		2				2						1
											1			1			2	2	2	2	2										7				1	1	1	5	1	1	6
											2	2	3	3	3	3	3	3	2	2	2	2	2	3	3	3	3	2	2	3	20		1	4	1	7	5	18	4		7
											1				2		2	2		3	2	2	3	3	2	2	2	3	2	2	15	6	1	5	1	7		10	2		7
											1		2																		2	1			1						2
											1	1	2	2	2	2	2	2		2	2	2	2	2	2	3	2	2	2	3	19	8	2	8	2	8		7	2		7
											3	2		2	2	2	2	2					2	2	2				2		11	1			1	7	4	3	3		6
											1		2	2	2	2	2	2				2		2	2	2	2	3	2	2	15	9	6	6	2						4
											1													2							2				1		1				2
											2	2	2																		3					2	1	2			3
											2																				1					1					1
											1		2				2	2	2				2		2						7	2	3	3	1	1	1				6
											1		2		2	2	2	2	2	2	3	2			2	1	3	2	2	2	3	17	1						17	4	6	4
											2	2	2	2	2	2	2	3	2													9				1			2	2	9	4
											2		2	2	2	2	2			2		3			2	2	2	3	3	2	2	15	2	1	2		2		11	9		6
											2	2	2	2	2	2	2	2	2							2	2	2				12							1	1	12	3
											2	2	2	2	2	2	2		2		2											9							1	3	8	3
											2	2	2																			3							1	1	3	3
											2					2	2	2	2				2									7									7	1
											2						2	2	2		3											5							1		5	2
											2																					1									1	1
											2																					1									1	1
											2																	2	2		3	4							1	2	2	3
												2	2	2	2	2	2	2	2		2		2	2	3	2	2	2	2	2	17	3		1		1	2	12	8	1	7
												2	2	2	2	2	2	2	3	2											9					2	3	4	1	7	5
												2																			1						1				1
												2																			1						1				1
												2																			1						1				1
												2	2																		2							1			2
												2	2	2	2	3	2	2	2	2			2		2			2	2	2	14	1	1	1				13	2		5
												2	2			2	2	2	2	2	2					1		2	2		11							1	1	10	3
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												2	2				2		2					3			2				6	2		1	1					4	4
												2			2	2	2	2	2		2	2	2	2	2	2		1	2	2	15	7	4	1	1	3		3	1	2	8
												2					2	2	2												4									4	1
												2							2												2									2	1
												2																			1									1	1
												2																			1									1	1
												2																			1							1			1
												2																			1							1			1
												2																			1							1			1
												2																			1							1			1
													2	2	2	2	2	2	2	2	2										9							1	7	4	3
													2		2	2	2	2	2		3	2	3	3	3						11				1			9	5		3
													2	3	2	2	2			2	2				2					2	9	1	1			3		9	1		5
													2																		1						1				1
													3	3			3	2	2	2	2	2	2	2	2	2	3	2	3		15	2	7	3		3		8			5
													2		2	2		2								3			2	2	7	1					1	5	3		4
													1											2							2							2			1
													2																		1						1				1
													2	2	3	2	2		2	2	3	2	2	3				2		2	13					2	8	10	3	1	5
													2																		1							1			1
													2																		1							1	1		2
													2																		1						1				1
													2																		1						1				1
													2																		1				1						1
													2																		1						1				1
													2																		1						1				1

Cont.

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1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+	NWA	SJF	SVI	WVI	NBC	#areas
													2																			1						1				1
													2																			1						1				1
													2																			1					1					1
													2		2									2		3	3	3				6	5			1	2			1		4
													2			2	2	2		2				2	3	3	2	2	2	2	12	10	1	1							3
													2																			1	1									1
													2				2	2			2	2		2	2	2	2	2	2	2	12	5	1		1	2	1	4	3	1	8
													2																			1	1									1
													2	2	2	2	2	2	2	2	2		2	2	2	2	3	2				15	11	2	4		1	1	3	1		7
													2																			1	1									1
													2			2	2	2	2			2				2	3	2	2	2		11	5	6	4		1					4
													2																			1	1									1
													2			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	16	10	8	2		1		6	1		6
													2	2	2	2	2	2	2			2	2	2		3	2	2	2	2	2	15	4		4		9		7	2	1	6
													2	2		2	2	2		2	2		2	2		2	2	1	2	2	2	14	5	2	9		1					4
													2																			1			1							1
													2	3	3			2				2	2	2	2							8	2		2		1		5	2		5
													2	2	2	2	2	2	2	2												8	2	1	3		2		3	2		6
													2	3	2		2	2	2	2	2	2	3	3	3	2	2	2	2	3		16	1		9	1	7	1	10	4	3	8
													2	2		2	2	2	2		2	2		2	2	2	2	2	2	2	2	15	1	1	6		1		5	5		6
													2																			1					1					1
													2	2	2	2	2	2	2		2		2									9							2	6	4	3
													2											1								2							2			1
													2	2			3	2	2	2	2	2	2	2		3	2	2	2	2	2	15	2		2				5	8	4	5
													2	2																		2	1							1		2
													2	2	2	2	2	2	2		2	2	2	3	3	2	3	2	2	2	2	17	6		4	1	3		3	11		6
													2			2									2							3	1						2	1		3
													2																			1								1		1
													2	2	2	2	2	2	2	2	2	3	2	3		3	3	2	3	2	17		1	6		3	2	11	13		6
													2		2	2	2	2	2		2		2	2	2	2	2	2				13	5	1	4		4		4	4		6
													2	2	3	2	2	2	2	2												8							4	4	5	3
													2		2		2		2	2	2		2	2	2				2			10							4	3	8	3
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													2																			1								1	1	1
													2																			1						1				1
														2																		1								1		1
														2																		1						1				1
														2																		1			1							1
														2																		1	1									1
														2																		1										1
														2																		1										1
														2																		1	1									1
														2																		1	1									1
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														2																		1	1									1
														2																		1	1									1
														2																		1	1									1
														2																		2						1				2
														2																		1							1			1
														2																		1	1									1
														2		2	2	2	2			2										6	1	2	1		1		2	1		6
														2																		1								1		1
														2																		1	1									1

Cont.

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1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+	NWA	SJF	SVI	WVI	NBC	#areas
														2																	1			1							1
														2	2	2	2					2	2	2	3	3					9	8		3							2
														2																	1	1									1
														2																	1			1							1
														2																	1							1			1
														2																	1							1			1
														2																	1	1									1
														2																	1	1		1							2
														2																	1	1									1
														2																	1							1			1
														2																	1			1							1
														2																	1	1									1
														2																	1	1									1
														2																	1	1									1
														2																	1	1									1
														2																	1	1									1
														2																	1							1

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															2			2				2	2	2	3	2	2	2	1	1	11	8	4	1		1					4
															2	2	2		2												4			1						3	2
															2		2														2					1			1		2
															2		2		2					2	3	2	2	2	2		9	6	3	3		1		2	1		6
															2		2		2	2											4	2						2			2
															2																1	1									1
															2		2	2			2			2	2	2	2	3			9	8	3	2				1			4
															2																1	1									1
															2																1	1									1
															2																1	1									1
															2																1	1									1
															2																1	1									1
															2	2	2	2	2	2	2	2	2	3	3	3	2	3			14	6		3	1	5		11	4		6
															2		2		2												3	2	1								2
															3																1	1									1
															2																1	1									1
															2		2					2		2	2	2	2	3	3	2	10	8	1	6	1						4
															2				2						2						3	2					1				2
															2	3	2	2													4							3	3		2
															2	2	2	2	2	2	2			2	2	2	2	2		2	14							3	9	8	3
															2	2		2	2	2	3					1					7							5	1	3	3
															2	2	2	2	2	2							2	2	2	2	10					3	4	3	2	6	5
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															2	2		2	2												4									4	1
															2		2	2	2	2	1	3	2			1		2	2	2	1	13	1						9	2	9	4
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															2																1							1			1
															2																1							1			1
															2																1							1			1
															2																1							1			1
															2																1							1			1
															2										2						4	1		1				3			4
																2	2	2												3					2			3	1		3
																2														1							1			1
																3														1							1			1
																3														1							1			1
																2				1										2					1		1			2
																2														1							1			1
																2														1							1			1
																2														1					1		2			2
																3	2													2							2			1
																3														1							1			1
																3														1							1			1
																2		2	2	1	2	2						3	2	2	9					1	3	4	2	4
																2														1							1			1
																2	2	2		3	2	3	2	3	3	3	3	2	1	3	14	1		1			2	11	9		5
																2	2		2	2	2	2									6							3	2	4	3
																3	3														2							2			1
																2	3														2						1	1	1		3
																3															1							1			1
																2															1							1			1
																3															1							1			1
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																2															1							1			1
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																2	2														2					1			1		3
																2															1							1			1
																2															1					1					2

Cont.

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																2															1					1							1
																2		2								2					3	1				1		1				3
																2	2	2	2		1										5					4	2	2	1			4
																2															1							1	1			2
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																2															1					1						1
																2															1						1					1
																2						2		2	2	2	2	2	2		8	6	1	4				1	1			5
																2	3	3													3							3	1			2
																2															1							1				1
																2	2						2	2	2	2	2	2			8	7						1				2
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																2															1							1				1
																2															1							1				1
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																2		2	2												3	1	2	1								3
																2						2		2							3	2		1								2
																2															1	1										1
																2	2	2													3	2				1		1				3
																2	2														2	1	1									2
																2	2	2		2			2	2	2	2	2	3	2	2	12	8		1	1	1		3	3			6
																2															1	1										1
																2															1									1		1
																2	2	2	2				2				2	2		2	8							3		7	2
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																	2		2							2		2	2		5	3				1			1	2	4
																	2														1	1										1
																	2														1		1									1
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																	2	2													2		2									1
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																	2														1		1									1
																	2														1	1										1
																	2		2				2		1		2		3	2	7	2	2	2		2		1				5
																	2	2	2				2	2	2	2	2	1	3	2	12		11	1	1			1				4
																	2			2											2	1	2									2
																	2														1										1	1
																	2														1							1	1			2
																	3	2	2	2	3	3	2	3	3	3	2	3	2	2	14	1			1	6	7	13	5			6
																	2						2								2							2	1			2
																	2														1							1

Table 1: Sighting histories of whales seen in the PCFG in at least one year. In year columns, a 1 means the whale was only sighted in the spring (March-May), 2 means it was only seen in June-Nov, and 3 means it was seen in both March-May and June-Nov. The region value is the nunber of years the whale was seen in that region.

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+	NWA	SJF	SVI	WVI	NBC	#areas
																	2		2		3	2		1					2			6	2		2	1	3		2			5
																	2															1	1									1
																	2		2			2		2		2		2				6	5	1								2
																	2															1	1									1
																	2															1	1									1
																	2															1	1									1
																	2															1	1									1
																	2															1	1									1
																	2	2														2	1						1			2
																	2															1	1									1
																	2															1	1									1
																	2	2		2	2	2	2	3	2	2	2	2	2			12	3			1	1		4	8		5
																	2															1								1		1
																	2				2	2	2	2	3	2	3	2	2	2		11	4	2	2	1	6	2	3	6		8
																	2			1												2						1		1		2
																	2										2		1			3						2	1			2
																	2	2		2	2	1	2	3	3	3	3	2	1	2		13						1	10	8	2	4
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																	2	2	2	2							3					5					1				5	2
																	2	2	2			2		2	3	2	3	3	3	2		11	6	3	5	1	2					5
																		2	2	2	2	2	2									6		1	2				2	2	1	5
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																		2	2		2											3					1	2	1			3
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																		3		2	3	1	2	3	3	3	3	2				10					6	1	10	4		4
																		2	2	2				2	2	2	3	2	2	2		10	5				4	3	8	2		5
																		2	2													2							2			1
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																			2	2	2	2	2	3	2	2	2	3	2	2		12	1			1	5	7	10	3		6
																			2													1		1								1
																			2													1			1							1
																			2	2												2								1		2
																			2	2	2	3	3	2	3	3	3	2		3	11					5	7	9	5		4
																			2		2		2									3						2		1		2
																			2	2												2						2	1			2

Cont.

Table 1: Sighting histories of whales seen in the PCFG in at least one year. In year columns, a 1 means the whale was only sighted in the spring (March-May), 2 means it was only seen in June-Nov, and 3 means it was seen in both March-May and June-Nov. The region value is the nunber of years the whale was seen in that region.

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+	NWA	SJF	SVI	WVI	NBC	#areas
																			2	2										2							1	1	2
																			2											1					1					1
																			2											1					1					1
																			2								2			2	3							3		1
																			2											1								1		1
																			2											1								1		1
																			2											1								1		1
																			2											1					1					1
																				2			2	2	2	2	3	2	3	3	9	7		1		4	1	4			5
																				2											1							1			1
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																				2			2	2	3	3	2	2	2	2	9	6	3	5		2		1	1		6
																				2											1							1			1
																				2	2	3									3							1	3		2
																				2											1							1			1
																				3											1						1	1			2
																				2											1							1			1
																				2											1						1			1	2
																				2	2	1	2		2	2	1	1			8					4	1	3	4		4
																				2	2		3					3		2	5		1	1		5		2			4
																				2	2	3	3	2	1						6						2	4	1		3
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																						2	2		2			2	2		5	1	3	2							3
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Cont.

Table 1: Sighting histories of whales seen in the PCFG in at least one year. In year columns, a 1 means the whale was only sighted in the spring (March-May), 2 means it was only seen in June-Nov, and 3 means it was seen in both March-May and June-Nov. The region value is the nunber of years the whale was seen in that region.

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+	NWA	SJF	SVI	WVI	NBC	#areas
																							2			2	2				3					2	2	2	1		4
																							2								1								1		1
																							2			2					2				2	1					2
																							2	2	1	3	3	2	2		7	3			2	6	3		1		5
																							2	2							2	1			2	2					2
																							2				2	2	2		4				2	3					2
																							2	3	2	2	3	2	2		7	1				6	5	2			4
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																							2								1					1					1
																							2	2	2						3	2			1	1					3
																							2								1					1					1
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																							2		2	2	2	2	3	2	7	1	5	3							3
																							2		2	2		1			4	3				1					2
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																							2	3	2			2	2	2	6	1		1		2	3	3	2		6
																								2				2	2		3	1						2	1		3
																								3	2	2	2	2	2	3	7						1	5	4			3
																								2	3		3				3	3									1
																								2	2	3	2	3	3		6	6									1
																								2							1							1			1
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																								3							1							1			1
																								2							1							1	1		2
																								2							1	1									1
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Cont.

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																								1			3				2					1		1	1		3
																								2							1					1					1
																								2							1						1				1
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																								2	2	2	3	2	2	2	7			3		3	1	4	2		5
																								2							1	1									1
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																									2	2	2	3	2	2	6	4	1			2	2	2			5
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																									2						1									1	1
																									2		2				2					2					1
																									2		2	2	3		4	3	1	1							3
																									2						1	1									1
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																									3	3	3	2	3	3	6							6	3		2
																									2	2	3	2	3	3	6					1	1	6	3		4
																									2		3	2	3	2	5	2	2	1		1		2	1		6
																									2						1	1									1
																									2	2	2	3	3	2	6		3	1		3	1	2	3		6
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																										3	2	2	3	2	5						1	5	1		3
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Cont.

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																											2				1	1									1
																											2	2	3	3	4	1		2			2	2	3		5
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																												2	3	2	3						2		3		2
																												2			1			1			1				2
																												2			1	1						1	1		4
																												2	2	3	3	1						2	1	1	4
																												2			1	1									1
																												2			1	1									1
																												2		2	2						2		1		2
																												2			1									1	1
																												2			1									1	1
																												2			1									1	1
																												2	3	3	3							1	2	1	3
																												2			1								1		1
																												2			1								1		1
																												2	3	2	3					2	1	3			3

Cont.

Table 1: Sighting histories of whales seen in the PCFG in at least one year. In year columns, a 1 means the whale was only sighted in the spring (March-May), 2 means it was only seen in June-Nov, and 3 means it was seen in both March-May and June-Nov. The region value is the nunber of years the whale was seen in that region.

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+	NWA	SJF	SVI	WVI	NBC	#areas
																												2	3	3	3					1			3	1		3
																												2	2		2						1	2			2
																												2	2	2	3			1				3			2
																												2	3	2	3		2				2	1			3
																												2	3	2	3							3	1		2
																												2	3	3	3						2	3			2
																												2			1							1	1		2
																												2			1	1		1							2
																												2			1								1		1
																												2	3	3	3	1						3			2
																												2			1								1		1
																												3	2	3	3	1						3	1		3
																												2	2		2							2			1
																												2			1								1		1
																												3			1	1							1		2
																												2			1								1		1
																												2	3		2					1		1	1		3
																												2			1								1		1
																												2			1								1		1
																												2		2	2					1		1	1	1	4
																												3			1	1									1
																												3			1	1									1
																												2			1	1									1
																												2			1								1		1
																												2			1			1							1
																												2	2	2	3			1		1	2	1			4
																												2	2		2	1		1							2
																												2			1			1							1
																												1	2	2	3		2	1							2
																												2			1									1	1
																													2	2	2					1	1	1			3
																													2		1					1					1
																													2		1					1					1
																													2	2	2					1	1	1			3
																													2	2	2	1		2			1			1	3
																													3		1	1	1								2
																													2		1	1									1
																													2	3	2	2							1		2
																													2	2	2	1	1								2
																													2	2	2	2	1								2
																													2		1	1									1
																													2		1			1

Table 1: Sighting histories of whales seen in the PCFG in at least one year. In year columns, a 1 means the whale was only sighted in the spring (March-May), 2 means it was only seen in June-Nov, and 3 means it was seen in both March-May and June-Nov. The region value is the nunber of years the whale was seen in that region.

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	#years	NCA	SOR	OR	GH+	NWA	SJF	SVI	WVI	NBC	#areas
																													2		1	1						1	1		3
																													2	2	2						1		1	2
																													2		1							1		1
																													3	2	2					1		1		2
																													2		1						1			1
																													2		1						1			1
																													2		1						1			1
																													2		1				1					2
																														2	1						1			1
																														2	1				1					2
																														2	1						1			1
																														2	1					1				1
																														3	1						1	1		2
																														2	1						1			1
																														2	1						1			1
																														2	1				1					1
																														2	1				1					1
																														2	1				1					1
																														2	1				1					1
																														2	1	1			1					2
																														2	1				1					1
																														2	1						1			1
																														2	1							1

Table 2: Sighting histories of whales seen in the MUA during 1 June - 30 November in at least one year. 1: whale sighted in PCFG but not in the MUA during that year, 2: only seen in MUA that year, and 3: seen in both MUA and another PCFG area.

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	3	3	1	1	1	1		1	1	1									
1		3	1	1	1	1	1	1	1	1	1	1		1	1	1	1		1
1		3	1	1	1	1	1	1	1	1		2		3	1	1	1	1	
3		3	1	1	1	1	1	1	1	2		1	2	1	1	1	3	1	1
1		3	3	1	1	1	1	1	1	1	1	3	3						
1	3	3	1	1	1	1	3	1											
2	2		3			1		3	2	2					2	3	1	3	
2	2																		
1		3	3	1	1	1	1	3	3										
3		3	3	1	1	1	1	1	3										
3	2	3	1	3	3	1	1	1				1							
2		1	1	1	1	1	1	1	1	3	1	3	1	1	1	3	1	1	1
2																			
1	1	3		1	1	1	1		1		1	1			1			1	3
1	3	3	1	1	1	1	3	3	3	3	3	3	3	1	1	3	3	3	1
1	1	3	1	1	1	3	1	3		1		1	1		1	3	1	1	1
1		3	1	1	1	1	1	1	1	3	1	3	1	1	1	3	1	3	1
1		1	1	1	1	1	1		1	1		3	1	1	1	1	1	1	1
3		1	1	1	1			1	1	3									
2	2	3	1	1	3	1	1	1	1	1		3	1	1				1	3
2	3	2																	
2	2	3	1	1	1	1	1	1	3	3	3								
2	2	1	1	1	1		1	1	3	1	3	2	2		3		3	2	1
3	2	1	3	1	1	1	1	1	3	3	1	3	3	1	3	3	1	3	1
3	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1
2	3	3	1	1	1	1	1	1				1		1					
2	3	3	1	1	1	1	1	1	1	3	1	3	3	1	3	1	3	3	1
2	2		2	2	2	1	3					3	3	1				1	
1	2	3																	
2																			
2	2	1	1		1	1		1											
1		1	1	1	1	1			1		1		1	1	3	3	1	1	1
	2	3	3	1	3	1	1	1	1	3	1		1				1		
	1	1	1	1	1	1	1	1	1	3	3	3	3	1	3	3	3	3	1
	3	3		1	3	2	3	1	1	1	1	3	1	3	1	3	1	1	1
	2	1	1	1	3	1	1		1		1		1	1	1	1	1	1	1
	1	1		1	3	1	1	1	1	1	1	3	3	1	1	1	3		1
	1	3	1	1	1	1	1	1		1		1	1	1	1	1	3	1	1
	3	1	3		1	1	1	1	3	1	3	1	1			1	1		1
	2	1	3																
	2																		
	2	1	1	1	1	1	2	3	3										
	2																		
	2																		
	2	1	1	1	1	1	1	3	1	3	1	3	3	1	1	3	3	1	1
	2																		
	1	1	1	1	1	1	1	1	3	3	3	3	3	1	1	3	1	1	1
	1	1	1	1	1	1		1	1	3	1	3				1	1		
	1	1		1	1		1	1	1	1		1				1	3		1
	1	1	1	1	1	1	1	1	1	1		3	1		1	1	1	1	1
	1			1	1	1	1	1		2	1	3	3	1	1			1	1
		1			3	1	3	1	3										
		3	1																
		1	1	1	1	1	1	1	3	1	1	3	3	3	3	3	3	1	1
		1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	3	3	3
		1	1	1	1	1	1	1	1	3	3								
		1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1
		1	1	3	1	1	1		1	1	1	1	3	3	3	3	3	1	3
		1				1	2	1			1		1						
		1	1	1	3	1			1	3				1					3
		2																	
		1	1			1	1	1	1	3	1	1	1	1	1	3	1	2	
		1		1	1		1								1			1	2
		2																	
		3	3	3	3	1		1	1	3	2	3	1				1		3
		2																	
		2																	
		2																	
		2																	
		2																	
		2																	
		2																	
		2																	
		2																	
		1				1	1			1	1		1	1	3	1	3	1	1
		1	1	1	1	1	3	1	1	2		1	1	1	1	1	1		
		1			1	1	1	1	1	2	1	1	1	1	1	1	1	1	1
		1	1	2	2	3	3	1		3	3	2			1	1	3	1	2
		1	1		1	1	2		1	1		1	1		1	1		1	1
		1	1	1	1	1	1	2	3										
		1	1	1		1	1	1	1	3	1	3	1	3	3	3	3	1	
		1	1		1	1	1	1		2	1		1	1	1	1	1	1	1
		2																	
		1	1	1	1	1	1	1		1	1	1	1	1	3	3	1	1	1
		1	1	1	1	1	1	1	1	1	1	3	3		1	3	1	1	1
		1		3	3	1	1	1		3		3	1	1	1	1	1		

Cont.

Table 2: Sighting histories of whales seen in the MUA during 1 June - 30 November in at least one year. 1: whale sighted in PCFG but not in the MUA during that year, 2: only seen in MUA that year, and 3: seen in both MUA and another PCFG area.

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
		1				1	1	1		1		3	2	2		1	1		1
		2																	
			1		1	1		1			1	1	3	1	1	1	1	1	
			2																
			1	1		1			1		1		3	1	1	1	1	1	1
			1		1	1								1	1	1	3	1	1
			1	3		1	1	1	1	3	1		3	3	1	3	3	2	3
			1		1	1	3	1			1								
				1	3	1		1											
				1		1	1		1	3	3	1	3	3	1	3	3	1	3
				3	3	3	3	1		3		3	3	3	3	3		1	3
				1		1						1	1	1	3	1	1		1
				1	3														
				3															
				2	2	3	1	1		1	1	3	1	3	1	3	3	3	3
				3	3	1													
				2															
				1	1	1		1	1	1	1	3	1	3		1	1	1	1
				3	2	1	1	1	2	3		3	1	1	3	3	3	3	
				1			1				1	1	1	1	3	1	1		
				2		1													
				1		1		1					1	3	1	1	1	1	
				1	1	1	1	1	1	3	1	1	1	1	3	3	1		
				1	1	1	1	1	1							3	3	2	2
					3	1		1							1				
					2	1	1	1	3	2	1	3	1	1	1	3	1		1
					3	1	3												
					3														
					1	1	1		1	1	1	3	3	1	1	1	1		1
					3														
					3														
					3	1													
					2														
					2														
					2		1								1				
					3	3	2	2											
					2	3													
					2														
					2														
					1	1	3												
					1	1	1		1				1	1	1	1	3	1	1	1
					1	1	1	1	1			1	1	2	1	1	1	1	1	
						1	3	1	1	1										
						1		1								1		1	3	
						1		1				1	1	1	1	3		1		
						1		1			1					2		1	2	
						1	1	2	1	3	1	3	3	1	3	1	3	3	3	
						1			1	2	1	1	1	1						
						1	1	1	1	3	1	3		1	3	1	3		3	
						3	3	3	3	2		3	3	3	3	3	1			
						1	1	1	1	3	1	3	1	1	3	1	3	1	1	
						1		1		3	3						1			
						1	1		1	1	1	1	3	1	1	1	1	1		
						1				3	1	3	3	1	3	3	3	3	3	1
						1	1		1	1		3	1	1	1	1	1			1
						1	3	3	1	3	1	3	3	3	3	3	3	3	3	1
						1	1	1			1		1	1	1	1	3	1	1	
							1	1	1	1							1	3		
							2	1		2										
							3	3	2											
							1	1	1	3	1	3	1	1	1	3	3	3	3	3
							1	3	2	2	1	3		1	3	1	1	3	3	
							3		2											
							1		1	3		3	3	3	1	3	3			
							1	1	1				1	3	3	3	3	3	3	1
							1	1	1	1	1	3	1							1
							1	1	3											
							2	1	1	2	1	1	1	3	1	3	3	3	3	1
								2												
								3	3	3	1	3	3	1	3	3	1	3	3
								1	1	3										
								3	2	3	2	3	3	1	1	1	3	1		
								3	2	2	3	2	2	3	3	3	3	1	3	
								3	3			3	3	3	3	3	1	3	1	
								1	1	3	2	3	3	3	3	3	3	3	1	
								2	3	3	3	3	1	3	1	3	3		1	
								2		2		1								
								2	3											
								2												
								2												
								2												
									1			1	3	1	3	3	3	1	3
									2											
									1		2	2	2	1	3	1	1	3	1
									2			1	1	1	1	1	1	3	1
									3											
									2	3		2		2	1				

Cont.

Table 2: Sighting histories of whales seen in the MUA during 1 June - 30 November in at least one year. 1: whale sighted in PCFG but not in the MUA during that year, 2: only seen in MUA that year, and 3: seen in both MUA and another PCFG area.

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
									3	2		1					3		3
									1	1	2	1	2						
									3	3	2	3	3	1	3		3	1	1
									1	3									
									1	3	3	3	3	1	1	3	1	1	1
										3	2	3	3		1				
										2									
											1	1				2			
											1		2						
											1	2	3						
											1	1	3						
											1			1	2				1
												2							
												1	1	1	3	1	1	1	
												3			3	3			
												2			2				
												3	3		2	1	3	2	
												3	2						
												2				2	2	2	
												2	3	1	3	3	3	3	
												2							
												2	2	2					
												2							
												2	3	1					
												2							
												3		1	1				
												2							
												2							
												2	3	1	1				1
												3							
												1	2	2	1	3	1		
												2	3	1			3	3	1
													3	1	1	1	1	1	1
													1	1	1		1	1	2
													2						
													2						
													2						
													2						
													1	1	1	3	3	2	1
														2	1		1		
														1	1	1	3	3	1
														2		2			
														1	1	1	1	3	1
														1		3	1	1	1
														1	1	3	3	2	1
															2	2			
															1	1	1	3	1
															3	2	1		
															3	1	3	3	2
															2				
																1			2
																3	2	1	1
																2			
																2			
																1	1	3	2
																1	1	3	3
																2			
																3			
																1	2		
																1	3	3	3
																1	1	3	3
																3	3	3	1
																1	1	3	1
																2			
																3	3	3	3
																2			
																2			
																2			
																2			
																2			
																3	1	1	1
																	1	1	2
																	3		
																	2		
																	3		
																	2		
																	3		
																	2		
																	3		
																	3	3	1
																	3		
																	3		
																	3	2	1
																	3		2
																	1	3	1
																	3	3	1
																	1	3	

Cont.

Table 2: Sighting histories of whales seen in the MUA during 1 June - 30 November in at least one year. 1: whale sighted in PCFG but not in the MUA during that year, 2: only seen in MUA that year, and 3: seen in both MUA and another PCFG area.

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
																	3	3	1
																	1	3	3
																	1	2	
																	3		1
																	1	3	2
																		1	2
																		2	
																		2	
																		3	1
																		3	1
																		3	1
																		3	
																		3	
																		2	1
																		2	
																		2	
																		2	
																		3	
																			3
																			2
																			2
																			2
																			2
																			2
																			3
																			3
																			3
																			2

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Are social aggregation and temporary immigration driving high rates of increase in some Southern Hemisphere humpback whale populations?

Phillip J. Clapham · Alexandre N. Zerbini

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Abstract Humpback whales (*Megaptera novaeangliae*) in the Southern Hemisphere were heavily exploited by commercial whaling. Today, their recovery is variable: Humpbacks remain surprisingly scarce in some formerly populous areas (e.g., New Zealand, Fiji), while in other regions (such as eastern Australia), they appear to be rebounding at or even above the maximum plausible rate of annual increase. Here, we propose that this phenomenon cannot be explained solely in demographic terms. Through simulation, we test the hypothesis that reported high rates of increase represent a combination of true intrinsic growth rates and temporary immigration, driven by a strong tendency to aggregate for mating. We introduce the idea that overexploitation diminished density at major breeding grounds such that these were no longer viable; then, during subsequent population recovery, a critical mass was attained in certain areas which drew in whales that formerly bred elsewhere. The simulations show that, to maintain high increase rates, the contribution to that rate by temporary immigration from a second, "source" population would have to represent a larger and larger proportion of the source stock and would require relatively high (but quite plausible) intrinsic rates of increase for each population. In the modeling scenarios, the demand for immigrants would eventually exceed the supply and exhaust the source population, but the simulations demonstrated that high increase rates can be sustained over periods of more than 20 years. This hypothesis, if correct, would not only explain excessively high rates of increase in current "hotspots" such as eastern Australia, but also imply that formerly important areas (e.g., Fiji) host few whales today not necessarily because of a failure to recover, but because the species' mating system leads the whales concerned to migrate to higher-density breeding grounds elsewhere. Overall, we caution that assessments of depleted animal populations that do not consider the social behavior of a species are missing a potentially vital component of the picture.

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P. J. Clapham (✉) · A. N. Zerbini
Alaska Fisheries Science Center, NOAA Fisheries,
7600 Sand Point Way NE, Seattle, WA 98115, USA
e-mail: phillip.clapham@noaa.gov

P. J. Clapham
South Pacific Whale Research Consortium, Box 3069,
Avarua, Rarotonga, Cook Islands

A. N. Zerbini
Cascadia Research Collective, 218 ½ 4th Ave W, Olympia,
WA 98501, USA

Introduction

Humpback whales, *Megaptera novaeangliae*, were extensively exploited by modern commercial whaling in the twentieth century. In the Southern Hemisphere, humpbacks feed in Antarctic waters during the austral summer and migrate north to tropical mating and calving grounds in winter. For the purpose of management, the International Whaling Commission (IWC) recognizes six management zones (labeled Areas I–VI) in the Antarctic and seven "breeding stocks" (labeled A–G) which are variously connected to the feeding grounds in the six management Areas.

More than 200,000 Southern Hemisphere humpbacks were killed from 1904 to 1973 (Clapham and Baker 2008; Rocha et al. 2014). This total includes more than 48,000 whales taken in illegal whaling operations by the USSR after World War II; more than 25,000 of these were killed

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in just two seasons (1959/1960 and 1960/1961), primarily in the Antarctic management regions Areas IV, V and VI which lie to the south of Australia, New Zealand and eastern Oceania (Clapham et al. 2009; Ivashchenko et al. 2011). The total number of twentieth-century humpback catches by all whaling operations in breeding area E (linked largely to Antarctic Area V) was 50,484 whales. Breeding stock D off western Australia (which has been linked to feeding grounds in Area IV) was also hit heavily by these catches. Catches in Areas I, II and III were smaller but still substantial, and in at least Area II (the western South Atlantic), the exploitation in the early part of the century was so intense that whales appear to have been effectively extirpated from at least one key historical habitat, South Georgia (Clapham et al. 2008).

It is not known how many humpback whales remained extant following these huge catches, but there is no doubt that the great majority of the Southern Hemisphere population was removed and many stocks were reduced to a low percentage of their pre-exploitation abundance (IWC 2006, 2010). Following this, humpback whales have shown apparently variable recovery rates in different regions. For example, off both western and eastern Australia (feeding ground Areas IV and V, and breeding areas D and E, respectively), the populations concerned are exhibiting strong recovery, with reported rates of increase in excess of 11 %/year (Bryden et al. 1996; Paterson et al. 2004; Noad et al. 2011a). A paradox (much discussed within IWC) is that these rates are close to, or exceed, the maximum plausible for the species given the biological factors that inevitably constrain reproduction. Maximum plausible rates were reviewed by Zerbini et al. (2010), who concluded that typical estimates of population growth rate are 7–8 %/year and an annual growth rate of 11.8 % is the maximum that can be realistically expected for a population of humpback whales. Furthermore, this maximum rate requires values for age at first parturition, birth rate and survival which are at the extremes of those observed in any humpback whale population.

In contrast, humpbacks in some other areas where they are known to have once been abundant have shown little or no recovery in recent years. One example is Fiji, a formerly important breeding area in which shore surveys directed by the late William Dawbin recorded hundreds of whales between 1956 and 1958, but where very few animals are observed today (Paton and Clapham 2002; Gibbs et al. 2006). Another is New Zealand, a migratory corridor where the population supported shore-based whaling at several locations until the huge Soviet catches of 1959–1961 caused a population crash and forced the fishery to close; although whales appear to be returning to Cook Strait today, numbers observed remain very small (Childerhouse and Gibbs 2005).

The assumption regarding these areas has been that the populations concerned were relatively discrete and were so heavily exploited in their Antarctic feeding grounds that they have failed to recover in recent times (Clapham et al. 2008; Constantine et al. 2012). Although this might be true, there may be an alternative explanation for the continued low densities of whales in these formerly populous areas, as well as the unusually high rates of increase observed in some other populations. Here, we explore what we term the Social Aggregation Hypothesis (SAH). This hypothesis proposes that overexploitation by whaling disrupted, reduced or even eliminated existing breeding aggregations of humpback whales and that, during recovery, new aggregations eventually formed, which drew in whales which formerly bred in other areas. In this scenario, the new aggregations might be expected to show high apparent rates of increase, while those populations from which temporary immigrants were drawn would appear to be depressed.

Here, using the IWC's breeding stock E (eastern Australia to Tonga) as an example, we first present the biological and historical background to the SAH, including the social ecology of the species, catch history and current abundance, and evidence for the plasticity of humpback whale distribution following major episodes of whaling. We then use simulation modeling to examine the population dynamics that would have to exist in order for an observed population to show a consistently high rate of increase if a significant portion of that rate was actually due to immigration from a second stock that formerly bred elsewhere.

Background to the Social Aggregation Hypothesis

Social ecology of the humpback whale

The social ecology of humpback whales is reviewed by Clapham (1996, 2000). Both male and female humpbacks undertake seasonal migrations from high-latitude feeding areas to mating and calving grounds in tropical or subtropical waters. The primary features of the mating system include male intra-sexual competition and singing; the system has been compared to a non-traditional lek in which males display (sing) and females presumably practice mate choice based upon characteristics that we do not fully understand.

Central to the argument evaluated here is the undisputed fact that this mating system involves areas of aggregation: Although humpbacks are found in widely varying (and sometimes low) densities throughout any winter breeding range, they frequently return in large numbers to specific locations. Some prominent examples include the Hawai'ian Islands (Cerchio et al. 1998), Silver and Navidad Banks in the West Indies (Whitehead and Moore 1982; Mattila et al. 1989) and Abrolhos Bank off Brazil (Martins et al. 2001).

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Similar aggregations occur off the coasts of both western and eastern Australia (Bannister et al. 1991; Paterson et al. 1994); although traditionally labeled as migratory pathways, the widespread occurrence of newborn calves, singing and competitive behavior in these areas leaves little doubt that they also represent major mating and calving grounds in their own right (Franklin et al. 2011).

Another key characteristic of the humpback's mating system is that it does not involve dependence upon spatially fixed resources. Although the argument has been made that females require shallow, protected waters for calving or avoidance of male harassment (Whitehead 1981; Herman et al. 2011; Craig et al. 2014), there are usually many such sites within a breeding range. Furthermore, because all humpbacks fast during the winter, they are not tied to habitats with high biological productivity. Consequently, there is potentially considerable plasticity in their distribution.

Breeding stock E: catch history and current abundance

The range of breeding stock E as currently defined by the IWC extends from eastern Australia to the Tongan archipelago. Within this region are found current or formerly important humpback whale breeding habitats, including the eastern Australian coast, the Great Barrier Reef, Norfolk Island, New Caledonia, Fiji and the Tonga Island group, as well as the once-major migratory corridor around New Zealand; some movement among these areas has been documented with both photo-identification and genotyping of individual whales (Constantine et al. 2007; Steel et al. 2008). Discovery marking and photo-identification have established that whales from at least portions of this region feed primarily in Antarctic Area V, although there are also known connections to Areas IV and VI (IWC 2006).

During the early years of large-scale commercial whaling following World War II, humpback whales were known to be abundant in many of the breeding grounds listed above. The migratory corridors off eastern Australia, New Zealand and Norfolk Island became the sites of several coastal whaling stations which collectively caught hundreds of humpbacks each year, culminating in a peak catch of 1,341 animals in 1960 (Chittleborough 1965; Clapham et al. 2009). Following the large Soviet Antarctic catches of more than 25,000 humpbacks in 1959/1960 and 1960/1961, none of these stations met their quotas and all were forced to close by 1963 (Clapham et al. 2009).

There was no recorded twentieth-century whaling in New Caledonia or Fiji, and little is known about the abundance of humpbacks in the former area prior to the extensive catches made in the Antarctic feeding grounds. In Fiji, land-based surveys and Discovery tagging were conducted by the late William Dawbin during the austral winters of 1956, 1957 and 1958 (Paton and Clapham 2002). The surveys recorded hundreds of whales passing through the region, with a peak weekly count of 238 animals in late August 1957.

Recovery in all of these areas within breeding stock E has been remarkably variable in the years since whaling ceased. The population off eastern Australia appears to be recovering strongly; the stock size in 2010 was estimated at 14,522 whales (95 % CI 12,777–16,504, Noad et al. 2011b), with a rate of increase estimated at 10.9 % (±0.4 %). This is consistent with a rate of 10.5 % (95 % CI 10.0–11.5 %) reported by Paterson et al. (2004); an even higher rate of 12.3 % (95 % CI 10.1–14.4 %) was given by Bryden et al. (1996). The population using Tonga also appears to be recovering: A photo-identification mark-recapture estimate of 2,311 whales (CV = 0.22) was calculated by Baker et al. (2006), although the lack of long-term data precluded an estimation of trend.

In contrast, the observed density of whales elsewhere within breeding stock E ranges from moderate to very low. In New Caledonia, Garrigue et al. (2004) used photo-identification and genotype data collected from 1995 to 2001 to calculate mark-recapture estimates of 327 (CV = 0.11) and 533 (CV = 0.15), respectively, and a more recent estimate of 472 (CV = 0.18) for 2003 was given by Baker et al. (2006); there are no data with which to even qualitatively assess pre-whaling abundance for this population. In Fiji, observations made in 2001 at the same land sites used by Dawbin in the 1950s recorded very few whales (Gibbs et al. 2006). Similarly, surveys at Norfolk Island conducted over 3 years in 2003–2005 found only 14 whales in 300 h of survey effort (Paton et al. 2006); in contrast, catches at Norfolk from 1956 to 1962 totaled 884 whales. A recent mark-recapture study estimated the abundance of humpback whales throughout Oceania at 4,329 (95 % CI 3,345–5,313) and noted no statistically significant increasing trend in this region (Constantine et al. 2012).

The crash in sightings and catches in the various insular and coastal areas above confirmed their migratory links with Areas V and VI where the huge Soviet catches took place.

How plastic is the distribution of humpback whales?

There have been suggestions that humpback whales can radically change their winter distribution following periods of intensive whaling. Despite the high densities of humpback whales found in the Hawai'ian Islands today, Herman (1979) claimed there was no evidence for their occurrence there in historical times, before the major periods of commercial whaling in the North Pacific. He cited the absence of a name for the humpback whale in the Hawai'ian language, as well as the lack of reports of whales from local media. He also noted the absence of any mention of this

species in the logbooks and journals of Arctic whalers overwintering in Lahaina and other Hawai'ian ports during the nineteenth century. However, Herman's (1979) sample of read logs was very small. Furthermore, Lebo (2010) examined local newspapers, diaries and other historical material, as well as a larger sample of whaling logbooks and journals than that used by Herman, and found reports of the presence of humpback and sperm (*Physeter macrocephalus*) whales in Hawai'ian waters in the nineteenth century. Further work on this topic is ongoing (F. Sharpe, pers. comm.), but it appears that humpback whales were likely not uncommon in this region, especially during the winter months.

A similar case to Herman's was made by Reeves et al. (2001) for the northern West Indies. Today, the Silver and Navidad Banks region of the Dominican Republic hosts densities of humpback whales that are one to three orders of magnitude greater than anywhere else in the West Indies; in contrast, it is clear from whaling logbooks that a major center of aggregation during the nineteenth century lay in the southeastern Caribbean, where whales are found in very low densities today (Swartz et al. 2003). Reeves et al. (2001) suggested that social aggregation and chance were responsible for the distributional shift to the northern West Indies; Clapham et al. (2008) suggested that such a shift could have been influenced by the range over which humpback whale song can be heard. However, while it is possible that whales were not present in large numbers in this region in the nineteenth century, it appears more likely that the absence of whaling there was driving more by political considerations and an inability to obtain the necessary permissions (I. Bonnelly di Calventi, pers. comm.). Another suggestion of an apparent shift concerns the modern breeding area off the coast of Ecuador, to which humpback whales from the Antarctic Peninsula migrate in the austral winter. A study of local language, art, media and whaling records gives no indication that humpback whales occurred in this region prior to recent times, yet they are abundant there today (C. Castro, pers. comm.).

All three of the cases described above involve wintering grounds. As noted above, with the possible exception of protected water for mothers and calves (which can be found in numerous coastal locations), there are no required resources for humpback whale breeding areas. Consequently, and notwithstanding the disputable nature of the studies described above, this potentially lends considerable plasticity to the distribution of this species. In other words, humpback whales—whose mating system is strongly characterized by aggregation—should be free to seek suitable breeding habitats in other areas if a particular aggregation is greatly reduced or eliminated by whaling.

Materials and methods

To explore the SAH, we developed a hypothetical scenario simulating the population of humpback whales migrating past the coast of eastern Australia. This population has been well studied at several sites in recent years, and a variety of methods has been employed to estimate abundance and rates of increase. In our scenario, two hypothetical populations, named base and source, migrated from different feeding grounds (e.g., in the Antarctic) to different breeding grounds (e.g., to the coastal waters of eastern Australia and to islands in the western South Pacific). The term "population" is used here to represent two spatially separated groups that interact (breed) at some level through the exchange of individuals. The base population migrates past a location where the land-based abundance surveys are conducted (as off the eastern coast of Australia). The source population migrates from a different feeding ground and supplies individuals to the base population by social aggregation at an incremental annual rate. These individuals joined the base population during the migration before the abundance surveys were conducted. Individuals of the two populations may reproduce, but return to their original Antarctic feeding grounds for the austral summer.

With that, we tested whether the mixing of the two populations could produce an estimated (apparent) rate of increase higher than the actual (true) rates of each population. In this example, the base population corresponds to the eastern Australian stock. The identity of the source population is irrelevant to the theoretical argument explored here, but it is not unreasonable to assume that this constitutes the stock from western Oceania which, prior to whaling, migrated past New Zealand and on to breeding grounds in Fiji and elsewhere. Under the SAH, the low density of whales observed in Fiji today would be a consequence not of a lack of recovery, but of these whales abandoning their historical winter destination and instead migrating into centers of aggregation off eastern Australia. As noted above, while individuals of the two populations can mix in the breeding grounds, they return to their feeding ground of origin. Therefore, in this study, the term "immigration" refers to temporary immigration.

We assessed whether the apparent rate of increase measured in the migratory routes was equal to the recent estimate of trend of the eastern Australian population for the period 1984–2010 (10.9 %/year, 95 % CI 10.5–11.3 %/year; Noad et al. 2011b). This rate of increase is close to that proposed as the maximum possible (11.8 %) by Zerbini et al. (2010). We simulated the dynamics of the two populations from 1987 to 2015 by assuming that the biological rate of increase in the base and the source populations were actually less than the 10.9 % estimated from surveys off eastern Australia (Noad et al. 2011b). Through

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this modeling exercise, we address the question of what proportion of temporary immigrants from the source stock would be required to maintain relatively high apparent rates of increase that would be consistent with the 10.9 %/year observed in the eastern Australian base population if the true biological rate was actually less than this. In various combinations, we chose two values for true rates of increase in the base and source populations: (1) 7.3 %/year, which is the median rate of increase obtained by Zerbini et al. (2010, Approach A) from the means of observed parameter values from different populations of humpback whales worldwide; and (2) 9.6 %/year, which is intermediate between the average and the 11.8 %/year "maximum" rate of increase given by Zerbini et al. (2010).

We explored twelve scenarios involving these two rates of increase as well as different incremental immigration rates of 1, 2 and 3 %, where the increased proportion of individuals migrating from the source to the base population was additive over time (e.g., for the 1 % example, the immigration rate from source to base was 1 % in 1987, 2 % in 1988, 3 % in 1989 and so on). We wanted to examine a range of possibilities, including some that are behaviorally more or less plausible. The initial size of the base population in 1987 is approximately 879 individuals, corresponding to the estimated size of the eastern Australia population in that year (Brown et al. 2003). The size of the source population was arbitrarily set at 500 individuals as the SAH hypothesis assumes that individuals are drawn from a smaller source population to the more populated base population breeding ground.

The simulation model structure is presented in Fig. 1. The base (eastern Australia) and the source (western Oceania) population dynamics in the breeding and feeding grounds were simulated as follows:

Initial population sizes

$$N^{\mathrm{FG}}_{\mathrm{base},1987} = 879$$

$$N^{\mathrm{FG}}_{\mathrm{source},1987} = 500$$

Number of immigrants

$$I_{\mathrm{source}\rightarrow\mathrm{base},t} = N^{\mathrm{FG}}_{\mathrm{source},t} \cdot \alpha \cdot (t - 1986)$$

$$I_{\mathrm{base}\rightarrow\mathrm{source},t} = N^{\mathrm{BG}}_{\mathrm{base},t} \cdot \alpha \cdot (t - 1986)$$

Abundances

$$N^{\mathrm{MC}}_{\mathrm{base},t} = N^{\mathrm{FG}}_{\mathrm{base},t} + I_{\mathrm{source}\rightarrow\mathrm{base},t}$$

$$N^{\mathrm{BG}}_{\mathrm{base},t} = \left(N^{\mathrm{FG}}_{\mathrm{base},t} \cdot \lambda_{\mathrm{base}}\right) + \left(I_{\mathrm{source}\rightarrow\mathrm{base},t} \cdot \lambda_{\mathrm{source}}\right)$$

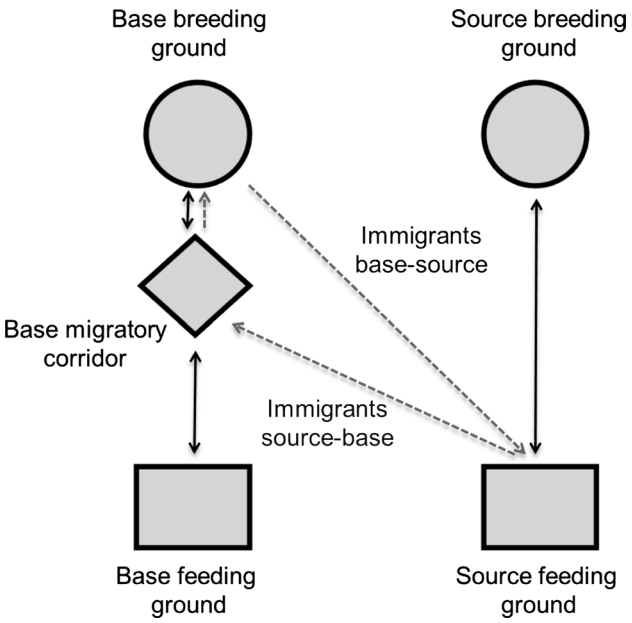

Fig. 1 Model structure to simulate the dynamics of the base and source populations to assess the SAH

$$N^{\mathrm{BG}}_{\mathrm{source},t} = (N^{\mathrm{FG}}_{\mathrm{source},t} - I_{\mathrm{source}\rightarrow\mathrm{base},t}) \cdot \lambda_{\mathrm{source}}$$

$$N^{\mathrm{FG}}_{\mathrm{base},t+1} = N^{\mathrm{BG}}_{\mathrm{base},t} - I_{\mathrm{base}\rightarrow\mathrm{source},t}$$

$$N^{\mathrm{FG}}_{\mathrm{source},t+1} = N^{\mathrm{BG}}_{\mathrm{source},t} + I_{\mathrm{base}\rightarrow\mathrm{source},t}$$

where:

- $N^{\mathrm{FG}}_{\mathrm{base},1987}$ and $N^{\mathrm{FG}}_{\mathrm{source},1987}$ are the initial population sizes for the source and base population in the feeding grounds in 1987
- $I_{\mathrm{source}\rightarrow\mathrm{base},t}$ is the number of immigrants moving from the source population feeding grounds to the base population in year t,
- $I_{\mathrm{base}\rightarrow\mathrm{source},t}$ is the number of immigrants returning from the base to the source population feeding grounds in year t,
- $N^{\mathrm{MC}}_{\mathrm{base},t}$ is the abundance in year t in the migratory corridor (MC) of the base population (equivalent to the observed population migrating past east Australia)
- $N^{\mathrm{BG}}_{\mathrm{base},t}$ is the abundance in year t in the breeding grounds of the base population
- $N^{\mathrm{BG}}_{\mathrm{source},t}$ is the abundance in year t in the breeding grounds of the source population (western Oceania)
- $N^{\mathrm{FG}}_{\mathrm{base},t+1}$ is the abundance in year $t + 1$ in the feeding grounds of the base population

Table 1 Simulation scenarios, rates of population change (ROC in %/year) of the source population on the breeding grounds/migratory routes of the base population, as well as the proportion of animals from the source population migrating to the base by 2015

Scenario	α (%)	λ source	λ base	Average observed $ROC_{source, BG}$	Average observed $ROC_{base, MC}$	Proportion of migrants to base in 2015
1	1	7.3	7.3	6.2	7.9	29
2	1	7.3	9.6	6.2	10	29
3	1	9.6	7.3	8.7	8.3	29
4	1	9.6	9.6	8.7	10.2	29
5	2	7.3	7.3	4.2	8.4	58
6	2	7.3	9.6	4.2	10.2	58
7	2	9.6	7.3	6.6	9.3	58
8	2	9.6	9.6	6.6	10.7	58
9	3	7.3	7.3	−0.1	8.8	87
10	3	7.3	9.6	−0.1	10.5	87
11	3	9.6	7.3	2.2	9.7	87
12	3	9.6	9.6	2.2	11.2	87

The initial size of the base population is set at 879 individuals, which corresponds to the estimated size of the eastern Australia population in 1987 (Brown et al. 2003)

- $N^{FG}_{source,t+1}N_{t+1,\ source,\ FG}$ is the abundance in year $t + 1$ in the feeding grounds of the source population
- $\alpha =$ temporary immigration rate,
- $\lambda =$ is the population-specific (source or base) finite intrinsic rate of increase (7.3 %/year or 9.6 %/year in the scenarios simulated in this study).

The observed (or apparent) rates of change (ROC) in abundance in the period from 1987 to 2015 for the population in the base migratory corridor ($N_{t,\ base\ MC}$) and the source population breeding grounds ($N_{t,\ source,\ BG}$) were computed as the average annual rate of change in the abundance. The proportion of migrants moving from the source to the base population at the end of the simulation period (2015) was also calculated.

The simulation model presented above assumes an exponential rate of population growth under the assumption that the populations were too small (relative to carrying capacity) for density dependence to have a significant impact on growth during the time frame of the simulation (1987–2015). This model is equivalent to log-linear regression methods typically applied to compute population growth rates from time series of humpback whale abundance estimates (Bannister and Hedley 2001; Stevick et al. 2003; Zerbini et al. 2006; Noad et al. 2011a, b) and is consistent with the growth rate patterns of recovering endangered whales within the time frame examined here.

There is of course an almost endless set of scenarios which could be tested in this work. However, our aim is not to conduct an exhaustive exploration of all options but rather to test the possible validity of the SAH. We wish to assess how, under a range of values, this phenomenon would be manifest if real, and whether high apparent rates of increase in a base population could be maintained over extended periods by temporary immigration from another stock.

Results

The results of the simulation are shown in Table 1 and Fig. 2. The results show that in some scenarios (2, 4, 6, 8, 10 and 12), relatively high rates of increase (10–11 %/year) in the observed base population migratory route can be maintained. These scenarios typically require the higher λ values among the two that we selected for the simulation work for the base (larger) or both populations. Higher rates (e.g., >10.4 %/year) are observed only in scenarios 8, 10 and 12, which require an annual increment of 2–3 % of individuals from the source population immigrating to the base population. Except for scenarios 2 and 4, where the observed ROCs are around 10 %/year, higher ROCs require a relatively large number of individuals (58–87 %) immigrating from the source population to the base population at the end of the simulation (in 2015). In scenarios 10 and 12, the source population numbers decline in the breeding grounds (Fig. 2) because a large number of individuals moving toward the base population is needed in order to maintain the relatively high observed rates of increase observed on the base population's migratory routes.

In scenarios where λ values are lower (7.3 %/year) for both source and base populations or when a higher λ is assigned to the source (smaller population), ROCs above 10 % are not possible irrespective of the proportion

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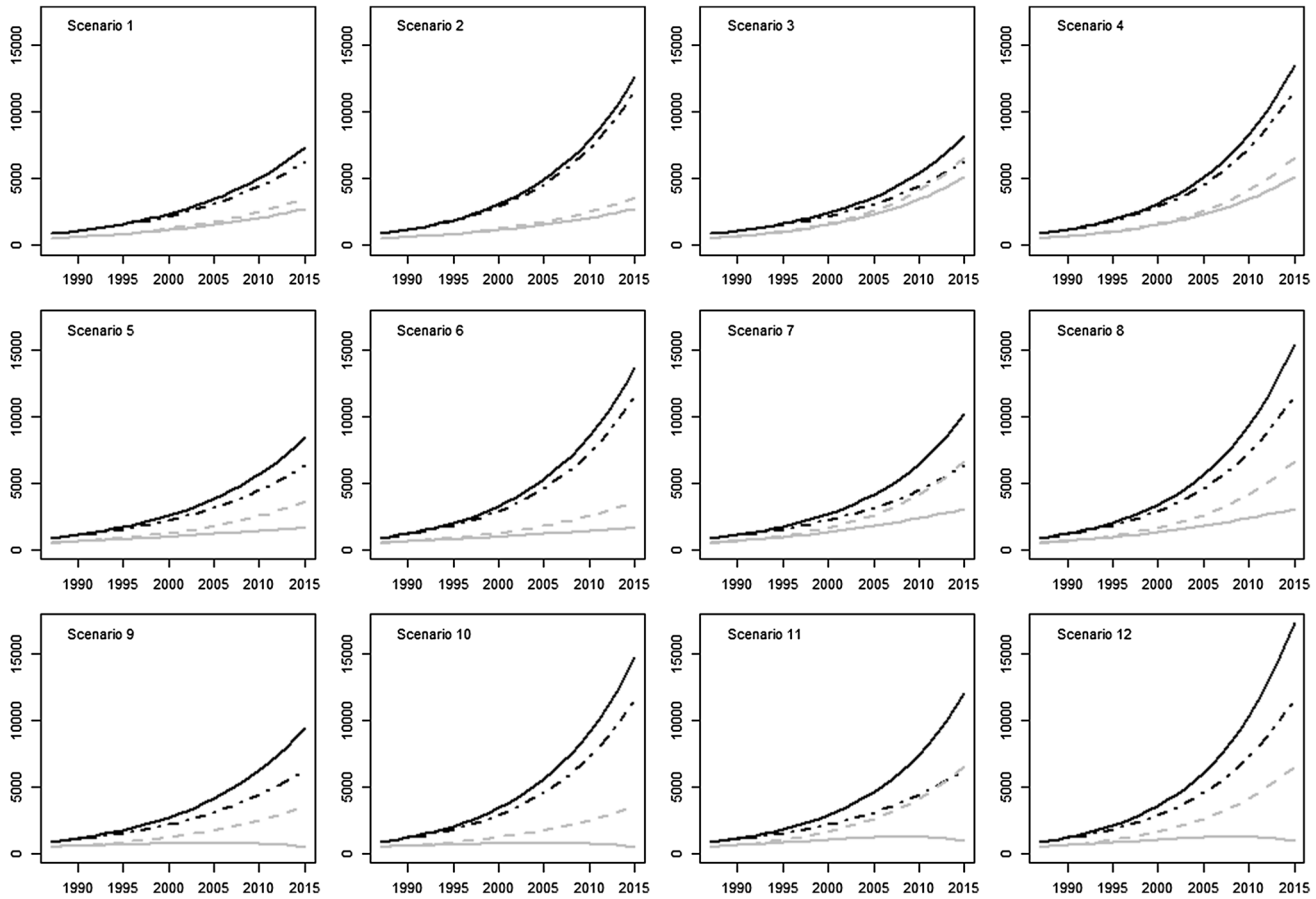

Fig. 2 Simulated population trajectories of humpback whales under twelve scenarios of varying rates of increase and temporary immigration rates. *Gray and black lines* correspond to the "source" and "base" population, respectively. *Dotted* and *continuous lines* represent, respectively, the true population (feeding ground) and "observed" population (migratory corridor for base and breeding ground for source)

of migrants visiting the breeding grounds of the base population.

Discussion

We undertook this exercise to assess whether, at least in theory, temporary immigrants from a depleted population drawn into (for them) a new breeding area could artificially inflate apparent observed rates of increase in that area. The modeling exercise conducted here shows that in order to maintain the same rate of high growth observed off eastern Australia (or any other population), the contribution to that rate by immigration from a source population would have to represent an increasingly larger proportion of the source stock each year. The demand for immigrants would eventually exceed the supply and exhaust the source population, but the simulations demonstrated that high increase rates can be sustained over extended periods (well over 20 years). From this, we conclude that, at least theoretically, the SAH could account for observed high rates of increase such as those reported since 1987 for the eastern Australia component of Breeding Stock E. However, in other scenarios (e.g., 9–12 here), it cannot.

It is possible that any population large enough to support a protracted high apparent rate of increase in the base stock would form its own centers of aggregation in historically important habitats rather than seeking social centers elsewhere. However, this might not be the case if the immigration trend began when the population was small (e.g., prior to surveys being conducted in the base) and then became a self-sustaining collective behavior which continued as the stock recovered, and/or if the cultural memory of the existence of historically important habitats was lost. It is probably pointless to speculate on the identity of such a population given that we do not know whether it even exists, but it is worth noting that the feeding grounds of Area VI were not exploited as heavily as those in Area V and might therefore have retained more animals than the latter. However, we know neither the pre- and post-whaling size of the Area

VI stock, nor whether the survivors would seek or find any connection to breeding area E.

In the scenarios investigated in this study, the proportion of the source population moving to the base population (the immigration rate) increased over time in order to maintain the relatively high apparent rate of increase estimated with the surveys. Additional scenarios, not included in this study, could assume that individuals move from the source to the base population at a constant rate. Under these circumstances, the most likely outcome is that the growth rate observed at the survey site corresponds to a combination of the growth rate of two populations, bounded by the rates observed for each individual population. For example, if the base and source populations are growing at the same rate, say 5 %/year, then the observed rate of increase should be 5 %/year irrespective of the size of either population and of the immigration rate from the source to the base population. If, by contrast, the base and source populations have different growth rates, say 7 % for the base and 4 % for the source population, then the observed rate must be a figure between 4 and 7 %. The actual observed rate will depend upon the size of both populations and the immigration rate.

It is interesting to note that estimates of growth rates reported for Oceania (Constantine et al. 2012) are consistent with those observed for the source population in their breeding grounds in some of the modeling scenarios presented here. For example, Constantine et al. (2012) estimated nonsignificant but positive growth rates of 4–7 %/year for the Oceania population with mark-recapture population models. The observed ROC for the source population breeding ground in scenario 8 is consistent with their estimates and still allows for the maintenance of an observed high (10.7 %/year) ROC in the base population.

Although we did not examine the dynamics involved, even more complicated scenarios can easily be envisaged involving more than one source population and more sophisticated models. Obviously, immigration from two (or more) source stocks would increase the time taken for demand in the base stock to exceed the combined supply from elsewhere. Nonetheless, given the results presented here, the SAH is likely to represent at best an incomplete explanation of the high rates of increase observed in some Southern Hemisphere humpback whale populations. Irrespective of what is mathematically plausible, it is difficult to believe that social aggregation would produce the remarkable consistency that has been observed in the rates of increase reported from eastern Australia.

Certainly, the highly social nature of humpback whales during their winter breeding season makes it unlikely that no temporary immigration into large aggregations occurs, notably in situations where commercial whaling essentially destroyed such assemblages in certain areas. It is clear that the large whaling catches of the late 1950s and early 1960s so reduced some populations of whales that the remaining animals were small in number. For example, whales which formerly migrated past New Zealand and (presumably) on to Fiji would, in the post-whaling era, no longer have found the sizeable breeding aggregations which once existed in such places.

Similarly, the current relatively low density of whales in the southeastern Caribbean (the major West Indies whaling ground in the nineteenth century, Reeves et al. 2001; Swartz et al. 2003) might not be due to a lack of recovery but to whales changing their migratory destination to the much more populous Silver/Navidad Bank complex in the northern part of the Antillean arc.

The key point here is that, given what is known of the mating system, it is unrealistic to believe that humpback whales would continue to return to largely empty habitats if an alternative, more attractive destination was available to them. Song represents a potential means by which whales could be drawn into aggregation centers (Herman 1979; Reeves et al. 2001; Herman et al. 2013). Although even high densities of singers in shelf waters would not be audible over great distances due to transmission loss in shallow water, it is not necessary for a distant whale to initially detect the aggregation itself; rather, all that is required is for a whale to hear a few singers in the right direction, and then to pick up increasing numbers of singing males as it traveled closer and closer to the actual aggregation site.

There is evidence from both photo-identification resighting histories and analysis of mitochondrial DNA for long-term female fidelity to breeding areas, including in Oceania (Olavarría et al. 2007). Accordingly, it is possible that movement among breeding areas, if it occurs, is more likely to be undertaken by males seeking to increase opportunities for mating.

Although the high increase rates indicated by the point estimates from eastern Australia could be real, as noted above, they require values for survival, age at first parturition and calving rate that represent a combination of extreme values from among those observed elsewhere in the world (Zerbini et al. 2010). Accordingly, we conclude that some portion of these high growth rates is likely due to immigration, but we have no way of assessing the extent of this phenomenon without data on true growth rates, population structure and the movement rates of individuals among the base stock and any source population(s) elsewhere.

Although distributional shift by some animals may partly explain the low densities of whales today in Fiji, New Zealand and some other areas, and indeed the apparent delay in recovery of the Oceania population as a whole (Constantine et al. 2007), we cannot contradict the prevailing belief that these areas were host to one or more relatively discrete management units and that these populations

have failed to recover from the intensive whaling to which they were subject during the last century.

However, we believe that it is dangerous to dismiss the SAH idea completely. Although inevitably impossible to validate, we believe that—given what we know of the social ecology of humpback whales—it is entirely plausible that social aggregation has been a factor in determining the distribution and demographics of depleted populations of this endangered species as they attempt to recover from the damage inflicted by commercial whaling. Through whaling, humans may well have wrought major changes in the distribution and habitat use of humpback whales. There are currently not enough data to speculate on whether social aggregation following depletion by whaling would be manifest in other species of large whale. However, the principle potentially applies to any species with a population that is characterized by discrete hotspots of distribution during the mating season; as such, it might apply to at least right whales (*Eubalaena* spp.) and gray whales (*Eschrichtius robustus*).

More generally, population modeling for whales (and many other taxa) is invariably a numbers game in which estimates of abundance, trend and demographic parameters are examined and modeled; such exercises, and interpretations of model output, rarely attempt to incorporate knowledge regarding the social behavior or mating system of the species concerned. A major lesson from the modeling exercise conducted here is that changes in distribution caused by disruption of a species' social system could explain anomalously high rates of population growth, as well as unusually low rates observed in highly depleted source stocks. Whether or not that is actually what has occurred with humpback whales, we strongly caution that assessments of depleted animal populations that do not take into account the social ecology of the species concerned are missing a potentially vital component of the picture.

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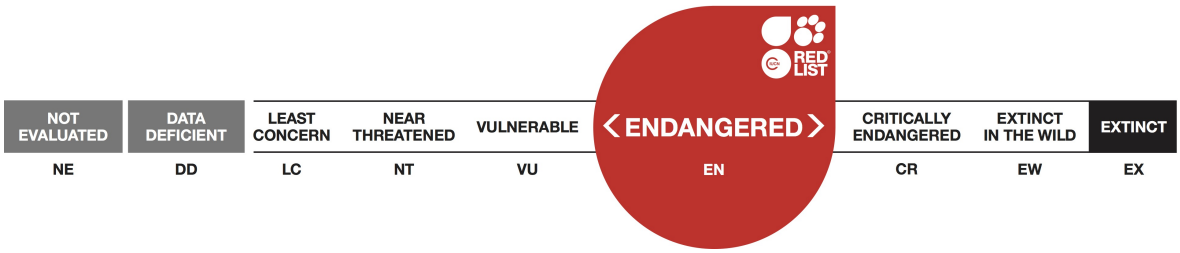
Eschrichtius robustus (western subpopulation), Western Gray Whale

Assessment by: Cooke, J.G., Taylor, B.L., Reeves, R. & Brownell Jr., R.L.



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Taxonomy

Kingdom	Phylum	Class	Order	Family
Animalia	Chordata	Mammalia	Cetartiodactyla	Eschrichtiidae

Taxon Name: *Eschrichtius robustus (western subpopulation)* (Lilljeborg, 1861)

Parent Species: See *Eschrichtius robustus*

Common Name(s):

- English: Western Gray Whale

Taxonomic Notes:

This is a subpopulation of the Gray Whale, *Eschrichtius robustus.*

Assessment Information

Red List Category & Criteria: Endangered D ver 3.1

Year Published: 2018

Date Assessed: January 1, 2018

Justification:

The Gray Whales that summer in the western North Pacific, mainly off northeastern Sakhalin Island and the southeastern coast of Kamchatka, appear to be a genetically and demographically self-contained group and are therefore listed as a subpopulation, even though many of them migrate to wintering areas in the eastern North Pacific. The number of reproductive females is estimated to have been between 51 and 72 in 2016, hence the total number of mature individuals is well below 250, the threshold for Endangered under IUCN Red List criterion D. Historically Gray Whales migrated through Japanese and Korean waters to wintering grounds thought to be located in the South China Sea. Recent sightings and bycatches off Japan and China showed that some individuals, including at least two that were known to feed off Sakhalin Island, migrated through Asian waters in winter and spring. Although one recent record exists of a mother and calf migrating through Japanese waters in spring, it is unclear whether a specific wintering ground still exists in Asian waters. If the western subpopulation were defined to include only those whales that winter in the western North Pacific, then that subpopulation would be classified as Critically Endangered because the number of mature individuals in that group is most probably less than 50.

Previously Published Red List Assessments

2008 – Critically Endangered (CR)
http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T8099A12885692.en

2000 – Critically Endangered (CR)

1996 – Endangered (EN)

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Geographic Range

Range Description:

The main known summering grounds of Gray Whales in the western Pacific are off the northeastern coast of Sakhalin Island (Russian Federation) in the Okhotsk Sea and in bays on the southeastern coast of the Kamchatka Peninsula. They also occur at least occasionally in other coastal waters of the northern Okhotsk Sea (Vladimirov 1994, Weller *et al.* 1999, Yakovlev *et al*. 2011). Historically there was a migration along both coasts of Japan (Sea of Japan and the Pacific Ocean side), the mainland coast of the Sea of Japan, and the Korean Peninsula (Nambu *et al*. 2010). At least 1,700 Gray Whales were taken by modern whaling during 1890-1966 in the Sea of Japan/East Sea, mainly off the coast of Korea, plus unknown numbers in the Yellow Sea (Kato and Kasuya 2002). The catches in the Jangjeon ground (= Changjin northeast Korea) had two peaks, in December and April, which reflect the southbound and northbound migrations, respectively, while the catches in the Ulsan ground (off southeast Korea) were concentrated in December and January.

Until recently, the Gray Whales summering off Sakhalin Island were thought to belong to the historical Asian Gray Whale subpopulation, hence the term "Korean-Okhotsk Gray Whale" used in the Russian literature (Blokhin *et al*. 1985), but evidence from tagged whales (Mate *et al*. 2015) and photographic and genetic matches with whales off Canada and the U.S. and in wintering lagoons along the coast of Baja California, Mexico (Weller *et al.* 2012) show that many of the Sakhalin and Kamchatka whales migrate to the eastern North Pacific in winter.

Although Bowen (1974) speculated that the Asian Gray Whale population was extinct after summarizing available negative findings, this idea was rebutted by Brownell and Chun (1977), who reported that Gray Whales were captured in Korean waters until 1967 and observed there in 1968 and also during research cruises in the Okhotsk Sea in 1967 and 1974. The last confirmed sighting in Korean waters was of two Gray Whales in January 1977 in the Sea of Japan /East Sea (Park 2001, Kim *et al*. 2013). Small numbers of gray whales were observed off Piltun, Sakhalin, in the 1980s (Blokhin *et al*. 1985). About 20 records were documented in Japan between 1990 and 2016, mainly on the Pacific coast (Kato *et al*. 2016). These include at least one female that moved between Sakhalin and Japan and one individual seen in successive years off Sakhalin in summer and off Japan in winter and spring (Weller *et al*. 2008, 2016; Nakamura *et al*. 2017). The last recorded living Gray Whale sighted in Chinese waters was around Wangjia Island, China (36°50'N, western Yellow Sea) in January 1979 (Wang 1984). A Gray Whale stranded near Zhuanghe (Korea Bay, northern Yellow Sea) in December 1996 and died soon after (Zhao 1997). A Gray Whale was caught in fishing gear in the Taiwan Strait (Fujian Province of China) in November 2011 (Wang *et al*. 2015). There are no confirmed records of Gray Whales from the coastal waters of Taiwan (excluding fossils). Two mother-calf pairs were caught in "spring" 1953 (month not stated) in the eastern Gulf of Tonkin off Leizhou Peninsula, Guangdong Province, China (Zhu 2002 cited in Nambu 2010). This is near the Hainan Strait where pre-modern whalers took Gray Whales in January and February in the 19th century (Henderson 1984). The westernmost record is a stranding in October 1994 on the island of Ng□c Vùng, Viet Nam, in the western Gulf of Tonkin. The specimen was misidentified at the time as a Fin Whale (*Balaenoptera physalus*), but the skeleton was placed in the Qu□ng Ninh Historical Museum where it was recently confirmed to be a Gray Whale (Pham *et al*. 2014). Therefore, it appears that at least some of the Gray Whales that feed in the Okhotsk Sea migrate through Japanese waters in winter and spring. These may be a remnant of the historical Asian population, but it is not known whether any calving and nursery aggregations still exist in the west as

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they do in the east (Baja California, Mexico).

Country Occurrence:

Native: Canada (British Columbia); China; Japan; Mexico (Baja California); Russian Federation (Central Asian Russia); United States (Alaska, California, Oregon, Washington)

Possibly extinct: Korea, Democratic People's Republic of; Korea, Republic of

FAO Marine Fishing Areas:

Native: Pacific - northwest, Pacific - eastern central, Pacific - northeast

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Population

Gray Whales were hunted in the western North Pacific in prehistoric times both in Korea (Park 1995, Lee and Robineau 2004) and in the Okhotsk Sea (Krupnik 1984), but to an unknown extent. They were taken by Japanese hand-harpoon whalers in the Sea of Japan starting at least in the 17th century, and in larger numbers by Japanese net whalers in the Sea of Japan and East China Sea, on the Pacific coast of Japan, and along the Korean Peninsula from 1675 to 1890 (Omura 1984, 1988). Gray Whales were also taken by European and American whalers in the Okhotsk Sea from the late 1840s to perhaps the start of the 20th century (Henderson 1984, Reeves *et al.* 2008), and by Russian steam whalers on the southern coast of the Russian Far East and then by Norwegian steam whalers off the Korean Peninsula in the early years of the 20th century (Andrews 1914, Weller *et al.* 2002). Quantitative information is scarce, but it is possible that the western subpopulation was already depleted by the start of modern whaling at the end of the 19th century. During 1890-1966 an estimated 1,800–2,000 Gray Whales were taken off the Korean Peninsula and Japan (Kato and Kasuya 2002). Nearly 85% of these whales were killed off southeastern Korea (Ulsan) while the remainder came primarily from northeastern Korea (Jangjeon, Sinpo and Yujin) with a small number of whales also taken in Japanese waters and the Yellow Sea in the early part of the 20th century. Occasional catches are recorded from China during 1916-1958 (Nambu *et al*. 2010). It is not known whether any Gray Whales have been taken since 1945 in the waters of the Democratic People's Republic of Korea. The Gray Whale population off Sakhalin and Kamchatka has been increasing at a rate of 3.4-4.8% per year, albeit with some fluctuations, over the period 2006-2016 (Cooke 2017). The population in 2016 was estimated at 271-311 whales, excluding calves, of which 175-192 whales were considered predominantly Sakhalin-feeding individuals. The number of breeding females was estimated at 51-72. The nominal number of mature individuals for the purpose of Red List assessment is taken to be twice the number of mature females (102-144 mature individuals). Some of the whales are known through tagging (Mate *et al*. 2015) and photographic matches (Weller *et al*. 2012) to migrate to the eastern North Pacific in winter, including to the wintering lagoons in Baja California, Mexico. While some have been observed to migrate to the western North Pacific (Weller *et al.* 2016), the analysis by Cooke (2017) indicates that the number doing so is 100 or less.

Based on analyses of individual identification data including mother-calf pairs, and the results of paternity analysis of genetic samples (Lang 2010), Cooke *et al.* (2017) concluded that the Gray Whales that summer off Sakhalin and southeastern Kamchatka may constitute a demographically self-contained subpopulation where mating occurs at least preferentially, and possible exclusively, within the subpopulation. Significant genetic differences between Gray Whales sampled off Sakhalin and those sampled in the eastern North Pacific have been found in both mitochondrial and nuclear DNA (Le Duc *et al* 2002, Lang *et al*. 2011). However, another genetic study involving 28 Gray Whales sampled off Sakhalin Island and one sampled in the eastern North Pacific concluded that the putatively 'eastern' individual was no more or less related to the whales sampled in the west than would be expected by chance alone (DeWoody *et al.* 2017).

Current Population Trend: Increasing

Habitat and Ecology **(see Appendix for additional information)**

Gray Whales are predominantly benthic feeders. The best-studied and apparently main feeding habitat of this subpopulation is the shallow (5-15 m depth) shelf off northeastern Sakhalin Island, particularly off the mouth of Piltun Lagoon, where the main prey species appear to be amphipods and isopods

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(Weller *et al.* 1999, Demchenko *et al.* 2016). Mother-calf pairs appear to feed exclusively in the shallow water but other individuals also use an offshore feeding ground in 30-50 m depths southeast of Chayvo Bay where benthic amphipods and possibly cumaceans are apparently the main prey species (Demchenko *et al.* 2016). The prey composition in other Gray Whale feeding areas in the Okhotsk Sea and off Kamchatka is unknown. Historically, Gray Whales were observed to feed during their northbound migration in the East Korean Bay (North Korea; formerly known in English as Broughton Bay) between the two Japanese land stations Sinpo and Yujin in the early 20th century (Andrews 1914, Tago 1922).

Systems: Marine

Threats (see Appendix for additional information)

Three female Gray Whales, including a mother-calf pair, were fatally entangled in net-traps on the Pacific coast of Japan in 2005 (Kato *et al.* 2006). Based on projections, this level of mortality, if continued, would result in a high probability of decline towards extinction (Cooke *et al*. 2006). Following the deaths of two further females, at least one of which was fishery-related, in northern Japan in 2007, the western subpopulation was classified on the IUCN Red List in 2008 as Critically Endangered under criteria C2a(ii) and E (Reilly *et al*. 2008). From 2008, the deliberate killing and marketing of the species was prohibited in Japan (Kato *et al*. 2008), and no fishery-related deaths have been documented there since then. One of the Gray Whales found entrapped in a set net in May 2005 and a Gray Whale carcass that stranded in April 2016 at Ito City (35°N) on the Pacific coast of Japan both exhibited spinal pathologies severe enough in at least the first case to visibly impair mobility (Yamada *et al*. 2016). Since 2013, trap nets for Pacific Salmon have been deployed in the Western Gray Whale feeding ground off northeastern Sakhalin, resulting in two observed entanglements and at least one probable entanglement death (Lowry *et al*. submitted). Based on analysis of photographs, approximately 20% of Gray Whales observed off Sakhalin during 1995-2005 showed evidence of scarring from past entanglements (Bradford *et al*. 2009), but it is not known where the scars were acquired. Lowry *et al*. (submitted) conclude that the coastal salmon set net fishery operating at northeastern Sakhalin, and to a lesser extent elsewhere in the Russian Far East, poses a high risk of entangling Gray Whales from the western subpopulation. They also conclude that bottom-set gillnet, demersal longline, snurrewad, and trap and pot fisheries overlap substantially with Gray Whale distribution in the Russian Far East, and bycatch in those fisheries is possible. One Gray Whale was caught and died in fishing gear off China in the Taiwan Strait in 2011 (Wang *et al*. 2015). In addition to fishery-related hazards, the substantial nearshore industrialization and shipping congestion throughout the migratory corridors of those Gray Whales that migrate through Asian waters in fall, winter and spring increases the likelihood of exposure to ship strikes, chemical pollution, and general disturbance (Weller *et al.* 2002). Offshore gas and oil development in the Okhotsk Sea within 20 km of the primary feeding ground for mother-calf pairs off northeastern Sakhalin Island also represents a potential threat. Potentially harmful activities include geophysical seismic surveying, vessel traffic, and disturbance from construction work (IUCN 2017). However, the continued increase in the numbers of Gray Whales summering off Sakhalin implies that the impacts to date have been sustainable.

Conservation Actions (see Appendix for additional information)

Gray Whales have been legally protected from commercial whaling by the 1946 International Convention for the Regulation of Whaling (ICRW) since its entry into force in 1948, and by its

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predecessor convention, the Convention for the Regulation of Whaling, since 1935, to which U.S.A., Canada, and Mexico were parties. The ICRW came into effect for the U.S.A., Canada, and the USSR in 1948, Mexico in 1949, Japan in 1951, Republic of Korea in 1978, and China in 1980. Canada withdrew from the ICRW in 1981 but Gray Whales remain protected under Canadian law. Gray Whales have a measure of legal protection in Russian waters through inclusion in the Russian Federation Red Book of Threatened Species: the Korean-Okhotsk population is listed as "Endangered" while the eastern North Pacific population, which occurs in Russian waters in summer, is listed as “Recovery and Restoration”. The Gray Whale has been legally protected in Japan since 2008, and deliberate killing and commercial utilization are prohibited. The species is listed in Appendix I of Convention on International Trade in Endangered Species. Western Gray Whales are listed as endangered under the U.S. Endangered Species Act and are considered depleted and strategic under the U.S. Marine Mammal Protection Act Five range states – Japan, Russian Federation, Republic of Korea, U.S.A. and Mexico – have signed a Memorandum of Cooperation Concerning Conservation Measures for the Western Gray Whale Population. A stakeholders’ workshop to develop a conservation plan is planned for 2018 or 2019.

Credits

Assessor(s): Cooke, J.G., Taylor, B.L., Reeves, R. & Brownell Jr., R.L.

Reviewer(s): Weller, D., Mate, B. & Lang, A.

Facilitators(s) and Compiler(s): Lowry, L.

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External Resources

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Appendix

Habitats

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Habitat	Season	Suitability	Major Importance?
9. Marine Neritic -> 9.1. Marine Neritic - Pelagic	-	Suitable	Yes
10. Marine Oceanic -> 10.1. Marine Oceanic - Epipelagic (0-200m)	-	Suitable	Yes

Threats

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Threat	Timing	Scope	Severity	Impact Score
1. Residential & commercial development -> 1.2. Commercial & industrial areas	Ongoing	Majority (50-90%)	Negligible declines	Low impact: 5
3. Energy production & mining -> 3.1. Oil & gas drilling	Ongoing	Majority (50-90%)	Causing/could cause fluctuations	Medium impact: 6
4. Transportation & service corridors -> 4.3. Shipping lanes	Ongoing	Majority (50-90%)	Negligible declines	Low impact: 5
5. Biological resource use -> 5.4. Fishing & harvesting aquatic resources -> 5.4.1. Intentional use: (subsistence/small scale) [harvest]	Past, unlikely to return	Unknown	Causing/could cause fluctuations	Past impact
5. Biological resource use -> 5.4. Fishing & harvesting aquatic resources -> 5.4.2. Intentional use: (large scale) [harvest]	Past, unlikely to return	Majority (50-90%)	Rapid declines	Past impact
5. Biological resource use -> 5.4. Fishing & harvesting aquatic resources -> 5.4.3. Unintentional effects: (subsistence/small scale) [harvest]	Ongoing	Minority (50%)	Negligible declines	Low impact: 4
5. Biological resource use -> 5.4. Fishing & harvesting aquatic resources -> 5.4.4. Unintentional effects: (large scale) [harvest]	Ongoing	Majority (50-90%)	Causing/could cause fluctuations	Medium impact: 6
9. Pollution -> 9.2. Industrial & military effluents -> 9.2.1. Oil spills	Future	Minority (50%)	Causing/could cause fluctuations	Low impact: 3
9. Pollution -> 9.6. Excess energy -> 9.6.3. Noise pollution	Ongoing	Majority (50-90%)	Causing/could cause fluctuations	Medium impact: 6

Conservation Actions in Place

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Conservation Actions in Place
In-Place Research, Monitoring and Planning

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Conservation Actions in Place
Action Recovery plan: No
Systematic monitoring scheme: Yes
In-Place Education
Included in international legislation: Yes

Conservation Actions Needed

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Conservation Actions Needed
1. Land/water protection -> 1.2. Resource & habitat protection
2. Land/water management -> 2.1. Site/area management
3. Species management -> 3.2. Species recovery

Research Needed

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Research Needed
1. Research -> 1.1. Taxonomy
1. Research -> 1.2. Population size, distribution & trends
1. Research -> 1.3. Life history & ecology
1. Research -> 1.5. Threats
2. Conservation Planning -> 2.1. Species Action/Recovery Plan
3. Monitoring -> 3.1. Population trends
3. Monitoring -> 3.4. Habitat trends

Additional Data Fields

Distribution
Continuing decline in area of occupancy (AOO): Unknown
Extreme fluctuations in area of occupancy (AOO): No
Continuing decline in extent of occurrence (EOO): Unknown
Extreme fluctuations in extent of occurrence (EOO): No
Population
Number of mature individuals: 102-144

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Population
Continuing decline of mature individuals: No
Extreme fluctuations: No
Population severely fragmented: Unknown
Habitats and Ecology
Continuing decline in area, extent and/or quality of habitat: Unknown
Movement patterns: Full Migrant

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Population Assessment of the Sakhalin Gray Whale Aggregation

Justin G. Cooke[1,2], David W. Weller[3], Amanda L. Bradford[4], Olya Sychenko[5], Alexander M. Burdin[5] and Robert L. Brownell, Jr.[3]

ABSTRACT

A population assessment of the Sakhalin feeding aggregation of gray whales (*Eschrichtius robustus*) was conducted using photo-identification data collected on their summer feeding ground off Sakhalin Island from 1994 to 2011, fitted to an individually-based population model. This is an update of the assessments by Reeves *et al* (2005) and Cooke *et al.* (2006; 2008). For this assessment, the model has been extended to incorporate the following additional factors: individual heterogeneity in sampling probability; time lags in the effects of environmental variability on population parameters; an explicit age-specific maturation ogive; and immigration. As in previous assessments, the sampling probability is found to be significantly stage-dependent and is lowest for immature animals. Allowing, additionally, for individual heterogeneity in sampling probability results in a very substantial improvement in model fit but has only a small effect on estimates of population size and demographic parameters. There is found to be significant inter-annual variability in both calving rates and "calf" survival rates, but no evidence of net trend in these parameters.. For these data, "calf" survival represents survival from the first summer season (~6-8mo age) to the second summer season (~18-20 mo age). The best fit to the data is obtained by introducing a 2-year time lag in the correlation between calving rates and calf survival rates: *i.e.* a low (high) calf survival rate from year *t* to year *t*+1 tends to be associated with a low (high) calving rate in year *t*+2. There is little evidence for immigration: the level of immigration is estimated to be zero or negligible in recent years, but immigration early in the period cannot be excluded. Estimates of key population parameters from the best-fitting model are 0.975 (±E 0.005) for the non-calf annual survival rate; 0.67 (±0.07) for the average calf survival rate; 11.5 yr (±1.1 yr) for the mean age at first parturition. 3.3% *per annum* (±0.5%) for the estimated realised average annual rate of population increase over the last 10 years (2002-2012); 140 (±6) whales for the 1+ (non-calf) population size in 2012 and 36 (±2) mature females in 2012. These estimates are insensitive to the choice of model. Forward projections of the population model to 2020, assuming no additional mortality or deterioration in environmental conditions, indicate a high probability (>95%) of continued population increase. The results suggest that the Sakhalin feeding aggregation has been demographically self-contained, at least in recent years, in the sense that the only new recruits are calves born to mothers within the group, even though tagging results show that Sakhalin gray whales migrate to common gray whale breeding grounds in the eastern North Pacific.

1. INTRODUCTION

Gray whales (*Eschrichtius robustus*) have been regularly reported during the summer months (June to October) off northeastern Sakhalin Island since the early 1980's (Brownell et al. 1997) and have been intensively studied there since 1997 (Burdin et al. 2013). Initially the Sakhalin gray whales were assumed to be a remnant of the western gray whale population formerly hunted in Korean and southern Japanese waters until the 1960s. The timing of gray whales catches in the Korean grounds was suggestive of a migration to a wintering ground in Asian waters. However, a whale ("Flex") tagged off Sakhalin in 2010 was followed to the waters of Oregon State, USA (Mate *et al*. 2011). Further tagging results and photo-id and genetic matches have shown that (at least some of) the Sakhalin gray whales migrate to breeding grounds in Mexican waters along with the bulk of the eastern North Pacific gray whale population (Weller et al. 2012). Whether a gray whale breeding ground in Asian waters still exists, and if so, whether any whales seen off Sakhalin migrate to an Asian

[1]Institute for Terrestrial and Aquatic Wildlife Research, Werftstr. 6, 25761 Büsum, Germany
[2]CEMS, Höllenbergstr. 7, 79312 Windenreute, Germany. Email: jgc@cems.de
[3]Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 3333 North Torrey Pines Court, La Jolla, CA, 92037-1022 USA
[4]Protected Species Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Honolulu, HI, USA
[5]Kamchatka Branch of Pacific Institute of Geography, Russian Academy of Sciences, Far East Division, Petropavlovsk, Kamchatka 683000, Russia

breeding ground is, at the time of writing, unknown but cannot be excluded on current evidence (Weller and Brownell, 2012).

An ongoing annual summer photo-identification study was initiated in 1995 as part of the Marine Mammal Project under Area V: Protection of Nature and the Organization of Reserves within the Russia-U.S. Agreement on Cooperation in the Field of Environmental Protection,. This study has been continued since 2009 by the Kamchatka Branch of the Pacific Institute of Geography (Burdin *et al*. 2013). The photo-identification data (supplemented by genetic sex determinations from biopsies) from this study are used in this paper to conduct a population assessment.

A parallel vessel-based photo-id study sponsored by the petroleum industry has been conducted off Sakhalin since 2002 by the Institute of Marine Biology, Vladivostok (Tyurneva *et al* 2013). Individuals identified off Sakhalin in both these studies have also been identified off eastern Kamchatka in summer (Tjurneva *et al* 2013) and in Mexican waters in winter (Weller *et al*. 2012; Urbán *et al*. 2012).

On the assumption that Sakhalin whales constituted a separate population, Reeves et al. (2005) conducted a population assessment using photo-id data collected through 2003. This assessment was subsequently updated by Cooke *et al*. (2006 and 2008).

The model developed by Reeves *et al*. was an individually-based model in which each individual in each year is in a given stage (such as calves, immature whales of various ages, adult males, calving females and resting females). The transition probabilities between stages, and their variation over time, are modelled and estimated.. The model was fitted to the photo-id data in an annual capture-recapture framework, where capture (i.e. photo-sampling) probabilities vary over time and between stages. It was used to estimate population size, survival, reproductive and population growth rates, and to project the population forward under various scenarios.

For this analysis, the model has been developed further to incorporate the following additional processes:

- individual heterogeneity in sampling probability (in addition to the stage-specific differences)
- time lags in the effects of environmental variability on population parameters;
- an explicit age-specific maturation ogive (to improve estimation of the mean age at first reproduction) ;
- immigration (i.e. the possibility for new whales to enter the aggregation in addition to those born to mothers within the group)

The latter issue is potentially important for the question of whether the Sakhalin whales constitute a demographically self-contained group and whether they should be managed as a unit, despite sharing breeding grounds with other gray whales.

2. MATERIAL AND METHODS

2.1. Photoidentification and sex-determination data

Photo-identification data have been collected in the summer season (June to September) in the Piltun area of north-eastern Sakhalin by the joint Russia-US programme from 1997 to the present, with some data also collected in 1994 and 1995. Since 2009 the programme has been continued by the Kamchatka branch of the Pacific Geography Institute (Burdin et al. 2013). Data from the seasons up to and including 2011 were available for this analysis. A total of 205 distinct individual whales had been catalogued as of 2011. The catalogue has been published and annually updated since 2006 (Weller *et al*. 2006).

Calves of the year (age approx 6-9 months, assuming births occur during December-January) were identified as such using the criteria specified by Bradford (2009). Associations between mothers and calves were recorded. Many of the catalogued whales have also been biopsied, enabling their sex to be determined genetically, and for apparent mother-calf relationships to be cross-checked genetically.

The following information on each identified whale was used for this analysis:

- the year first seen, and whether first seen as an accompanied calf, as an unaccompanied calf, or as a non-calf;
- the subsequent years in which the individual was seen, and the subset of years in which it was seen with a calf;
- sex, where known (determined genetically from biopsies)

Genetic sex determinations from biopsy were available for 141 whales (58 females and 83 males) for this analysis, including all but one of the whales seen with an accompanying calf. Further biopsy samples are awaiting analysis.

A total of 101 calves have been identified. Of these calves, 87 could be linked to an identified mother (in all but one case by observed association, the remaining case genetically). Of the 101 observed calves, 63 have been sexed genetically: 22 female and 41 male. Of these 63 calves, 54 were biopsied in the year that they were a calf : 18 female and 36 male.

While the observed sex ratio of non-calves may be subject to an availability bias, we assume that calves of each sex are equally available and that the sex ratio of calves, when sampled as calves, reflects the true sex ratio amongst calves. The sex ratio of these 54 calves is significantly biassed towards males ($\chi^2 = 6.0$; d.f. = 1; $p < 0.01$). Therefore, we included the sex ratio of calves as a parameter in the model, instead of assuming that was 50:50.

Twenty-nine (29) individual females, have been observed with a calf. Two of these had originally been observed as calves and are hence of known age (age 9 and 10 respectively).

A total of 58 apparent inter-birth intervals have been observed, including 31 two-year intervals, 16 three-year intervals, 5 four-year intervals, and 6 longer intervals. Because no 1-year intervals were observed, we assume that all 2- and 3-year intervals were real inter-calf intervals, but that intervals of 4-years or longer may in some cases have spanned missed calvings.

The parallel vessel-based photo-id programme has been conducted off Sakhalin since 2002 by the Institute of Marine Biology had, of 2011, also identified 205 distinct individuals. A comparison of the two photo-id catalogues showed that 187 whales were common to both catalogues (IUCN, 2013). These data were not used in this analysis (but see further comments in the Discussion).

2.2. Population model

The population model is an individually-based stage-structured population model with stages and their transitions shown in Fig. 1. The model is discrete time with a time step of one year.

The breeding females are divided into three stages: pregnant, lactating, and resting. Females are assumed not to be simultaneously pregnant and lactating. A female can become pregnant immediately following lactation , resulting in a 2-year calving interval (the minimum observed). Optionally, a female can enter the resting phase for one or more years, resulting in a 3-year or longer calving interval.

These stages are to be interpreted schematically rather than literally. "Lactating" females include all females that lactated in the given year: some may have already have weaned their calf if encountered later in the season. The "Pregnant" stage includes only those whales which will actually give birth and bring a live calf to the feeding ground the following summer. Pregnancies which fail or where the calf is lost before arrival on the summer feeding grounds cannot be separately identified by the data used and are subsumed into the "Resting" stage. The age at first pregnancy is assumed to range from 7 to 12 years (i.e. first calving from 8 to 12 years of age).

Males are arbitrarily placed into an "adult" class from age 8. The adult males play no explicit role in this model. There are assumed to be more than enough males available for mating, and furthermore the females are under no obligation to choose a mate from within the Sakhalin population. The only reason for separating adult from immature males in the model is to allow the model to account for the differential availability of immature and adult animals in the study area.

The basic version of the model contains a total of 24 living stages: calves (2 stages); immature males (7 stages); adult males (1 stage); immature females (11 stages); and adult females (3 stages). In addition, there is an unborn stage and a dead stage, making a total of 26 stages.

Where there are multiple options for transition to the next stage, these are modelled as successive binary choices, starting with the choice survive/not survive. The probability p for the first option in each binary choice is modelled as a logit function $p = e^z/(1 + e^z)$ of a linear predictor z. The model for z contains, in each case, an intercept term plus zero or more optional factors as indicated below. The probability for the second option in the binary choice is $1 - p$.

Transition to the dead stage (not shown in Fig. 1.) represents mortality. If any permanent emigration occurs, this would be subsumed into the mortality rate as far as this model is concerned. There is no explicit transition probability form the unborn stage to a calf stage. Births are treated as a life choice of the mother, not of the calf. For each birth, the mother selects an unborn animal randomly from an inexhaustible pool of unborns. Sex is assigned randomly at birth: the sex ratio at birth is a parameter of the model.

Individual (as opposed to stage-related) heterogeneity in sampling probability is modelled by assigning each individual with equal probability to one of three availability strata: low, medium and high. The sampling probability is allowed to be stratum-dependent. While each individual has an equal prior probability of belonging to each stratum, the posterior probabilities that a given individual belongs to each of the three strata will depend on the data. When such heterogeneity is included, there are 3×24 live stages, to make a total of 74 stages.

The model parameters and the factors on which they depend (or may depend) are summarised in Table 1.

Table 1. Models used for each parameter

		Core terms in linear model	*Optional terms*
Transition probabilities			
From	*To*		
Female aged *a* (*j* = 6, ..., 11)	Pregnant	intercept; age (linear)	year
Lactating	Pregnant	intercept	year
Resting	Pregnant	intercept	year
Survival probabilities			
Calves		intercept	year
Others		intercept	year
Other parameters			
Sex ratio at birth	female proportion	intercept	
Sampling probability		intercept; year	stage group; availability class
Initial population size		intercept	
Immigration		intercept; year (linear)	
Sex ratio of immigrants	female proportion	intercept	
Weaned probability		intercept	

The year effect in each case is modelled as a series of annual random effects, plus (optionally) a linear trend.

The transition probabilities to the pregnant state are referred to loosely as calving probabilities, because in this model the pregnant state includes only successful pregnancies

Immigration is optionally allowed. An "immigrant" is defined as an individual whose mother was not a member of the population. The number of immigrants is assumed to follow a Poisson distribution with an exponential trend. Immigrants are assumed to be immature animals. The sex ratio of immigrants is a parameter of the model.

To complete the model, we require a means to specify the initial numbers in each stage at the start of the modelled period. To reduce the sensitivity of the results to the initial conditions, we start the model in 1980, well before the first data in 1994. We take the 1980 population size (total across live stages) as a parameter to be estimated, while the stage distribution in 1980 is drawn randomly with replacement from the stable stage distribution implied by the deterministic version of the model (with all random effects set to zero). Sensitivity tests showed that taking the initial year further back had negligible effect on the results.

2.3. Sampling model

An animal is 'sampled' in a given year when it is photographed in that year, and the photographs have been processed and assigned to an existing known whale in the catalogue, or to a new whale which is added to the cataloguet.

The sampling probability includes a year effect (to account for varying research effort over time), and, optionally, a stage effect and an "availability stratum" effect.

For the stage effect, the stages are grouped as follows: calves; immature animals; 'adult' males; lactating females; pregnant and resting females.

To allow for the fact that some lactating females of the year have already separated from their calf when encountered, a 'weaned probability' parameter, *w*, is included in the model to represent that probability that mother and calf have separated before they are first encountered in the season. Letting p_L and p_C denote the sampling probabilities for lactating females and unaccompanied calves in a given year and stratum: the probability that a lactating whale and its calf will be seen together is: wp_L; the probability that a calf will be seen alone is wp_C; and the total probability that the calf will be seen in that year is: $(1-w)p_L + wp_C$.

The data consist of the matrix of sampling histories *H*, where an entry H_{lt} denotes the sampling result for history *l* in year *t*. The sampling result of each history in each year takes one of the following five values: (0) not seen; (1) mother with calf; (2) accompanied calf; (3) unaccompanied calf; (4) other whale. Each sighting history has an associated sex datum that takes one of three values: male; female; or unknown. The index *l* runs from 0 through *n*, where 0 denotes the null history (animals which have never been seen, and which remain unknown) and observed histories 1 through *n* where *n* is the number of individuals in the photo-id catalogue. The index *t* runs across all years for which there are data (they are not necessarily consecutive).

The sampling model enables us to calculate the array $P(j,t,k)$ of probabilities that an animal in stage j in year t will have sampling result k.

2.4. Fitting the model

2.4.1 Maximum likelihood estimation

Each individual in the population (whether observed or not) has a (hypothetical) biography, which consists of the true stage of the individual in each year. In the matrix of biographies, the entry B_{it} refers to the stage of biography i in year t.

Using the array P from sampling model of the previous section, we calculate the matrix Q defined by:

$$Q_{il} = \prod_t P(B_{it}, t, H_{lt})$$

where each entry contains the probability that an individual with biography i gets a sampling history l. The index i ranges over the set $\mathcal{B}$ of all possible biographies.

Given an expression for b_i, the prior probability (given the population model and parameters, prior to the fit to the data) for biography i, the likelihood of sighting history l is given by:

$$L_l = \sum_{i \in \mathcal{B}} b_i Q_{il}$$

We avoid calculating explicitly the probability of all possible biographies (there would be too many), and instead use the standard forward-backwards algorithm for Markovian state space models. This obtains mathematically the same result by sequentially evaluating the posterior probability distribution of the stage probability distribution for each individual in each year.

The overall likelihood of the data is customarily taken as the product of the likelihoods of the individual histories. Strictly speaking, this is not a correct procedure because births are occurring and some known individuals were born from other known individuals. Thus, even if the sampling of each individual is independent, the production of each individual is not. Any potential biasses arising from ignoring this dependence are overcome in the sampling of the Bayesian posterior distribution as described in the next section.

The overall log likelihood is taken as the sum of the sampling histories log likelihood and the residual log likelihood of the random effects, if any. The AIC (Akaike Information Criterion) is used for model comparison and selection. The effective number of parameters for the purpose of calculating the AIC is fractional when random effects are included.

Estimation standard errors for basic model parameters were determined from the variance-covariance matrix obtained by inverting the Hessian matrix at the point of best fit. Estimation standard errors for functions of model parameters were estimated using the linear approximation:

$$\mathrm{var}(f(\mathbf{p})) \simeq \left(\frac{\partial f}{\partial \mathbf{p}}\right) \mathbf{V(p)} \left(\frac{\partial f}{\partial \mathbf{p}}\right)^{\mathrm{T}}$$

where $\mathbf{p}$ is the vector of basic parameters and $\mathbf{V}$ is its variance-covariance matrix. For parameters subject to annual random effects, the process variance (sigma) of functions of the parameter is estimated using the linear approximation:

$\hat{\sigma}\left[f(p)\right] \simeq \left|df/dp\right| \hat{\sigma}_p$ where σ_p is the process variance (sigma) of the parameter p.

2.4.2. Estimation of the Bayesian posterior distribution

Once a model has been selected using AIC, the Bayesian posterior distribution of simulations of the population can be sampled. For this purpose, the population model is simulated explicitly on an individual basis, including all births and deaths. The dependence between individual biographies mentioned above is thereby automatically accounted for. The maximum likelihood estimates, obtained as described in the previous section, are used here only as an aid to efficient sampling of the posterior: the likelihood of each simulation is calculated separately. Each simulation was started in 1980 and run forward to 2020. Percentiles of key population parameters were generated.

For all parameters representing probabilities (survival and transition probabilities, and sex ratios), the prior distribution was taken to be uniform U(0,1). For all random effect variances, the prior distribution of log σ^2 was taken to be normal N(0,1).

Prior distributions for positive quantities (initial population size and immigration rate) were taken as uniform on a log scale (improper priors). Priors for trends were taken as normal N(0,1) after scaling to the length of the data series. Trends in parameters were not extrapolated beyond the data series.

3. Results

Table 2 shows the results of fitting various models in a sequential process, along with estimates of selected parameters of interest. The estimates of population parameters shown in Table 2 are fairly insensitive to the choice of model, especially once heterogeneity has been accounted for.

Case 1 represents the minimal reasonable model. The inclusion of stage-specific availability factors (case 2) substantially improves the fit (ΔAIC = − 15.6) and was therefore retained in all subsequent cases. Inclusion of individual heterogeneity in availability (case 3) further substantially improved the fit (ΔAIC = −61.0) and was retained in all subsequent cases.

Allowing variability in the calving rate (case 4) results in a further significant improvement in fit (ΔAIC = 10.1) and is retained in subsequent cases. Allowing, additionally, for independent variability in "calf" survival rate (case 5) produces only a modest improvement in fit (ΔAIC = −2.7). Having the two parameters vary in unison (through sharing the same sequence of annual random effects) (case 6) substantially worsens the fit relative to either keeping calf mortality constant or allowing it to vary independently (ΔAIC = +7.3 and +10.0 respectively). However, the fit is considerably improved if we introduce a time lag in the correlation between calving rates and calf survival rate. The best-fitting time lag is 2 years (case 8) (ΔAIC = −16.4 relative to no time lag (case 6), or −6.4 relative to no correlation (case 5)). Other time lags fit less well than 2yr lag, although a 3yr lag is less strongly rejected (ΔAIC = +2.8 relative to a 2yr lag) than other lags. Even if we adjust the AIC by +2 to allow for the fact that we are in effect treating the time lag as an additional parameter, the results still strongly reject both the unison and uncorrelated models relative to a 2yr lag. The 2yr lag was retained in subsequent fits. Allowing, additionally, an overall trend in the annual effects (case 11) does not improve the fit (ΔAIC = +0.1).

Allowing for immigration (case 12) produced a slight improvement in fit (ΔAIC = −1.9). However the estimates of immigration by year (Fig. 2b) show that immigration has been zero or negligible in recent years. For the earlier years, the data are consistent with immigration ranging from zero to a level comparable to the number of calves. It is in the nature of photo-id data that they cannot exclude immigration in the early years of a study, because new whales of all ages are encountered in the early years with no means to determine their origin. Because the results indicate that immigration has been zero or negligible at least over the most recent 10 years, and the evidence for earlier immigration is weak, we select both case 8 (no immigration) and case 12 (with immigration) into the shortlist of preferred models.

Estimates of further parameters of interest with their standard errors, and where applicable, their process standard deviations are listed in Table 3 for the two preferred models. The results show that the estimation errors are less than the process standard deviations where the latter can be estimated: the remaining uncertainty is therefore be dominated by the latter variance.

Figs 2a-b shows the estimated historical time trends from 1994 to 2012 of four population components of interest: calves; immigrants (where applicable); mature females and the total age 1+ population (*i.e.* the non-calf population, including mature females).

Figs 3a-b show various percentiles of the population trajectories of the 1+ and mature female population size from a sample of 1,000 simulations of the Bayesian posterior distribution of population simulations, projected forward to 2020, for the case (a) without immigration and (b) with immigration. Although there is estimated to be no immigration in recent times, allowing for the possibility of earlier immigration slightly increases the uncertainty in future projections, because it reduces the precision of estimates of population parameters, and ascribes some of the strong apparent growth in the early years to immigration. However in both cases there is a high (>95%) estimated probability of continued population increase forward to 2020.

4. Discussion

The results show that there is substantial heterogeneity in detection probability, both stage-related and individual-related, but it has a relatively minor impact on parameter estimates. There is compelling evidence of annual variability in both pregnancy and calf survival rates, and that these are correlated with a time lag of 2 years. The evidence is against any significant immigration in recent years, but is neutral to, or weakly in favour of, some immigration in earlier years. The estimate of "adult" (non-calf) annual survival rate at 0.975 (±0.005) implies a mortality rate of 0.025(± 0.5) . Since this parameter would reflect any permanent immigration in addition to actual mortality, its value implies that the extent of emigration, if any, is small.

The finding that variations in "calf" survival rate (from the first to the second summer season, *i.e.* between about age 8-18 months) and calving rates are correlated with a 2-yr time lag may throw light on the question of when in the reproductive process the impacts of external factors are most strongly felt. The 2yr lag implies that when calf survival from summer 20*xx*

to 20*xx*+1 is low, calf production, as recorded in summer 20*xx*+2 tends also to be low. It may be that if feeding conditions are poor in summer 20*xx*, calves of the year have trouble surviving to 20*xx*+1, and also that the mother switches from a 2yr to a 3yr breeding cycle, so that her next calf is "born" in 20*xx*+3 instead of in 20*xx*+2. (*Note*: we define the birth year as the year of the January: a calf born in December 20*xx* is assigned a birth year of 20*xx*+1). Analysis of the correlation between these parameters and time series of ecological factors know to affect gray whale survival and/or reproduction could throw further light on the question.

The estimates of small or zero immigration levels in recent years suggest that the Sakhalin gray whale population is demographically self-contained, in the sense that new entrants are almost exclusively calves of mothers from within the population.

However, the population is known, as a result of tagging, photo-identification matches and genetic matches, to share breeding grounds in the eastern North Pacific with other gray whales (Weller et al. 2012). These findings are not mutually inconsistent if there is a high degree of maternally directed feeding site fidelity. Such fidelity would also be broadly consistent with genetic information which shows a lower level of haplotypic diversity among Sakhalin whales (with 95 out of 142 animals belonging to just 2 haplotypes) than in North Pacific gray whales as a whole (Lang *et al*. 2011). The Sakhalin population is estimated in this assessment to have contained only 30 ±4 age 1+ females in 1994. Projecting back the observed growth rates to the end of commercial whaling for gray whales in the mid-1960s would imply a possible bottleneck population of less than 10 females. The presence of greater haplotypic diversity among males (Lang *et al*. 2011) could suggest that, if immigration has occurred, it was predominantly of males .

Given its apparent demographic discreteness, the Sakhalin population may continue to merit treatment as a management unit or "unit to conserve" as defined by the IWC Subcommittee on Stock Definition (Jackson and Pampouille, 2012). Given the current estimate of 35 breeding females, the Sakhalin population would merit continued listing as Critically Endangered on the IUCN Red List under criterion D in conjunction with Definition 3 (IUCN, 2001). It would not appear to qualify as a subpopulation under the 2001 criteria if there is male-mediated genetic exchange with other gray whales, but Guideline 4.2 (IUCN 2013b) suggests that it could nevertheless qualify as a subpopulation if there is found to be substantial fidelity to both feeding and breeding grounds.

For completeness we note here that an analysis of the data from the parallel photo-id team of the Vladivostok Institute of Marine Biology was presented to the May 2013 meeting of the Western Gray Whale Advisory Panel , using a slightly earlier version of the model used here (IUCN, 2013c *in prep*.). This resulted in a less optimistic population projection, with a high probability of future decline. Until the reasons for the apparent difference in results from the two datasets have been elucidated, this difference should be treated as a potential caveat to the assessment results presented in this paper.

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Table 2. Results of fitting various models to the photo-id data 1994-2011

Case	Sampling heterogeneity	Parameter variation*	Immi-gration	log-likelihood	Effective parameters	AIC	Median calf survival	Non-calf survival	Pop. growth 1992-2012**	1+ pop. in 2012
1	None	None	No	1 145.4	23.5	2 337.7	0.685	0.973	0.030	134
2	by Stage	None	No	1 133.6	27.4	2 322.1	0.691	0.974	0.033	139
3	Stage + indiv.	None	No	1 102.0	28.5	2 261.1	0.681	0.976	0.034	143
4	″	calving rate only	No	1 086.1	39.3	2 250.9	0.682	0.976	0.034	143
5	″	both, indep.	No	1 077.5	46.6	2 248.3	0.672	0.976	0.033	141
6	″	both, in unison	No	1 090.3	38.9	2 258.3	0.658	0.976	0.034	144
7	″	lag 1 yr	No	1 083.6	40.0	2 247.1	0.676	0.976	0.033	142
8	″	lag 2yr	No	1 080.6	40.3	2 241.9	0.678	0.976	0.034	142
9	″	lag 3yr	No	1 081.6	40.7	2 244.7	0.669	0.976	0.035	141
10	″	lyg 4yr	No	1 086.7	40.3	2 253.9	0.647	0.976	0.032	141
11	″	lag 2yr + trend	No	1 080.5	40.5	2 242.0	0.673	0.976	0.034	142
12	″	lag 2 yr	Yes	1 077.4	42.6	2 240.0	0.669	0.975	0.033	140

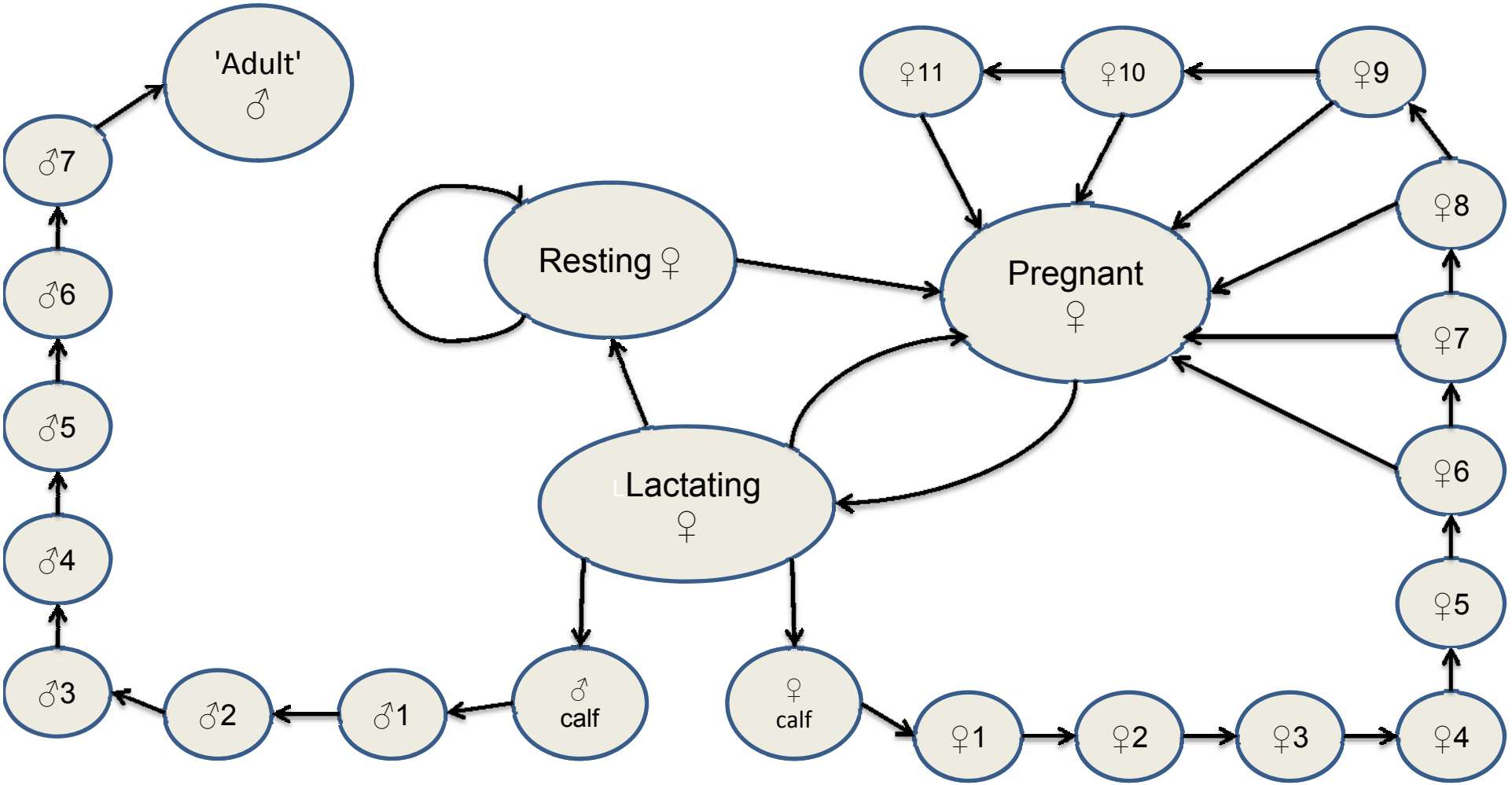
*annual variation calving rates and/or calf survival

**expressed as instantaneous rate

Table 3. Estimates of selected population parameters for the preferred models

	Case 8: no immigration			Case 12: with immigration		
Parameter	Best estimate	Estimation SE	Process SD	Best estimate	Estimation SE	Process SD
Calf survival	0.68	0.07	0.14	0.67	0.07	0.14
Non-calf survival	0.976	0.005		0.975	0.005	
Sex ratio at birth (female proportion)	0.39	0.04		0.39	0.05	
Calving probability after 2 years	0.50	0.08	0.16	0.49	0.08	0.16
Calving probability after 3+ years	0.56	0.12	0.16	0.52	0.12	0.16
Mean age at first calving (yr)	11.5	1.1		11.5	1.1	
Population growth rate 2002-2012	0.034	0.005	0.007	0.033	0.005	0.007
1+ Population size in 2012	142	6		140	6	
mature female numbers in 2012	36	2		36	2	

Fig. 1. Stage structured population model used for the analysis



Note. ♀1, ♂1, ♀2, ♂2 ... denote females/males aged 1, 2, ... years

Fig. 2a. Estimated population trajectory without immigration

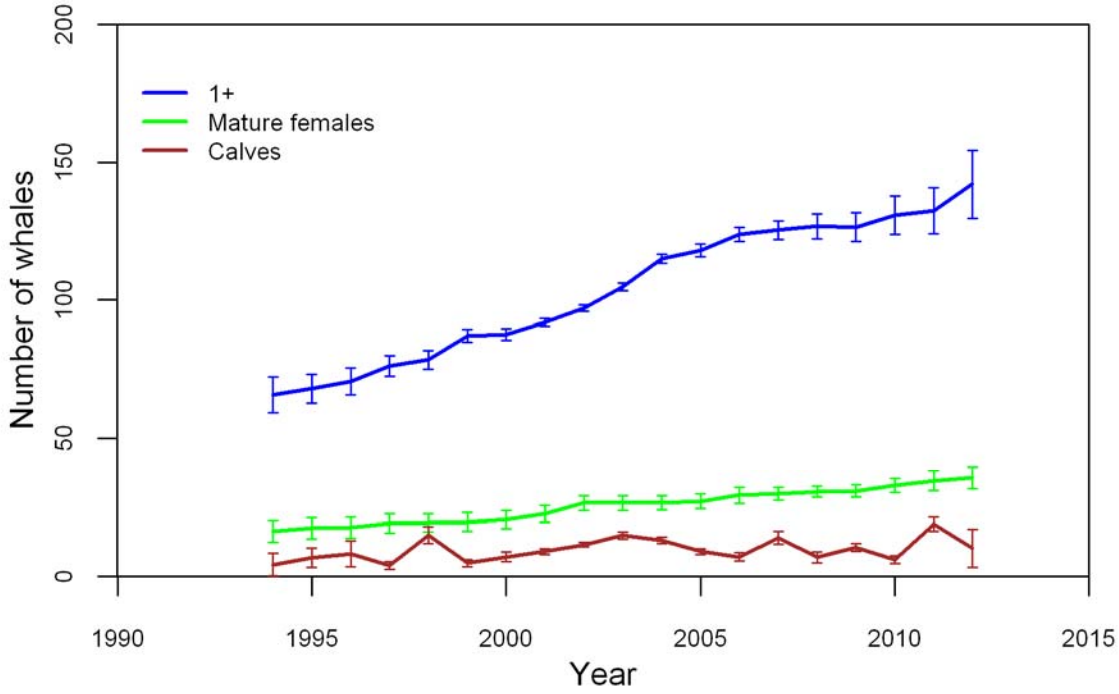


Fig. 2b. Estmated population trajectory with immigration

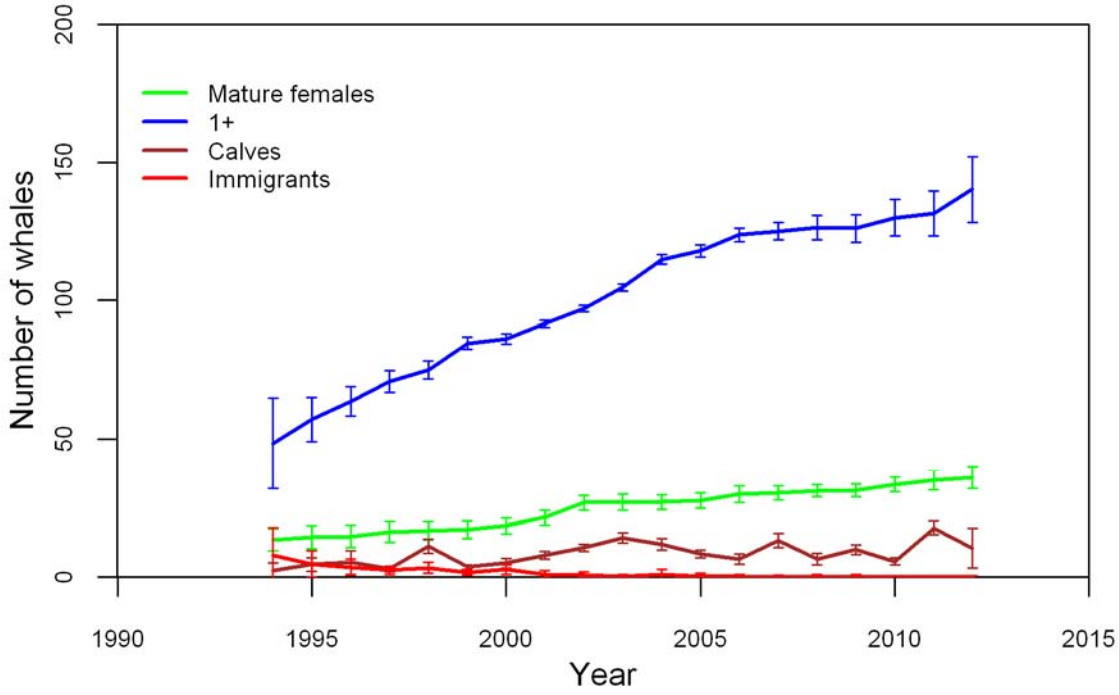
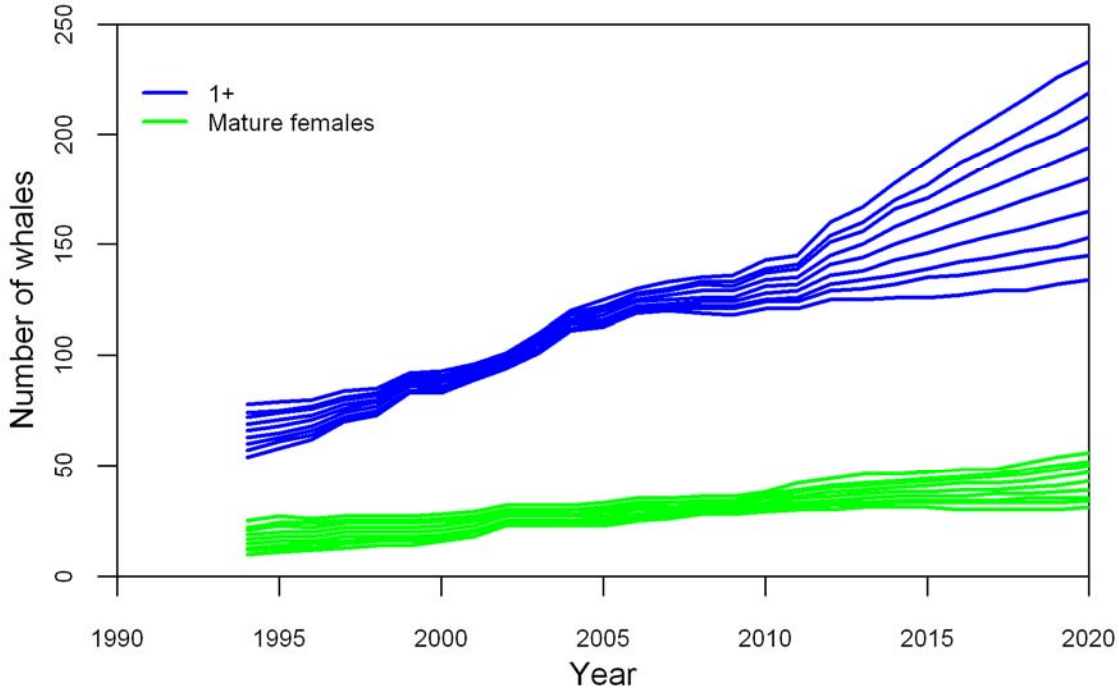
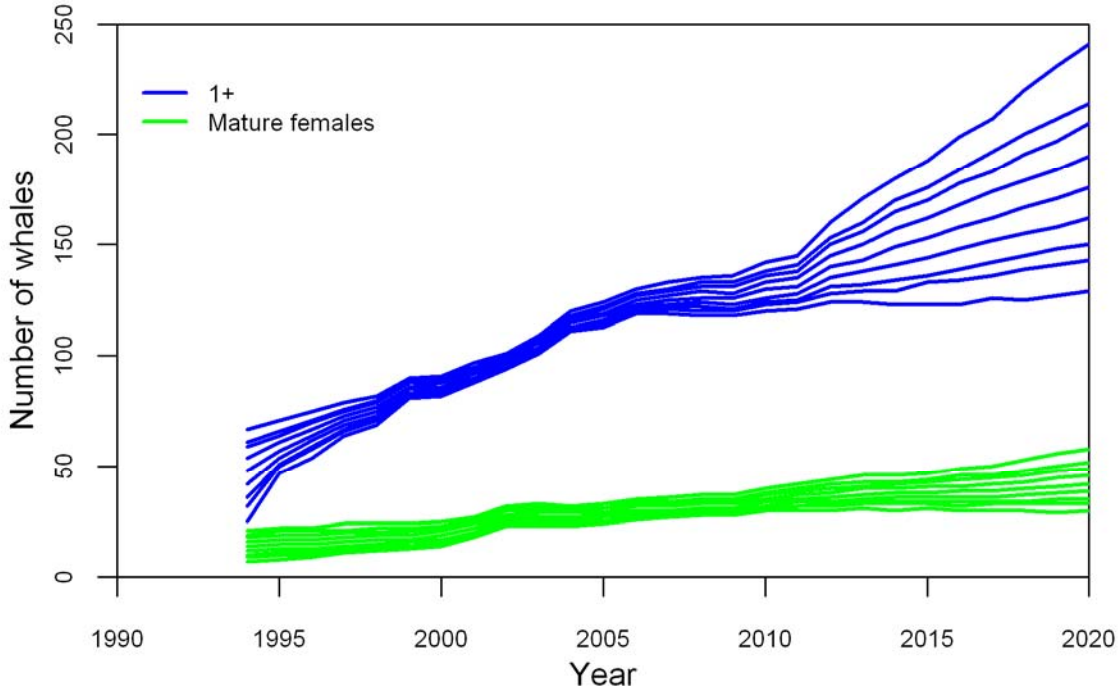


Fig. 3a. Percentiles of posterior distribution of population trajectories



a. Without immigration. Percentiles shown are: 1, 5, 10, 25, 50, 75, 90, 95, 99

Fig. 3b. Percentiles of posterior distribution of population trajectories



b. With immigration. Percentiles shown are: 1, 5, 10, 25, 50, 75, 90, 95, 99

SC/67A/NH/11

Population Assessment Update for Sakhalin Gray Whales, with Reference to Stock Identity

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Population Assessment Update for Sakhalin Gray Whales, with Reference to Stock Identity

Justin G. Cooke[1], David W. Weller[2], Amanda L. Bradford[3], Olya Sychenko[4], Alexander M. Burdin[4], Aimee R. Lang[2], and Robert L. Brownell, Jr.[2]

ABSTRACT

The population assessment of gray whales *Eschrichtius robustus* feeding off Sakhalin and Kamchatka is updated, using a population model that alows for multiple feeding and breeding areas. The model is fit to photo-id data collected of Sakhalin during 1995-2015 (Burdin *et al*. 2015), tracking of whales from Sakhalin to the eastern North Pacific (Mate *et al*. 2015), photo-id matches of gray whales between the Sakhalin and Mexico catalogues (Urbán *et al*. 2013) and reported photo-id results from Kamchatka collected during 2004-12 (Yakovlev *et al*. 2013),. The results show that the Sakhalin and Kamchatka feeding populations have been increasing at 2-5% per year over the 10 or 20 years to 2015. The number of non-calf whales in 2016 is estimated to be 320−410, of which 130−170 are predominantly Sakhalin-feeding whales or 180−220 are whales that feed at least occasionally off Sakhalin. A test of the population model output against the results of a paternity analysis by Lang (2010) just rejects the hypothesis of genetic closure of the Sakhalin feeding population ($p < 0.05$) but does not reject the hypothesis of genetic closure of the Sakhalin and Kamchatka feeding populations combined.

Of the predominantly Sakhalin-feeding whales, an estimated 0-50 belong to a possible relict western North Pacific breeding population (which may or may not be genetically closed). Using the IUCN Red List criteria, the Sakhalin and Kamchatka populations, if assessed as a subpopulation, either separately or together, would be classified as Endangered, on the basis of there being between 50 and 250 mature individuals (i.e. ~100-500 individuals when juveniles but not calves are included). If the relict western North Pacific breeding population were assessed as a subpopulation, it would be classified as Critically Endangered, on the basis of there being less than 50 mature individuals.

1. INTRODUCTION

Gray whales (*Eschrichtius robustus*) have been regularly reported during the summer months (June to October) off northeastern Sakhalin Island since the early 1980's (Brownell *et al*. 1997) and have been intensively studied there every year since 1995 (Burdin *et al*. 2015). Initially the Sakhalin gray whales were assumed to be a remnant of the western gray whale population formerly hunted in Korean and southern Japanese waters until the 1960s. The timing of gray whales catches in the Korean grounds was suggestive of a migration to a wintering ground in Asian waters (Kato and Kasuya 2002). However, tagging results and photo-id and genetic matches have shown that at least some of the Sakhalin gray whales migrate to breeding grounds in Mexican waters along with the bulk of the eastern North Pacific gray whale population (Mate *et al*. 2015; Weller *et al*. 2012). Many individuals observed off SE Kamchatka during 2006-11 have been matched with those off Sakhalin (Yakovlev *et al*. 2013, 2014) and some have been matched with whales seen in Mexico.

In an analysis of the data on movement between Sakhalin and the eastern North Pacific, including data from satellite tagging of individuals and photo-id matches between Sakhalin and Mexico, Cooke (2016)

[1]CEMS, Höllenbergstr. 7, 79312 Emmendingen, Germany. Email: jgc@cems.de
[2]Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 3333 North Torrey Pines Court, La Jolla, CA, 92037-1022 USA
[3]Protected Species Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Honolulu, HI, USA
[4]Kamchatka Branch of Pacific Institute of Geography, Russian Academy of Sciences, Far East Division, Petropavlovsk, Kamchatka 683000, Russia

concluded that 30-100% of Sakhalin whales migrate in winter to the eastern North Pacific. Thus, those data alone could not confirm or exclude the possibility of a western breeding migration.

However, sightings of Sakhalin-matched gray whale of the Pacific coast of Japan in spring are suggestive of the possibility that at least some of the gray whales seen off Sakhalin undertake a western North Pacific migration that may lead to a western North pacific breeding area whose location is unknown (Weller *et al*. 2016).

On the assumption that Sakhalin whales constituted a separate population, Cooke *et al*. (2016), using photo-id and biopsy data from the Russian Gray Whale Project (Burdin *et al*. 2015), estimated that the feeding aggregation off Sakhalin contained about 175 non-calf individuals by 2016 (although not all of these would be present every year), and had been growing at 2-4% per year.

In this note, the previous assessment is expanded to include additional information, including satellite tag data (Mate *et al*., 2015), photo-id data collected off Kamchatka, as reported by Yakovlev *et al*. (2013, 2014), and matches between Sakhalin and Mexico (Urbán *et al*., 2012). The results of the assessment are also compared with the results of a paternity analysis by Lang (2010), to test the hypothesis of genetic closure of the separate or combined feeding populations.

2. MATERIAL AND METHODS

2.1. Data

2.1.1 Photoidentification and sex-determination data

Photo-identification data from the Russian Gray Whale Project were available for each summer season (June to September) from the Piltun area of north-eastern Sakhalin from 1997 to 2015, with some data also collected in 1994 and 1995. A total of 248 distinct individual whales had been catalogued as of 2015. The catalogue has been published and annually updated since 2006 (Weller *et al*. 2006). Yakovlev *et al*. (2012, 2013) list a total of 155 distinct whales identified off SE Kamchatka, of which 85 were matched with whales seen off Sakhalin.

Genetic sex determinations from biopsy were available for 179 whales (89 males and 67 females) for this analysis. A total of 132 calves have been identified. Of these calves, 117 could be linked to an identified mother (in all but one case by observed association, the remaining case genetically). Of the 132 observed calves, 76 have been sexed genetically: 30 female and 46 male.

2.1.2 Tracking and long-range matching data

The three records of known whales successfully satellite-tracked from Sakhalin to the eastern North Pacific (Mate *et al*. 2015) were used.

17 matches between the Sakhalin catalogues and the San Ignacio lagoon catalogue for the years 2006-12 were found (Urbán *et al*. 2013). Of these, 15 were known to be alive as of 2011, of which 13 were known to be born in 2000 or earlier. Because of the low rate of matching of other whales, only whales satisfying these age criteria (born before 2000) and survival not satisfying these age and survival criteria (alive in 2011) were treated as candidates for matching with Mexico.

2.1.3 Paternity

A paternity analysis by Lang (2010) used genotypes collected from 57 mother-calf pairs up to 2007 and compared these with the genotypes of up to 83 males (of which some could be excluded as being too young to sire a calf) to establish paternity. Depending on the criteria used to determine paternity, 26-30 paternities were assigned to known genotyped animals, comprising 17-18 distinct fathers. These data were not used in the model of this paper, because paternity does not directly affect population dynamics, but the estimated population trajectories were compared with the results of Lang's paternity analysis to test the hypothesis of genetic closure.

2.2. Model structure

2.2.1 Basic (single-stock) population model

The core population model is as used by Cooke *et al*. (2016). It is an individually-based stage-structured population model, working in discreet time with a time step of one year.

The reproductive females are divided into three stages: pregnant, lactating, and resting. Females are assumed not to be simultaneously pregnant and lactating. A female can become pregnant immediately following lactation, resulting in a 2-year calving interval (the minimum observed). Optionally, a female can enter the resting phase for one or more years, resulting in a 3-year or longer calving interval. The minimum age at first (successful) pregnancy is 7 years; thereafter, the probability of becoming pregnant is assumed to increase as a logistic function of age, reaching a plateau at age 12.

Immigration is optionally allowed. An "immigrant" is defined as an individual whose mother was not a member of the population. A random number of immigrants enter the population independently each year. Immigrants are assumed to be immature animals. The sex ratio of immigrants is a parameter of the model.

The basic version of the model contains a total of 24 living stages: calves (2 stages: male and female); immature and maturing males (11 stages); adult males (1 stage); immature and maturing females (11 stages); and adult females (3 stages). In addition, there is an unborn stage, a "freshly dead" stage (where a carcass might be found and identified), and a "dead and buried" stage (no further possibility of being found), making a total of 27 stages in the core set.

2.2.2 Multi-stock population model

The main new feature of this analysis is the introduction of multiple feeding and breeding populations.

The "Sakhalin" feeding population is defined to consist of the whales that feed predominantly off Sakhalin but may also be seen off Kamchatka, and possibly in other areas. The "Kamchatka" feeding population is defined as whales that feed predominantly off SE Kamchatka but may also be seen off Sakhalin or in other areas. The two feeding populations are modelled by allowing individuals to have differing probabilities of being encountered in the two areas. These probabilities are determined by the parameters of the sampling model (see below) that are estimated by the data. Many individuals have been seen in both feeding areas, so the two feeding populations are not completely separate. The degree of separation is estimated by the model.

Two breeding populations are assumed: western North Pacific (WNP) and an eastern North Pacific (ENP). The Sakhalin feeding area is assumed to contain a mix of ENP and WNP whales, while the Kamchatka feeding area is assumed to contain only ENP whales. The population is divided into are three feeding/breeding subpopulations: (1) WNP breeding population, feeding off Sakhalin; (2) ENP breeders that feed predominantly off Sakhalin; and (3) ENP breeders that feed predominantly off Kamchatka. In each year, whales in each of the three subpopulations can be in any of the above 27 stages, which results in 81 possible states for each whale. The relative abundance of ENP and WNP whales, and of Sakhalin and Kamchatka feeders, are parameters of the model.

The meaning of "predominantly" is not fixed in advance. The sampling probabilities of whales in each group in each area are parameters of the model, as are the relative numbers of whales in each group. Individuals are not assigned definitively to either group, but the posterior likelihood of each whale belonging to each group depends in its sampling history, and is estimated together with all the parameters of the model.

The possibility that some Kamchatka-feeding whales belong to the WNP breeding population was not considered in this analysis, although in principle this would be possible.

2.2.3 Sampling model

2.2.3.1 Photo-id sampling

An animal is 'sampled' in a given year when it is photographed in that year, and the photographs have been processed and assigned to an existing known whale in the catalogue, or to a new whale which is added to the catalogue. A lactating (or post-lactation) female may be sampled alone or with its calf; likewise, a calf may be sample alone or with its mother. The probability that a mother-calf pair has separated before it is recorded is a parameter of the model.

An animal may be sampled off Sakhalin, off Kamchatka or off Mexico. The sampling probabilities off Sakhalin and Kamchatka are parameters of the model allowed to vary by year, location, stage and individual. Individual (as opposed to stage-related) heterogeneity in sampling probability is modelled by assigning each individual with equal probability to one of a number of availability strata. The sampling probability may also depend on various interactions between the above factors, as determined by the model-selection process.

The required number of strata is determined by the model-selection process (see below). When there are m strata, each whale can be in a total of $81m$ different states.

The sampling probability for Mexico was estimated externally by Cooke (2016). The sampling probability of an "adult" whale (i.e. one meeting the age criteria defined above) in the Mexican breeding grounds was estimated at 0.054 per year, or 0.32 in total for the years 2006-12 combined. There may be scope for refining this estimate.

2.2.3.2 Satellite tracking

We assume that the tracking success probability is independent of breeding location. That is, we assume that if the three whales tracked from Sakhalin to the eastern North Pacific had instead migrated south in the western North Pacific, they would have been tracked there too. With this assumption, we condition on the actual number and identity of whales successfully tracked, and do not need to model the tracking probability.

This approach implies a qualitative difference in the evidentiary value of satellite-tracked animals versus long-range photo-id matches: for photo-id, the relevant sampling probability must be known or estimated, but this is not necessary for tracked animals.

2.3. Likelihood, model fitting and model selection

Table 1 lists the factors/terms included in each of the alternative models fitted. Each model was first fitted by maximum likelihood (REML) to produce estimates of model parameters and of the population trajectory. The factors/terms to include in the model were selected using the AIC criterion, to identify a preferred model. The Bayesian posterior distribution of the population trajectory was sampled for the preferred model. Full details of the model and fitting procedure are given by Cooke *et al*. (2016).

In summary, each individual has a range of potential biographies, each of which consist of a time series of its putative true state in each year. Some aspects of the state are assumed to remain constant over its lifetime, such as sex and membership of a feeding and/or breeding group. Other aspects, such as age, reproductive status, live vs. dead, change from year to year according to the transition probabilities.

In addition, each individual has an observed history. The observed history may be null for some individuals (i.e. individuals that exist but have not yet been sampled). The likelihood is calculated by comparing each putative biography with the observed history. Some aspects of the comparison are probabilistic. For example, whether an individual is sampled in a given area in a given year: the likelihood depends on the relevant sampling probabilities. Other aspects, such as sex or membership of a breeding stock, are of an either/or nature. For example, if a whale is tracked to the eastern North Pacific, all its potential biographies that involve it being a western breeder get assigned a zero likelihood. Likewise, if a whale is determined through genetic sampling to be male, all the potential biographies that involve it being female get assigned a zero likelihood.

2.4. Testing genetic closure

No paternity data were used in the model-fitting process, because paternity is assumed not to affect population dynamics. However, the output of the preferred model was used to compute the expected distribution of number of identified paternities under the assumption that all paternities were from within the population (genetic closure) and there is random mating. This was compared with the observed number of identified paternities in order to test the genetic closure hypothesis. A range of 7-12 years was assumed for the age of effective reproductive maturity for males.

Two genetic closure hypotheses were tested: (i) paternities are within each feeding population; (ii) paternities are not necessarily within each feeding population, but are within the two feeding populations combined.

For each hypothesis, the comparison was performed by generating a random sample of 500 realizations from the posterior distribution of the individually-based population trajectories. In each realization, the father of each calf included in Lang's paternity analysis was selected randomly from the pool of potential fathers under the given hypothesis (i.e. reproductively mature males alive in the given population in the year of conception of the calf – assumed to be 1 year before the birth year). The size of the subset of these assigned fathers that were included in the genetic sample used in Lang's analysis was recorded for each realization. This produces a posterior distribution for the predicted number of known paternities, which can be compared with the observed number.

3. RESULTS

3.1. Model selection

Table 1 shows the results of fitting various models sequentially. Case A represents the minimal reasonable model, because the sampling probability is a function of the effort expended in each area by year. The inclusion of separate feeding populations differentially sampled in the two areas (case B) improves the fit very substantially (ΔAIC = −701) and shows that the two areas (Sakhalin and Kamchatka) cannot be treated as an homogenous unit. Including stage-specific availability factors (case C) improves the fit (ΔAIC = −8.3) and this factor was retained. Allowing for interaction between location and stage (case D) improves the fit substantially (ΔAIC = −147). Allowing for individual heterogeneity in the sampling probability by location and population using 5 strata (case E) substantially improved the fit further (ΔAIC = –151). Allowing for the pregnancy rate to vary by year (case F) also improved the fit (ΔAIC = −18,7), and this factor was retained. Including annual variation in calf mortality (case G) worsened the fit (ΔAIC > 0); this factor was not retained. Reducing (case H) or increasing (case I) the number of strata led to a worse fit in each case (ΔAIC > 0). The original choice of 5 strata for modelling individual heterogeneity was therefore retained. Allowing for immigration (whales born to mothers outside the population) into the two populations (case J) worsened the fit (ΔAIC > 0).

Table 1. Results of fitting various models in a sequential process.

Case	Model	AIC
A	Sampling:Location.Year	5 027.4
B	A + Sampling:Location.Population	4 326.1
C	B + Sampling:Stage	4 317.9
D	C + Sampling:Location.Population.Stage	4 170.8
E	D + Sampling:Location.Population.Stratum(5)	4 019.9
F	E + Pregnancy:Year	4 001.2
G	F + CalfSurvival:Year	4 029.7
H	F with 3 strata	4 019.4
I	F with 8 strata	4 044.6
J	F + Immigration:Population	4 020.3

The preferred model was, therefore, case F, where the sampling probability depends on interactions between location, feeding population and stage and between location, feeding population and stratum, and there is annual variability in pregnancy rate, but no annual variability in calf survival, and no immigration.

3.2. Population size and trajectories

A random sample of 50 trajectories from the posterior distribution of population trajectories is shown in Fig. 1 for (a) the aged 1+ population and (b) reproductive females only. In each plot the trajectories are shown for (i) the entire Sakhalin and Kamchatka feeding population; (ii) the Sakhalin feeding population only; and (iii) the western North Pacific breeding subset of the Sakhalin feeding population.

In contrast to the results of Cooke *et al*. (2016) no annual variability in the calf survival rate was found. The cause of the difference appears to be inclusion of data from Kamchatka: some of the calves which went "missing" from Sakhalin and would have been presumed dead in the analysis of Cooke *et al* (2016), were sighted alive in Kamchatka. The "pregnancy rate" (strictly, the production rate of live calves that survive their first migration to the feeding grounds) was, as before, found to show significant annual variability.

The results show that the Sakhalin and Kamchatka feeding populations have been increasing at 3-5% p.a. over the 10 (or 20) years to 2015. The total aged 1+ (non-calf) population for the combined is estimated at 321−412 whales in 2016 (95% confidence interval). The exclusively and predominantly Sakhalin-feeding population is estimated at 133−168 non-calf whales in 2016.

The new estimate for the Sakhalin feeding population is slightly lower than the estimate of 158−193 by Cooke *et al.* (2016) but the earlier analysis defined the Sakhalin population to include all whales that visit Sakhalin at some time in their lives, including those who visit only occasionally. The new estimate is for predominantly Sakhalin-feeding whales. Using the previous definition, the new estimate for the Sakhalin population in 2016 would be 182−222.

These estimates for Sakhalin whales include both eastern and western North Pacific breeders, if there are any. If the Sakhalin whales contain a subgroup that breeds in the western North Pacific, this part is estimated to have contained up to 50 whales in 2016 (95% CI 2−47). Because the model input contains no definite records of a western breeder, the posterior distribution for the number of western breeders essentially runs from zero to a (probabilistic) upper bound determined by the number of definite eastern breeders that have been observed.

3.3. Genetic closure

The predicted number of paternities was found to be insensitive to the choice of male age at first reproduction, varying by only about 1 paternity across the range 7-12 for male age at first reproduction. This uncertainty was subsumed into the confidence intervals for each hypothesis.
On the assumption that mating occurs only within each feeding population, the population model predicts, with 95% probability, 31−47 identified paternities on Lang's (2010) sample; if mating is random across the two feeding populations combined, the model predicts 14−27 identified paternities.

The observed value of 26−30 lies between the above two ranges. The result suggests that there is preferential, but not exclusive, mating within the Sakhalin feeding aggregation. The hypothesis of mating exclusively within the Sakhalin feeding population is just rejected ($p < 0.05$). We conclude that the Sakhalin feeding aggregation is probably not genetically closed but that the Sakhalin and Kamchatka feeding aggregations, taken together, may be genetically closed. However, genetic data from Kamchatka would be required to confirm this.

4. DISCUSSION

If these population estimates were used to update the IUCN Red List status, and either just Sakhalin or Sakhalin and Kamchatka whales are considered to constitute a distinct subpopulation, then their status would be Endangered, on the basis of there being more than 50 but less than 250 mature animals (mature animals make up about half the population). If there is a distinct western North Pacific breeding stock, this

would be classified as Critically Endangered, because the range of estimates for the number of mature animals is well below 50. Obtaining further information on the existence, nature and status of the relict western North Pacific breeding population is clearly a high priority.

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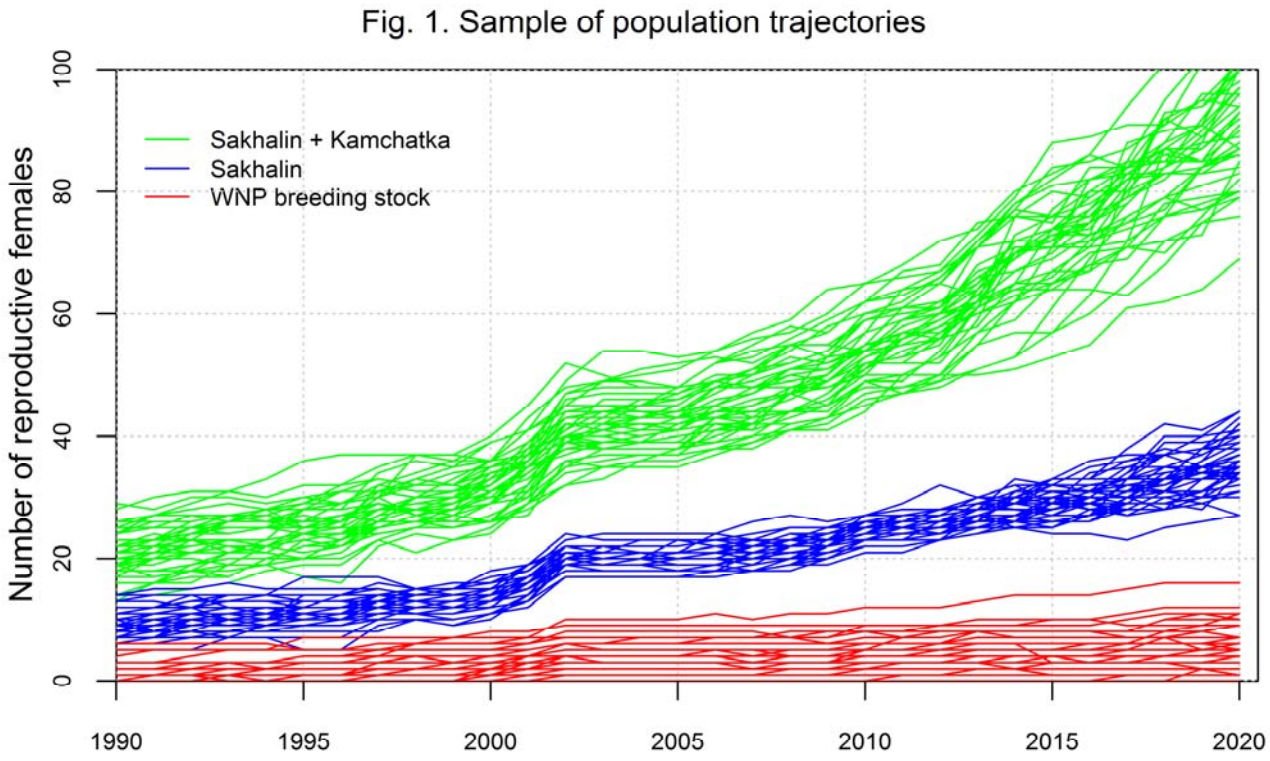

Fig. 1a. Sample of 50 trajectories from the posterior distribution for the preferred model. Reproductive females.

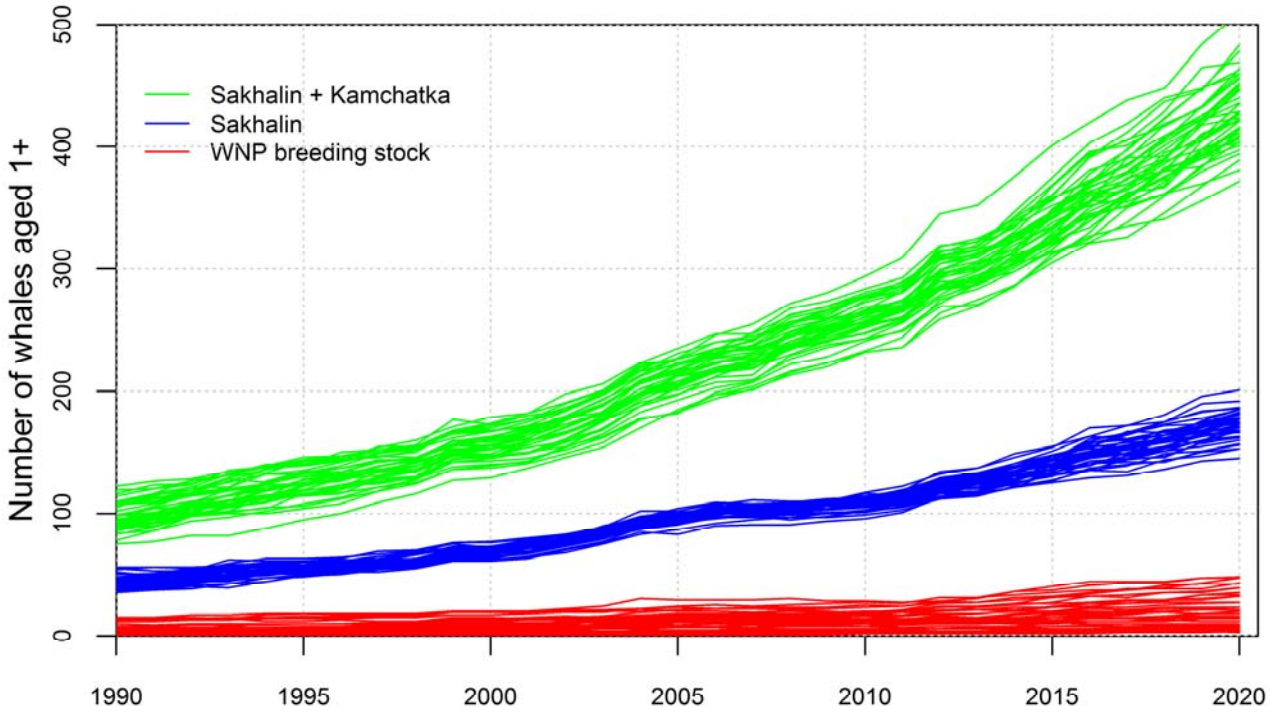

Fig. 1b. Sample of 50 trajectories from the posterior distribution for the preferred model. All animals aged 1+.

SC/67B/ASI/02

Abundance estimates for western North Pacific gray whales for use with stock structure hypotheses of the Range-wide Review of the Population Structure and Status of North Pacific gray whales

Justin G. Cooke

INTERNATIONAL WHALING COMMISSION

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Abundance estimates for western North Pacific gray whales for use with stock structure hypotheses of the Range-wide Review of the Population Structure and Status of North Pacific gray whales

Justin G. Cooke[1]

ABSTRACT

Abundance estimates are derived for western North Pacific gray whales *Eschrichtius robustus* that correspond to the various stock structure hypotheses developed by the IWC Scientific Committee's Range-wide Review of the Population Structure and Status of North Pacific gray whales (IWC 2018a), by fitting an individually-based population model to photo-id data and other data collected off Sakhalin, Kamchatka and Mexico. Abundance estimates are presented for the putative Western Feeding Group and Western Breeding Stock in 1995 and 2015. Abundance estimates for the Western Feeding Group in 2015 range from about 130 to about 300 whales (aged 1 yr and over) depending on stock structure hypothesis, while abundance estimates for the putative Western Breeding Stock are all less than 100.

1 INTRODUCTION

This paper presents abundance estimates for gray whales in the western North Pacific that correspond to the various stock structure hypotheses developed by the IWC Rangewide Workshops on North Pacific Gray Whales (IWC 2018a). Estimates corresponding to some further plausible stock structure hypotheses are also presented.

To derive the esitmates, an individually-based model is fitted to photo-id data collected during 1995-2016 from Sakhalin Island and Kamchatka Peninsula (Burdin et al. 2017; Yakovlev et al. 2013, 2017), supplemented with sex determinations from biopsies (Lang 2010), photographic matches with wintering grounds in Mexico during 2006-12 (Urbán *et al*. 2012; 2013), and satellite tracking of some tagged individuals from Sakhalin towards their wintering grounds (Mate et al. 2015).

The generic individually-based population model structure and the method of fitting to data is specified in Appendix I. The specific implementation choices used for western North Pacific gray whales are described in the Methods section.

2 METHODS

2.1 Stock structure hypotheses

The stock structure hypotheses developed by the 4th IWC Rangewide Workshop on North Pacific Gray Whales (IWC 2018a) which were still under consideration for consideration after the 5th Workshop (IWC 2018b) are hypotheses 3a, 3b, 3c, 3e, 5a, 6b listed in Table 6 (JCRM 19(Suppl.):528).

The hypotheses posit the existence of up to two breeding stocks: an eastern breeding stock (EBS) which winters off Mexico, and possibly a western breeding stock (WBS) which winters at one or more locations in Asian waters. The hypotheses also posit the existence within the eastern breeding stock of a western feeding group (WFG) which visits Sakhalin and Kamchatka in summer, and a northern feeding group (NFG) which feeds in the Bering and Chuckchi Seas and possibly also off SE Kamchatka.

Of these, hypotheses 3a, 3c, 3e posit only a single breeding stock, and are mutually indistinguishable with respect to the data collected on western North Pacific gray whales.

Hypothesis 6b posits a western breeding stock (WBS) but it only occurs in areas for which no data are available, and is therefore effectively invisible with respect to the available datasets. With regard to observed whales in the western North Pacific, 6b is indistinguishable from the hypotheses with just one breeding stock (3a/3c/3e).

[1] *Centre for Ecosystem Management Studies, Höllenbergstr. 7, 79312 Emmendingen, Germany. Email: jgc@cems.de.*

In order to implement the hypotheses, whales occurring off Sakhalin and Kamchatka were divided into four subgroups, whose numbers are to be estimated from the data:

Table 1. feeding subgroups defined for the purpose of implementing stock structure hypotheses

Subgroup	Description
S	Whales that visit Sakhalin but not Kamchatka
SK	Whales that visit Sakhalin and occasionally Kamchatka
KS	Whales that visit Kamchatka and occasionally Sakhalin
K	Whales that visit Kamchatka but not Sakhalin

The hypotheses and their definitions are listed in Table 2. In all the hypotheses considered by IWC (2018), whales seen off Sakhalin include WFG whales and possibly also WBS whales. Whales seen of SE Kamchatka include WFG whales and possibly also WBS and NFG whales. The hypotheses considered by IWC (2018) do not allow for the possibility that all whales seen off Kamchatka belong to the WFG. In view of the lack of evidence that any Kamchatka whales belong to the NFG, two further hypotheses were added (8 and 9) in which there are no NFG whales off Kamchatka.

Table 2. Definitions of stock structure hypotheses in terms of affiliations of feeding subgroups

Hypothesis	Description	WBS	WFG	NFG
3a/3c/3e	One breeding stock, some NFG in K		S, SK, KS	K
3b	Two breeding stocks, WBS in K	K	S, SK, KS	
5a	Two breeding stocks, some NFG in K	S, SK	S, SK, KS	K
8	One breeding stock, no NFG in K		S, SK, KS, K	
9	Two breeding stocks, no NFG in K	S, SK	S, SK, KS, K	

In each case, the initial population sizes of each feeding subgroup/breeding stock combination were modelled using a log-linear model with one intercept parameter with a uniform prior, plus a random effect term for the feeding subgroup/breeding stock combination.

2.2 Data

2.2.1 Photo.identification

Sampling with photo-identification was conducted in the summer feeding grounds off NE Sakhalin during 1995-2016 and off SE Kamchatka during 2004-12. There were two research teams working off Sakhalin and one off Kamchatka. Off Sakhalin, the Russian Gray Whale Project (RGWP, Pacific Geography Institute, Petropavlovsk, Kamchatka; a continuation of the former Russia-US project) has been collecting data since 1995 ((Burdin et al. 2017), and the Marine Biology National Research Center , (MBNRC, Vladivostok; formerly Institute of Marine Biology, IBM) has been collecting data since 2002 and cross-matched the results with photos from Kamchatka (Yakovlev et al. 2013, 2017).

A total of 287 distinct whales had been identified through the 2011 season, based on cross-matching of the individuals observed by each team. During 2012-2016, a further 56 whales were seen by the RGWP team and 73 whales by the MBNRC and Kamchatka teams, which have not been cross-matched.

Sampling also occurred in the wintering grounds off Baja California, Mexico. Because theses grounds are shared with the more numerous eastern North Pacific gray whales, only individuals matched with the western North Pacific were included in the analysis. Cross-matching was conducted between whales identified in Mexico during 2006-12 and all whales in the Sakhalin and Kamchatka catalogues up to 2011 (Urbán et al. 2012, 2013).

Because the matching rate in Mexico appeared to be strongly age-specific, only animals known to be at east 6yr old were considered as potentially samplable in Mexico, and only matches from those animals were used, for the reasons explained by Cooke (2016). Of 17 whales matched between Sakhalin and Mexico, 16 met this criterion. Of a further 4 whales matched between Kamchatka and Mexico, 2 met this criterion.

2.2.2 Additional features recorded

The additional features recorded for at least some identified animals were: sex; mother/calf status; breeding stock affiliation.

Sex. Sex was determined by biopsy for a total of 167 whales, including 156 by the RGWP project, 23 by the MBNRC project, and 12 by both projects. Of the 12 individuals sexed by both projects, 11 agreed with respect to sex. The one

whale without agreement was deemed to be female, because it had been biopsied as female by the RGWP project on four separate occasions. Sex determination is assumed for modelling purposes to be 100% accurate.

Cow/calf status. Of 3,602 encounters of living whales off Sakhalin and Kamchatka (where "encounter" means an individual identified at least once by a team in a season) 205 were of cow-calf pairs and 71 were unaccompanied calves. It is assumed that all cow-calf pairs and accompanied calves were correctly identified by the RGWP team from 1995 and by the MBNRC team from 2003. The mother/calf status was not recorded by the MBNRC team in 2002. It is assumed that all unaccompanied calves were correctly identified by the RGWP team from 1995 and by the MBNRC team from 2007, which used the same criteria from this date. For the years 2003-06, MBNRC unaccompanied calf identifications were not used (they were treated as indistinguishable from other whales).

Of the 23 matching identifications from Mexico that were used in this analysis, 8 were of cows accompanied by calves, but the calf identifications were not available for this analysis.

Breeding stock affiliation

Three individuals sighted off Sakhalin were successfully tagged and tracked to the eastern North Pacific (Mace et al. 2015). It is assumed that the successful long-term tracking of an individual reveals its breeding stock affiliation (eastern or western). Individuals sighted in Mexico are also assumed to belong to the Eastern Breeding Stock (EBS).

2.3 Population model

The structure of the generic population model structure and the method of fitting to data is specified in the Appendix. The specific implementation choices used for western North Pacific gray whales are described here.

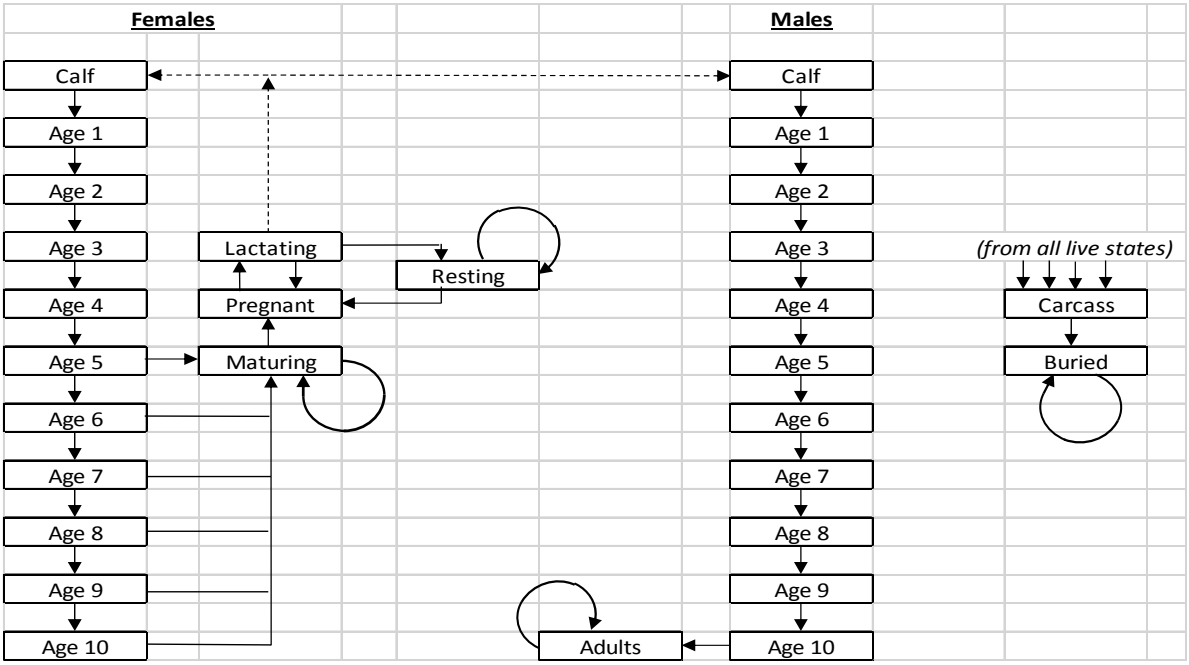
2.3.1 State space

The following attributes are represented in the state space:

- Life stage (sex, age and reproductive status, mortality status)
- Feeding subgroup affiliation
- Breeding stock affiliation
- Sampling availability (reflection of individual heterogeneity in capture probability)

The life stages and the possible transitions are shown in Table 3. Animals in any of these stages can die by entering a "carcass" state, where they have a (typically small) probability of being recovered and identified. From the following year they are assumed to be unobservable ("buried").

Table 3. List of living stages in the gray whale model



The youngest allowed age for a pregnant whale is 7 years and the youngest age for a lactating whale is 8 years. In the summer season, the "Age *x*" stage contains animals aged approximately x + ½ .

Feeding group and breeding stock affiliations are assumed to be maternally inherited and to remain constant throughout life.

Individual heterogeneity in availability was modelled using 1,3 or 5 availability classes. Each whale is born into a random class with equal probability. The individual availability class is assumed to be retained throughout life but not to be heritable. The purpose of including these classes is to reduce the bias in abundance estimation arising from capture probability heterogeneity.

2.3.2 Reproduction, mortality and other transitions

Each animal in the lactating stage has exactly one calf, assumed to be male or female with equal probability.

The calf mortality is modelled as a constant plus an optional annual random effect. The non-calf mortality rate is assumed to be constant.

The transition probability to the maturing class is assumed to be constant. The transition probability to the pregnant stage depends on the source stage (maturing, lactating or resting) plus an optional annual random effect.

2.4 Sampling model

2.4.1 Primary and secondary sampling occasions

The sampling in a season by a research team is treated as sampling occasion. Up to and including the 2011 season, each season of sampling by each team off Sakhalin and Kamchatka is treated as a primary sampling occasion (see Appendix section 2.1 for the definition). From 2012, two options were considered: (i) RGWAP team as primary team throughout, MBNEC and Kamchatka teams secondary from 2012; (ii) MBNRC and Kamchatka teams are primary throughout, RGWAP secondary from 2012.

Individuals sighted up to 2011 by a non-primary team only were treated as "identity lost" (see Appendix section 2.4) from 2012 onwards, because they might, unknown to the analysis, match whales seen by the primary team for the first time in 2012 or later. Sampling occasions in Mexico during 2006-12 are treated as secondary, because only whales matched with Sakhalin or Kamchatka were used.

2.4.2 Capture probability models

The capture probability model for the summer sampling includes a free parameter for each sampling occasion (team by year), and a parameter for each combination of feeding subgroup and location, where "location" means Sakhalin or Kamchatka. That is, each feeding subgroup may be differentially catchable in each location.

The summer capture probability model also contains optional random-effect terms for life stage, life stage × team interaction, and availability class. The life stages for this purposes were summarized into five stages: calves, subadults, lactating mothers, other mature females, and mature males.

The capture probability for the Mexican wintering grounds was estimated externally of this model, because the great majority of the animals there are eastern North Pacific gray whales. The average annual capture probability was estimated to be 0.054 (Cooke 2016).

Because only three identified carcasses were observed, a single value for the capture probability of carcasses was estimated. Unidentified carcasses were not used: each year, the observation of carcasses is treated as a secondary sampling occasion.

2.4.3 Additional features recorded

The additional features enter the likelihood through the Q factor in expression (A.13).

Sex is treated as a deterministically observed feature ($Q = 0$ or 1). Any gender bias present in the sampling of individuals is modelled through the capture probability model, which allows for sex-biased sampling.

The probability ($0 < Q < 1$) that a calf of the year was still with its mother when first sampled by a team in a season was modelled as a team-specific parameter, because the MBNRC team tended to observe the animals later in the season than the RGWP team, after more calves had been weaned.

Identifications of calves were assumed to be deterministic ($Q = 0$ or 1) in all years in which they were used (see above).

Individuals sighted in Mexico are automatically assigned belong to the eastern breeding stock (EBS), in the sense that the probability of sighting an animal from the western breeding stock (WBS) in Mexico is assumed to be zero ($Q = 0$).

Three individuals were successfully tagged and tracked to the eastern North Pacific were likewise assigned to EBS. It is assumed that, conditional on the location where they were originally sampled and tagged (in this case, Sakhalin) the probability of successfully tagging and tracking a sampled animal is independent of their breeding stock affiliation (that is, had the individuals been western breeding stock animals, this would have been verified).

2.5 Model selection

Model selection for the purpose of determining which nuisance covariates need to be included was performed with the AIC criterion applied to the large population approximation to the parameter likelihood (see Appendix, section 2.6.2). For this purpose, stock structure hypothesis 3a was used.

3 RESULTS

3.1 Model selection

The results of fitting various models are listed in Table 4 with the AIC criterion from the approximate parameter likelihood. The preferred model (F) includes the following factors: annual variability in calf survival and pregnancy rate; capture probability depends on: team/year interaction, stage effect and team/stage interaction, subgroup/location interaction and availability class (3 levels). Increasing the number of availability classes to 5 increased the AIC.

Fig 1 shows a comparison of the mean population trajectory using (a) the RGWP data; (b) the MBNRC data as the primary data set for the years 2012-16 (when no cross-matching was conducted). The difference in trajectories is seen to be negligible, and the RGWP data were treated as the primary data set for all other model fits.

3.2 Abundance and trends

Population trajectories for the aged 1+ population size for the WFG, the WBS and their sum, were extracted from the posterior distributions of the individual-based population trajectories for each stock structure hypothesis. The estimates of abundance for 1995 and 2015, and of the annual trend, are shown in Table 5. The reason for selecting years near the beginning and end of the data series is that the estimates for the two years have low covariance and together summarize the fitted population trajectories well. The mean abundance estimates for the western feeding group (WFG) in 2015 range from 132 to 287 depending on the stock structure hypothesis. The estimates for the western breeding stock (WBS) are all below 100. The estimate annual rate of increase from 1995-2015 is about 0.05 in all cases. Figs 2a-e show samples of population trajectories from the posterior distributions for each hypothesis.

Table 4. Results of model selection

Case	LogLike	Rank	AIC	Calf mortality	Pregnancy	Capture probability
A	-3806.9	60.0	7733.7	Constant	Stage	Team.Year + Subgroup.Location
B	-3773.9	64.1	7676.1	Constant	Stage	Team.Year + Subgroup.Location + Stage
C	-3697.2	71.6	7537.7	Constant	Stage	Team.Year + Subgroup.Location + Stage + Stage.Team
D	-3653.9	73.3	7454.2	Constant	Stage	Team.Year + Subgroup.Location + Stage + Stage.Team + AvailabilityClass
E	-3640.2	83.1	7446.5	Constant	Stage + Annual	Team.Year + Subgroup.Location + Stage + Stage.Team + AvailabilityClass
F	-3635.5	87.7	7446.4	Annual	Stage + Annual	Team.Year + Subgroup.Location + Stage + Stage.Team + AvailabilityClass

Table 5. Estimates of abundances and trends by stock structure hypothesis

			Abundance estimates (aged 1+)		
Year	**Hypothesis**	**Group**	Mean	SD	CV
1995	3a	WFG	74	4	0.05
1995	3b	WBS	33	6	0.17
1995	3b	WFG	75	4	0.06
1995	5a	WBS	27	6	0.24
1995	5a	WFG	47	7	0.16
1995	5a	WFG+WBS	74	4	0.05
1995	8	WFG	106	8	0.07
1995	9	WBS	27	6	0.24
1995	9	WFG	78	10	0.12
1995	9	WFG+WBS	105	7	0.07
2015	3a	WFG	200	6	0.03
2015	3b	WBS	86	11	0.13
2015	3b	WFG	202	5	0.03
2015	5a	WBS	67	14	0.20
2015	5a	WFG	132	14	0.11
2015	5a	WFG+WBS	199	6	0.03
2015	8	WFG	287	12	0.04
2015	9	WBS	67	14	0.20
2015	9	WFG	218	19	0.09
2015	9	WFG+WBS	285	14	0.05

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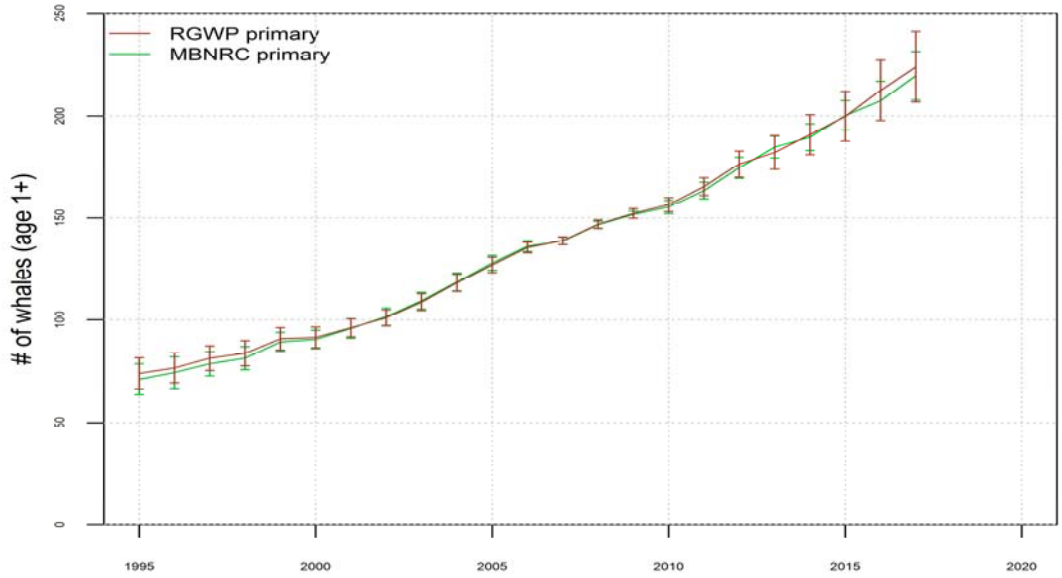

Fig. 1. Comparison of estimated population trajectories for Western feeding Group (WFG) for Hypothesis 3a using RGWP and MBNRC data sets as primary data sets during 2012-16.

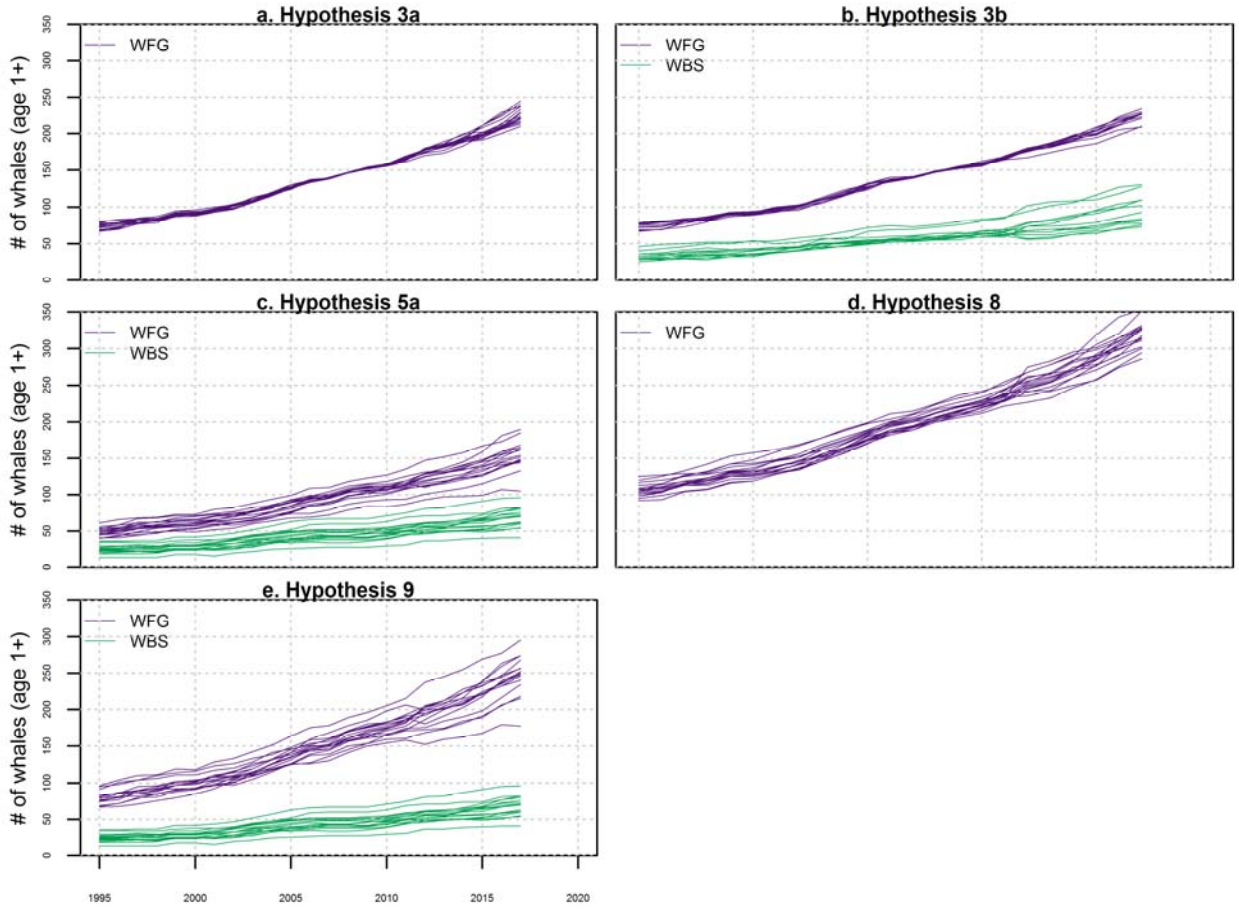

Fig. 2a-e. Posterior samples of population trajectories for WFG and WBS by stock structure hypothesis.

Appendix

Specification of the generic individually-based population model

This Appendix specifies the generic individually-based population model, applicable to any mammal population with seasonal breeding and litter size 1. The implementation choices for the specific application are noted in the main text. The generic model consists of a biological model and a sampling model.

1 BIOLOGICAL MODEL

1.1 State space representation

The biological model is a stochastic, individual-based model with a fixed time step, usually 1 year. At each time step, each individual is in one of n possible states. There are up to N individuals in total, where N is chosen large enough to accommodate any individual alive at any time during the era of interest, which runs from time $t = 0$ to t_{max}.

Each row of the $N \times n$ matrix S represents an individual biography, where S_{it} is the state of individual i in year t ($i = 1, \ldots N$; $t = 0, \ldots, t_{max}$). The matrix S as a whole represents the individual-based population trajectory.

If the state of an individual is characterized by r attributes, and the jth attribute can take n_j values, then the number of possible states is up to $\prod_{j=1}^{r} n_j$ but may be less if not all combinations of attribute levels are allowed.

The attributes reflected in the range of individual states include those that are relevant for the population dynamics (such as age, sex, health and reproductive status) and those that are relevant for the sampling process, such as migration habits, behavior etc. These two categories of attributes typically overlap. The attributes of an individual that define its state may or may not correspond to observable features of the individual. Some attributes remain fixed throughout life, such as sex, while others, such as reproductive status, may change each year.

The possible states of an individual include live states, dead states, and the unborn state (individuals which have not yet entered the population).

Because an unborn animal cannot be observed, only one unborn state need be recognized. All attributes of an individual, including inherited attributes, can, without loss of generality, be deemed to be acquired at birth or on entry into the population. The unborns include not only individuals which are literally unborn, but also immigrants prior to their immigration. All individuals count as unborn prior to $t = 0$.

Post-mortem states can be divided into one or more freshly dead "carcass" states where there is still some chance that the animal will be found and identified, and a terminal "buried" state where the animal has, for the purpose of the analysis, become permanently unobservable.

In order to limit the number of parameters to be estimated, individual variation in an attribute, such as migration behavior or reproductive output, is modelled by allowing individuals to belong to a fixed number of notional classes with respect to that attribute. The number of such classes is deemed sufficient when further subdivision has negligible effect on the results.

Some of the individuals will be individually identified at some point during the era of interest. Individuals which are identified at any time during the era of interest are termed "known", while those which are never identified are termed "unknown". At any given time t, individuals identified prior to that time are termed "identified" otherwise "unidentified".

The value of N need not be fixed in advance. Only those individuals which are alive and/or identified at some time within the era of interest need be represented explicitly in the model. Unknown individuals remain mutually indistinguishable with respect to the model until they are born. Whenever an unknown individual is born or otherwise enters the population, it can be taken from a presumed unlimited source of unborn unknowns, and the value of N incremented by 1. Where a distinction is required, N denotes the number of individuals alive at some point during the era of interest, N^+ denotes the indefinitely large number of potential individuals, and N^- denotes the number of known individuals.

The description of the population trajectory is completed by defining a vector of parents π, such that π_i is the parent (mother) of individual i. By convention, π_i is set to 0 (parentage unspecified) for individuals which are already alive at time $t = 0$, or which enter the population other than by birth to a member of the population, such as by immigration.

1.2 Aggregate population trajectory

The aggregate population trajectory is given by the matrix P where P_{kt} is the number of individuals in state k in year t. The aggregate population trajectory is related to the individual-based population trajectory by:

$$P_{kt} = \sum_{i=1}^{N} I(S_{it} == k) \quad \text{(A.1)}$$

I is the indicator function (1 for true, 0 for false) according to the equality of its arguments.

To fit a population trajectory to individually-based data, such as photographic or genetic identification of individuals, the full individual-based trajectory is required. To fit to aggregate data, such as abundance and trends, where individuals are not distinguished, the aggregate trajectory is sufficient. Many different individual-based trajectories share the same aggregate trajectory.

1.3 Population aggregates

Arbitrary linear population aggregates are defined as required. The value of the jth population aggregate in year t is a weighted sum of individuals by state:

$$A_{jt} = \sum_k W_{jk} P_{kt} \quad \text{(A.2)}$$

where the weight matrix W defines the population aggregates. Population aggregates can serve as explanatory variables for density-dependent effects.

1.4 Dynamics

The dynamics of the population are determined by two (time-varying) matrices, the transition matrix T and the reproduction matrix R.

For $j > 0$, the transition matrix entry T_{jkt} is the probability that an individual in state j at time t transitions to state k at time t+1. Some of the entries of T are constants, while others depend on unknown parameters, whose values are to be estimated. Entries of T that correspond to inadmissible transitions, such as sex change, are zero.

For any given source state $j > 0$, the set of allowed direct destination states (the set of values of k for which the entries T_{jkt} are non-zero), is assumed to be time-invariant. Let n_j denote the number of possible destination states from source state j, and let the integer-valued matrix U_{jl} (j=1,…, n; l = 1, … n_j) denote the lth possible destination state from source state j. Let φ_{jlt} denote the transition probability from state j to state Ujl during time t to t +1, conditional on the individual not having transitioned to any of the states $U_{j,1}$, …, $U_{j,l-1}$. The ordering of the allowed destination states is significant and forms part of the model specification. By definition, $\varphi(j, n_j, t) = 1$, because there are no further allowed destination states remaining.

Transition probabilities that depend on unknown parameters are modelled with a logit-linear model:

$$\varphi_{jlt} = 1 / (1 + \exp(-\zeta_{jlt}) \quad (l = 1, \ldots, n_j - 1) \quad \text{(A.3)}$$

where the values of ζ are unconstrained (can take any values from -∞ to +∞) and are modelled as linear combinations of unknown parameters:

$$\zeta_{jlt} = \sum_k X_{jltk} \beta_k \quad \text{(A.4)}$$

where β is the vector of parameters where the entries of the data matrix X are either constants or values of population aggregates.

The entries $T_{0,k,t}$, where $k > 0$, have a special meaning. $T_{0,k,t}$ represents the expected total number of individuals to enter the population in state k at time t, for example through birth or immigration. For convenience in formulae, $T_{0,0,0}$ is set to 1.

For j>0 and k > 0, The reproduction matrix entry $R_{j,k,t}$ is the probability that a female in state j in year t bears a calf that is in state k. The entry $R_{j,0,t}$ is the probability that an animal in state j does not bear a calf in year t. Entries of R which depend on unknown parameters are modelled in a similar way to the entries of T.

The entry $R_{0,k,t}$ denotes the expected number of individuals that enter the population in state k at time t other than by birth to a member of the population, for example by immigration. Expected numbers of immigrants that depend on unknown parameters are modelled in the same way as the expected initial numbers by state.

From these definitions of T and R it follows that:

$$T_{0,k,t} = \sum_{i=0}^{N} R_{i,k,t} \quad \text{(A.5)}$$

1.5 Initial conditions

The initial conditions for the population are handled by taking the initial time sufficiently far before the era of interest that the results are insensitive to the choice of initial conditions.

Expected initial numbers that that depend on unknown parameters are modelled with a log-linear model:

$$T_{0,j,0} = R_{0,j,0} = \exp(\psi_j) \quad \text{(A.6)}$$

where the values of ψ are unconstrained (can take any values from -∞ to +∞) and are modelled as linear combinations of unknown parameters:

$$\psi_j = \sum_l Z_{jl}\beta_l \quad \text{(A.7)}$$

where β is the vector of parameters and the entries of the data matrix Z are constants.

2 SAMPLING MODEL

2.1 Sampling occasions

The sampling process involves a fixed number of sampling occasions. Each sampling occasion involves sampling individuals randomly, without replacement, with a probability that can depend on the state of the individual. Each sampling occasion is tied to a specific time step. Multiple sampling occasions associated with the same time step are treated for analysis purposes as occurring in a specified order, even if in reality they overlap in time.

Sampling occasions can be *primary* or *secondary*. All individuals encountered on a *primary* sampling occasion are eligible for use in the analysis, including individuals identified for the first time. Individuals encountered on a *secondary* sampling occasion are eligible only if they are previously identified. Secondary sampling occasions include, for example, samples taken in areas or at times where conspecifics of other populations (other than the populations of interest) are also present.

The matrix entry J_{ij} takes the value 1 if individual i is eligible for sampling on sampling occasion j, 0 otherwise.

2.2 Sampling probability

Let p_{jk} denote the probability that an eligible individual in state k is sampled on sampling occasion j. The entries p_{jk} typically depend on unknown parameters, whose values are to be estimated. Sampling probabilities that depend on unknown parameters are modelled using a complementary log-log-linear model:

$$p_{jk} = 1 - \exp\left(-\exp(\eta_{jk})\right) \quad \text{(A.8)}$$

where the values of η are unconstrained (can take any values from -∞ to +∞) and are modelled as linear combinations of unknown parameters:

$$\eta_{jk} = \sum_l D_{jkl}\beta_l \quad \text{(A.9)}$$

where the entries of the data matrix D are constants, usually 0 or 1.

2.3 Observed features

When an individual is sampled, features of the individual may be observed, depending on the nature of the sampling occasion. They are called *features* to distinguish them from the *attributes* defined in section 1.1. The observation of features is conditional on the sampling of the individual.

Some features may be observed deterministically. For example, with genetic capture-recapture, the gender may be determined with effectively 100% certainty once the genetic sample has been analyzed. Any gender bias that may exist in the chance of being sampled would be modelled through the sampling probabilities p.

The observation of some features may depend on probabilities. For example, if an animal is suckling a calf, the probability of seeing the calf when the animal is sampled may be appreciably less than 100%.

Let Q_{fjkl} denote the probability that feature f an individual in state k sampled on occasion j is observed to have level l. For each f, j, k we require $\sum_l Q_{fjkl} = 1$. For deterministically observed features, the corresponding entries of Q are 0 or 1. Where the probability Q depends on unknown parameters, a normalized log-linear model is used for Q:

$$Q_{fjkl} = \frac{\exp(\theta_{fjkl})}{\sum_l \exp(\theta_{fjkl})} \qquad \text{(A.10)}$$

where the values θ_{fjkl} are unconstrained (can take any values from -∞ to +∞) and are modelled as linear combinations of unknown parameters:

$$\theta_{fjkl} = \sum_i G_{fjkli}\beta_i \qquad \text{(A.11)}$$

where the entries of the data matrix G are constants, mostly 0 or 1. There is no explicit time-dependence in the entries of θ, but they may depend on sampling occasion and thereby on time.

2.4 Loss of identity

Loss of identity can occur if artificial or natural marks are lost. Effective loss of photographic or genetic identity can also occur if the study is continued by a new research group without the possibility for cross-matching with the previous records. Loss of identity of an individual is modelled by appearance of a new individual into the same state as the old individual ("cloning"), coupled with the simultaneous transition of the old individual into an unobservable "lost" state.

2.5 Data

The data consist of a list or catalogue of identified individuals and an associated sampling history of each individual. Associated with each occasion on which an individual was sampled is a list of observable features that were checked for that individual, and the recorded levels of each observed feature.

The meta-data include a list of sampling occasions and any relevant properties of those occasions, such as the time or the primary/secondary attribute, and the number and nature of observable features that were checked (for at least some sampled individuals) on that sampling occasion. Let $\mathcal{T}_j$ denote the time of sampling occasion j, and m_j denote the maximum number of observable features checked on that occasion.

The sampling histories form a matrix Y where Y_{ij} is 0 or 1 according to whether individual i was sampled on occasion j. The entries in the array K_{ijf} are 0 or 1 according to whether feature f was checked for individual i on sampling occasion j. The matrix L_{ijf} specifies the observed level of feature f for individual i on sampling occasion j, when that feature is checked, otherwise 0.

2.6 Likelihood

We distinguish between the trajectory likelihood and the parameter likelihood. The trajectory likelihood is the likelihood of a single individually-based population trajectory. The parameter likelihood is the sum of the likelihoods all possible trajectories given those parameters.

2.6.1 Trajectory likelihood

The trajectory likelihood is the product of the simulation likelihood and the data likelihood. The simulation likelihood is given by:

$$\Lambda_S = \exp\left(-\sum_{t=0}^{t_{\max}}\sum_{j=1}^{n} R_{0,j,t}\right)\prod_{i=1}^{N}\left(\frac{R(S_{\pi_i,\tau_i},\, S_{i,\tau_i},\, \tau_i)}{R(S_{\pi_i,\tau_i},\, 0,\, \tau_i)}\prod_{t=\tau_i}^{t_{\max}-1} R(S_{i,t},\, 0,\, t)\; T(S_{i,t}, S_{i,t+1},\, t)\right) \quad \text{(A.12)}$$

where τ_i is the year of birth or entry into the population of individual i,

The first factor accounts for the fact that N includes only individuals born or alive during the era of interest. The first sub-factor of the second factor ensures that the birth probability of each individual is included only once, even though it is an event in the life both of the parent and of the child.

The probability of the data collected on individual i at time t, given the state k of the individual at that time is given by:

$$\phi_{ikt} = \prod_{j:\, \mathcal{T}_j = t} p_{jk}^{J_{ij}Y_{ij}}(1-p_{jk})^{J_{ij}(1-Y_{ij})}\prod_{f=1}^{m_j} Q(f,j,k,L_{ijf})^{J_{ij}K_{ijf}Y_{ij}} \quad \text{(A.13)}$$

where the first product sign is over the sampling occasions that occur in time step t. The first factor contains the probabilities that individuals are seen (captured) or not seen on each sampling occasion, while the second factor contains the probabilities that various features are observed on the occasions on which an individual is seen.

The data likelihood is then given by:

$$\Lambda_D = \prod_{i=1}^{N}\prod_{t=0}^{t_{\max}} \phi(i, S_{i,t}, t) \quad \text{(A.14)}$$

The trajectory likelihood is then given by: $\Lambda_T = \Lambda_S \bullet \Lambda_D$.

2.6.2 Parameter likelihood – large population approximation

The exact computation of the parameter likelihood as the integral of the trajectory likelihoods for the given parameter values is seemingly intractable. The model describes a hidden Markov process, which can, in principle, be solved by applying the forward-backward algorithm to the probability distribution over states (Eddy1996). However, the size of the population state space is approximately n^N, which is too large for computation of the probability distribution over states to be feasible.

An approximation to the parameter likelihood is obtained by computing the probability distribution over states separately by individual, on the assumption that population aggregates that affect the trajectory of an individual can be treated as independent of the state of the individual (the large population approximation). Population aggregates that affect an individual include, for example: (i) the breeding population, which drives the probability that an individual will be born in a given year; and (ii) the feeding population, which may have a density-dependent effect on the survival or reproduction probability of an individual.

Using the large population approximation, the probability distribution of the population state can be approximated by an independent distribution of each of N individuals over n states. This reduces the effective dimension of the state space from n^N to $n \times N$.

We take the notional individual $i = 0$ to represent unknown individuals, so that:

$$\phi_{0,j,t} = \prod_{l:\, \mathcal{I}_l = t} (1-p_{lj}) \quad \text{(A.15)}$$

We define the array Φ_{ijt} recursively as follows:

$$\Phi_{i,j,0} = T_{0,j,0} \quad (0 \le i \le N^{-};\ 0 \le j \le n)$$

$$\Phi_{i,j,t+1} = \sum_{k=0}^{n} \Phi_{i,k,t}\, \phi_{i,k,t}\, T_{k,j,t} \quad (0 \le t < t_{\max}) \tag{A.16}$$

The probability of the observed data for a known individual *i*, summed over all possible trajectories consistent with those data is then given by:

$$\Psi_i = \sum_{j=1}^{n} \Phi_{i,j,t_{\max}} \tag{A.17}$$

assuming that no data are available for time $t = t_{\max}$.

The approximate log-likelihood for all individuals is then obtained by summing the individual log-likelihoods, treating them as independent:

$$\log\left(\Lambda_P\right) = \sum_{i=1}^{N^{-}} \log \Psi_i - E(N^{-}) \tag{A.18}$$

where the final term is the expected number of known individuals. It accounts for the large potential number of unknown individuals, each of which has a vanishingly small probability of being born and identified (Poisson limit of the binomial). The final term can be computed by:

$$E(N^{-}) = E(N) - \sum_{j=1}^{n} \Phi_{0,j,t_{\max}} \tag{A.19}$$

where:

$$E(N) = \sum_{j=1}^{n} \sum_{t=0}^{t_{\max}} T_{0,j,t} \tag{A.20}$$

2.7 Priors

Where probabilities are modelled using generalized linear models, each term in the model is an intercept term or a random effect term.

The prior for each parameter associated with an intercept term is chosen such that the prior for the corresponding probability would be uniform on [0,1] if the model only included that intercept term. Thus, the prior for an intercept parameter in the transition probability model (A.3) is $\exp(\zeta)\Big/\left(1+\exp(\zeta)\right)^2$. The prior for an intercept parameter in the sampling probability model (A.8) is $\exp(\eta - \exp(\eta))$.

The prior for an intercept in a feature observation model of the form (A.10) is $\exp(\theta)\Big/\left(1+\exp(\theta)\right)^2$.

The prior for a random effect term is $N(0,\sigma^2)$ where σ^2 is either estimated or fixed at 1. If σ^2 is estimated, then $\log \sigma^2$ has an N(0,1) prior.

The use of proper (normalized) priors ensures that the posterior distribution of each parameter is normalizable.

Typically, the model for sampling probabilities will have at least an intercept term for each sampling occasion, while the remaining terms, if any, are modelled as random effects.

2.8 Fitting the model and model outputs

The primary output of interest is the posterior distribution of individual-based population trajectories. From this posterior distribution, posterior distributions of any population parameters of interest can be calculated. The posterior distribution of individual-based population trajectories is obtained from the prior distributions of parameters and the trajectory likelihood in the usual way.

The validity of the resulting trajectory posterior does not depend on the large population approximation. However, in order to enable reasonably efficient sampling of the trajectory posterior, the parameter likelihood is maximized as a first step, and an approximate posterior distribution of the parameter values is obtained using a quadratic approximation the likelihood. This approximate parameter posterior is then used for importance sampling of the

trajectory posterior. A poor approximation to the parameter posterior would not invalidate the resulting trajectory posterior, but would reduce the efficiency with which it can be sampled.

The estimates of parameter values and their nominal variances obtained by maximizing the approximate parameter likelihood can also be used directly, but the interpretation of such parameter values is, in general, model-dependent. Furthermore, the nominal variances of parameter values derived from quadratic approximation to the likelihood can be rather inaccurate.

2.9 Model selection

Preliminary model selection proceeds using the large population approximation of the parameter likelihood. The model selection is based on the Akaike Information Criterion (AIC; Akaike 1973).

For model selection using the trajectory likelihood, the Widely Applicable Information Criterion (WAIC; Watanabe 2009) is used. The definition of the WAIC is:

$$\mathrm{WAIC} \;=\; -2\overline{L} \;+\; \mathrm{var}(L) \qquad \text{(A.21)}$$

where $\overline{L}$ is the posterior mean of the log-likelihood and var(L) is the posterior variance of the log-likelihood.

The WAIC does not depend on the notion of a parameter count, which is not well-defined for individual trajectories, because the discrete individual transitions do not correspond to continuous, real-valued parameters. The WAIC coincides with the AIC in cases were the latter is applicable (i.e. where all parameters are real-valued and unconstrained, and the log-likelihood function is quadratic). Although the formula for the WAIC is not explicitly dependent on the prior distributions of the parameters, the priors affect the posterior distribution of the log-likelihood and hence the value of the WAIC.

A disadvantage of the WAIC is that its computation is subject to sampling error, because it is computed from a finite sample of the posterior distribution of the likelihood. This can make it difficult to measure small differences in WAIC.

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Novel single nucleotide polymorphisms from functional genes in the gray whale (*Eschrichtius robustus*) genome provide a powerful genotyping platform

J. Andrew DeWoody[1], Nadia B. Fernandez[1], Anna Brüniche-Olsen[1], Jennifer D. Antonides[1], Jacqueline M. Doyle[1], Phillip San Miguel[1], Rick Westerman[1], Céline Godard-Codding[2], and John W. Bickham[3]

[1]Purdue University, West Lafayette, IN 47907
[2]Texas Tech University, Lubbock TX 79409
[3]Battelle Memorial Institute, Houston, Texas 77441; and Texas A&M University, College Station, TX 77845

*Correspondent: J. Andrew DeWoody; Phone: 765-496-6109; Email: dewoody@purdue.edu

ABSTRACT

Molecular markers such as single nucleotide polymorphisms (SNPs) can reveal otherwise cryptic aspects of organismal ecology and evolution. Herein, we provide the first description of the gray whale genome and characterize a novel SNP panel that includes 88 gene-associated markers, two molecular sexing markers, and two mitochondrial markers. We sequenced the gray whale genome, repeatedly genotyped replicate whale biopsies at 92 SNP loci, then quantified genotyping error rates and variability at each marker. Mitochondrial DNA haplotyping and molecular sexing with SNPs was 100% concordant with conventional assays based on PCR and dideoxy sequencing or electrophoresis. Genotyping error rates, calculated across loci and across replicate samples, were very low (0.021%) and observed heterozygosity was 0.33 averaged over all autosomal markers. This level of variability across loci provides substantial discriminatory power, as evidenced by our genetic documentation of parent/offspring pairs. For example, the mean probability of identity was $<10^{-25}$ for unrelated individuals and the mean probability of exclusion was >0.9999 when neither parent was known. The characterization of the gray whale genome should enable comparative studies of natural selection in cetaceans and the SNP markers should be highly informative for future studies of gray whale population structure, demography, and relatedness.

INTRODUCTION

Gray whales (*Eschrichtius robustus*) were once common in both the North Pacific and North Atlantic Oceans but disappeared from the Atlantic by the early 1700s due to overhunting (Mead and Mitchell 1984). Contemporary gray whales are found only along the eastern and western coasts of the North Pacific Ocean (Andrews 1914; Rice and Wolman 1971). Herein, we follow the convention established by the International Union for Conservation of Nature (IUCN 2008; Reilly et al. 2013) and refer to an eastern gray whale (EGW) population and a western gray whale (WGW) population.

Like so many of the great whales, gray whale numbers crashed during the commercial whaling era (Mead and Mitchell 1984; Alter et al. 2012; Weller and Brownell 2012). Based on whaling records, Henderson (1984) estimated the size of the historic EGW population as 15,000 to 20,000 individuals prior to commercial hunting. Historically, the WGW population is thought to have been much smaller, numbering only 1,000 to 1,500 individuals prior to 1910 (Berzin and Vladimirov 1981). Although there is considerable uncertainty as to the historical size of the WGW population, its distribution was much larger than the contemporary WGW population that summers in the Sea of Okhotsk (Reeves et al. 2008).

The IUCN considers the extant WGW population to be critically endangered (IUCN 2008; Reilly et al. 2013), as there were only about 140 western gray whale adults in 2012 (Cooke et al. 2013) and the population was previously believed to be extinct (Bowen 1974; Weller et al. 2002). The EGW population was reduced to a low of approximately 2,000 individuals and has since made a strong recovery; the contemporary population numbers about 19,000 individuals (Laake et al. 2009).

Gray whales are occasionally sighted along the historical western migration corridor (Weller et al. 2008; Weller and Brownell 2012), which includes waters near Sakhalin Island (Russia), and some genetic studies have indicated that whales sampled near Sakhalin are differentiated from the EGW population (Lang et al. 2010; LeDuc et al. 2002; Alter et al. 2012; Meschersky et al. 2015). However, gray whales have the capacity to migrate among oceanic basins (>22,000 km; Scheinin et al. 2011; Shpak et al. 2013) and the gene pools of some other great whales are genetically homogenous across their range (e.g., sperm whales; Alexander et al. 2016). Geospatial and genetic data (e.g., Alter et al. 2015; Mate et al. 2015) suggest the extant WGW and EGW populations may be demographically linked and that contemporary signals of population differentiation may represent historical patterns. The development of additional, more powerful genetic assays would be a boon to gray whale conservation globally as the ability to identify individuals and family groups, confidently delineate populations, and track patterns of genetic diversity over space and time would result in more informed management decisions.

Suites of single nucleotide polymorphisms (SNPs) can be used to delineate breaks in genetic structure, but can also be used for definitive individual identifications (e.g., from biopsies) and for categorical assignment of parentage or relatedness (e.g., Ruegg et al. 2014; Doyle et al. 2016). We sought to develop a SNP panel from the gray whale genome in order to facilitate

genetic studies of population differentiation, parentage, and individual identity (e.g., comparing photographs to biopsy genotypes).

Herein we describe the genome sequence of the gray whale and use it to identify SNPs from genic and non-genic regions. We sequenced the genomes of two Sakhalin Island gray whales (a male and a female WGW) and a female EGW from Barrow Alaska. Subsequently, multi-locus SNP genotypes were generated for the single EGW (N=1) plus a set of WGW biopsy samples (N = 35) collected near Sakhalin Island to provide a preliminary estimate of genomic diversity in gray whales. The genome and genetic markers we describe herein will allow researchers to validate photographic or other means of individual identification and to demographically track individuals in space and time as has been done for other species of conservation concern (e.g., Nussberger et al. 2014).

METHODS

Sample collection

Biopsies of skin and blubber were obtained from WGWs (N=35) on their summer feeding grounds near Sakhalin Island using methods approved by the Scientific Committee of the International Whaling Commission. These include samples from six calves as well as adults. Biopsy samples were frozen and shipped to Purdue University processing. Skin samples from EGWs (N = 2) were cut from two dead gray whales that beached near Barrow, Alaska and then frozen until processing at Purdue University.

Genome sequencing, assembly, and annotation

DNA was extracted from two WGWs (male ER-14-168 and female ER-14-0147) and one EGW (female GFD-02). For the male WGW, we constructed one paired-end (PE) library without PCR amplification and one mate-paired (MP) no-gel library. For the two female gray whales (WGW and EGW) we only constructed PE libraries. In total, we sequenced 7 lanes of PE libraries and 1 lane of the MP library using an Illumina HiSeq (2x100).

We used FASTQC v0.11.2 to generate summary statistics for the sequencing data. TRIMMOMATIC v0.32 (Bolger *et al.* 2014) was used to remove adaptor sequences and low quality bases (Phred scores <20). Multiple genome assemblies were generated using ABySS version 1.9.0 (Simpson et al. 2009) with a variety of k-mer values (k-mer = 30, 40, 50, 60 and 70) to produce the most comprehensive assembly. We used the PE data during the contig-building steps and MP data during the scaffold-building steps. Genome annotation was based on the male WGW (ER-14-168) to include genes found on the Y-chromosome (Zfy) and the X-chromosome (Zfx). We used MAKER 2.28 (Cantarel et al. 2008) for annotation following Doyle et al. (2014). Briefly, we used SNAP (Korf 2004) to generate *ab initio* gene predictions. Gene predictions supported by expressed sequence tags, protein or InterProScan evidence were elevated to gene annotations. Eutherian protein data were downloaded from the UniProtKB database (www.uniprot.org) and EST evidence was derived from an assembled transcriptome of

an Alaskan bowhead whale (Keane et al. 2015). We used CEGMA to assess the completeness of our genome assemblies (Parra et al. 2007).

SNP identification and development

From published cetacean data, we generated a manually curated list of candidate genes potentially subject to strong natural selection. These include genes associated with osmoregulation, oxygen binding/delivery, and other aspects of marine life (referred to hereafter as "nonneutral" or "candidate" genes; see Kosiol et al. 2008). Using the MAKER transcripts from our genome annotation, we used BLAST 2.2.31+ to annotate these candidate genes in the gray whale genome. For SNP identification, we used BWA version 0.7.12 (Li and Durbin 2009) to map all PE reads to the male assembly. We used GATK 3.4 (DePristo et al. 2011; Van der Auwera et al. 2013) to 1) identify and realign reads around insertions/deletions (indels); 2) identify SNPs with a minimum Phred quality score of 30 and a minimum depth of 10 reads; and 3) disregard SNPs within 20 bp of each other. BEDOPS 2.0 (Neph et al. 2012) was used to identify variable sites (i.e., SNPs) within nonneutral genes. We used IGV version 2.3 to identify target SNPs with at least 60 nucleotides (nt) of high-quality flanking sequence upstream and downstream and GC content less than 65%. We deliberately minimized linkage disequilibrium (LD) by choosing only single SNPs from a given scaffold.

Ultimately, we developed and tested 92 autosomal nuclear markers from protein-coding genes specifically targeted because of evidence for selection in other marine mammals. Following preliminary population surveys via dideoxy sequencing (Alter and Palumbi 2009), we designed two mitochondrial DNA (mtDNA) markers for haplotyping. For sexing, we designed two redundant SNP assays to assess nucleotide variation in the Zfx/Zfy genes.

SNP genotyping, error rates, and variability

We genotyped 36 gray whale biopsy samples at 96 candidate SNP markers. Samples were genotyped using a Fluidigm Juno Genotyping System and a specific target amplification step was incorporated to facilitate genotyping of the low-quantity DNA samples that are typical of biopsies from endangered species. Individual SNP calls were visualized and edited using Fluidigm's Genotyping Analysis Software; data from nuclear loci that did not produce obvious clusters of homozygotes and heterozygotes (Figure 1) were excluded from further analyses.

In theory, our 35 WGW biopsies could include whales that were inadvertently sampled more than once (e.g., in subsequent years). Individual biopsies were genotyped at the SNP panel

multiple times, and ultimately 78 samples were genotyped at ≥88 loci (only DNA samples and

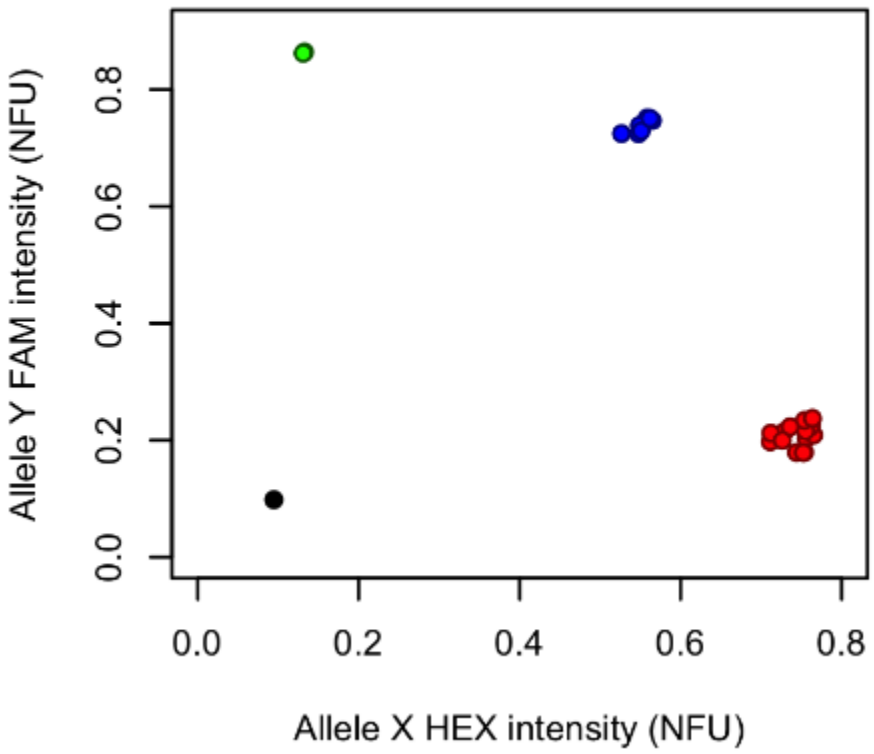


Figure 1. An example of Fluidigm data from an autosomal whale SNP: clustering results for locus 11737172_20296. GG homozygotes are shown in green, heterozygotes in blue, and TT homozygotes in red. The negative control is shown as the black data point.

SNP loci with <10% missing data were included in this analysis). We used allelematch in R (Galpern et al. 2012; R Development Core Team 2008) to group replicate genotypes into unique records that represent individual whales, allowing for a maximum of 2 mismatches between replicates. All genotypes identified as replicates were subsequently confirmed visually.

Error rates were calculated using replicate DNA samples (N= 69 in total) from 27 individual gray whales. The plurality principle was used to determine a consensus sequence for each individual whale by utilizing SNP calls across replicate samples (see Doyle et al. 2016). The SNP typing error rate (*e*) was calculated according to the equation $e=m/[d(s)]$, where *m* represents the total number of mismatches between each replicate sample and the consensus sequence across multiple samples from the same individual; *d* represents the total number of loci per replicate sample; and *s* represents the total number of replicate samples. Both incorrect SNP calls (errors of commission) and instances where no amplification occurred (errors of omission) contributed to *m*.

We used GENALEX v6.5 (Peakall & Smouse 2012) to quantify observed (H_O) and expected heterozygosity (H_E), the mean probability of identity (P_I), and the mean probability of exclusion with neither-parent known (P_E). We tested for deviations from Hardy Weinberg Equilibrium (HWE) and for linkage disequilibrium (LD) after applying a sequential Bonferroni correction to account for multiple tests (Holm 1979). The inbreeding coefficient *f* (Weir & Cockerham 1984) was evaluated in GENODIVE v2.0b27 (Meirmans & Van Tienderen 2004) using 10^3 permutations.

Molecular sexing and haplotyping

For validation purposes, all samples were sexed using a traditional PCR/gel method (Bérubé and Palsboll 1996) and also by using our novel sexing SNPs. Similarly, mtDNA haplotypes were generated using both traditional dideoxy methods (Alter and Palumbi 2009) and novel SNP markers. We then compared the concordance among assays in an attempt to validate our novel markers.

Relatedness, genetic structure, and effective population size

Relatedness among individuals was estimated using RELATED v1.0 (Wang 2011; Pew et al. 2015), which implements five widely used moment-based relatedness estimators. In order to identify the estimator that performed best with our data, we used our empirical allele frequencies to simulate 100 datasets for four types of dyads: parent-offspring pairs (expected $r = 0.5$), full-siblings ($r = 0.5$), half-siblings ($r = 0.25$), and unrelated individuals ($r = 0.0$). Point estimates and 95% confidence intervals (CI) were estimated based on 100 bootstrap replicates and the best estimator was identified using Pearson's correlation coefficient. This estimator was used to compare the observed mean pairwise relatedness of each individual whale (r_{pw}) to the mean for the population (r_{pop}). Thus, r_{pw} represents the mean relatedness of a single individual whale to every other whale in the population whereas r_{pop} represents the mean relatedness of the population as a whole. By comparing r_{pw} to r_{pop}, individual whales were identified that were more or less related to the population than expected by chance alone. CERVUS version 3.0.7 (Marshall et al. 1998; Kalinowski et al. 2007) was used to assign parentage to calves, considering all sampled adults as candidate parents. The minimum allowable confidence level for which a parentage assignment was accepted was 95%.

We used GENALEX to perform a principal components analysis (PCA) of genetic variation among distantly related (i.e., second-degree or greater) gray whales to assess overall population structure. We also included both western (N = 35) and eastern (N = 1) samples in a STRUCTURE v2.3.4 (Pritchard et al. 2000) analysis. Samples identified by our relatedness analyses as biological replicates from the same individual (i.e., r = 1) were excluded from the PCA and STRUCTURE analyses so only individual genotypes were used. We used two different approaches: i) including all whales and ii) including only one representative from pairs identified as first-degree relatives (e.g., full-siblings or parent-offspring pairs). We used the 'admixture' model, which allows individuals to have inherited different parts of their genome

from ancestors in different relatedness clusters. For each value of *K* from 1–6, we performed five iterations, using a burn–in of 10^4 iterations followed by an MCMC of 10^5 iterations. The most likely number of clusters was identified using STRUCTURE HARVESTER v1.1.2 (Earl & vonHoldt 2012) using the ΔK method (Evanno et al. 2005). CLUMPP v1.1.2 (Jakobsson & Rosenberg 2007) was used to combine STRUCTURE output and results were displayed with DISTRUCT v1.1 (Rosenberg 2004).

To estimate contemporary effective population size (N_e) and effective number of breeders (N_{eb}) of the WGW population we populated NeESTIMATOR v2.01 (Do et al. 2014) with the unique multilocus genotypes that represent individual whales. The software implements two different methods for estimating N_e from a single-sample, based on i) linkage disequilibrium (Waples & Do 2008) and ii) heterozygosity excess (Zhdanova & Pudovkin 2008). A molecular co-ancestry approach (Nomura 2008)—also implemented in NeESTIMATOR— was used for estimating N_{eb}. Note these methods assume selectively neutral markers and closed populations, so these N_e and N_{eb} estimates may be biased. Moreover, the influence of selection and migration on such estimates are unknown as they have not been investigated in a thorough, systematic manner (Waples 2006).

RESULTS

Genome sequencing, assembly, and annotation

Our WGW sequencing results are compiled in Tables 1-2. We generated >2.5 billion reads (~2 billion high-quality reads after quality-control) that collectively span ~200 billion bases and contain near all of the core genes common to eukaryotes (Table 2). The N50, which represents the value where more than half of the assembly is contained in larger contiguous regions, was ~180,000 bp for the best assembly. We annotated roughly 22,000 genes, a number similar to other cetacean genomes (Supplementary Table 1).

Table 1. Sequencing statistics associated with the Western gray whale genome.

Sample name	Total reads	Total bases	Quality reads	Quality bases
Paired-end libraries				
ER-14-0147	1,331,820,280	134,513,848,280	988,439,854	97,099,230,094
ER-14-0168	1,254,676,990	126,722,375,990	974,126,824	95,896,562,771
Mate-paired libraries				
ER-14-0147	184,404,728	18,624,877,528	146,095,780	13,350,014,231
ER-14-0168	213,408,466	21,554,255,066	168,844,292	15,387,314,171

Table 2. Summary statistics generated by ABySS for the western gray whale genome assemblies. In both cases, a kmer length of 60 produced the best assemblies shown here. The N50, measured in bases, represents a midpoint whereby half of the assembled sequence is contained in contigs larger than the N50. The n:N50 column refers to the number of sequences of length N50 and longer. Comp% refers to the percentage of 248 ultraconserved core eukaryotic genes detected in the gray whale assembly (Parra et al. 2007).

Sample	Sequences	Bases	Min. Length	Max. Length	N50	n:N50	Comp%
ER-14-0147	60,534	3,082,450,012	500	1,943,192	180,882	4,539	95
ER-14-0168	57,219	2,849,466,389	500	1,944,941	187,455	4,089	96

SNP identification and development

We identified 2,057,254 candidate SNPs from the WGW, of which 1,474,749 passed quality filtering criteria. Of this high-quality subset, 8,413 SNPs were located in exons that were identified in the genome annotation. From these exonic SNPs, we designed and tested 96 SNPs for our genotyping assay. Four were ultimately excluded because they were monomorphic, clustered poorly, or were otherwise of insufficient quality. These novel SNP loci and flanking sequences are described in an associated Excel spreadsheet. The 92 informative loci include 88 gene-associated nuclear markers (which may be targets of selection), two mitochondrial markers, and two nuclear molecular-sexing markers (Supplementary Table 2).

SNP genotyping, variability, and error rates

The vast majority of markers amplified in each individual DNA sample (Figure 1). By genotyping 27 of the 36 biopsy samples multiple times, we calculated an overall genotyping error rate (*e*) of 0.021%. According to allelematch, the 36 biopsies represented a total of 29 unique multilocus genotypes that correspond to 29 individual gray whales (i.e., 7 whales were sampled twice; Table 4). Observed and expected heterozygosities at autosomal SNPs were 0.33± 0.18 (mean±SD) and 0.31± 0.15, respectively, for all WGWs sampled (Supplementary Table 3). All autosomal SNP loci were in Hardy-Weinberg equilibrium following sequential Bonferroni correction. Male whales (N= 14) H_O and H_E averaged 0.30 ± 0.02 and 0.29 ± 0.02, respectively, across all autosomal markers whereas female whales (N = 21) H_O and H_E averaged 0.35 ± 0.02 and 0.32 ± 0.02. The mean inbreeding coefficient (*f*) was -0.05. The mean probability of identity (P_I; Waits et al. 2001) was 1.6×10^{-25} and the mean probability of exclusion (P_E; Jamieson and Taylor 1997) with neither parent known was >0.9999.

Table 4. Pairwise relatedness estimates (*r*) among each possible pair of individual gray whale biopsies in our sample. Bold rows indicate pairs of samples from the same individual that were inadvertently sampled more than once. Italicized rows represent likely first-degree relatives (e.g., parent-offspring pairs or full-siblings). The table was arbitrarily truncated at mean $r = 0.30$ due to space constraints; see Supplementary Table 4 for smaller values.

ind1.id	**ind2.id**	**Mean *r***	**SD *r***
ER-14-0157	**ER-14-0164**	**1.000**	**(1.000—1.000)**
ER-14-0147	**ER-14-0154**	**1.000**	**(1.000—1.000)**
ER-14-0158	**ER-14-0165**	**1.000**	**(1.000—1.000)**
ER-14-0159	**ER-14-0174**	**1.000**	**(1.000—1.000)**
ER-14-0166	**ER-14-0175**	**1.000**	**(1.000—1.000)**
ER-14-0151	**Z112748**	**1.000**	**(1.000—1.000)**
ER-14-0152	**ER-14-0153**	**1.000**	**(1.000—1.000)**
ER-14-0159	*ER-14-0173*	*0.631*	*(0.465—0.760)*
ER-14-0173	*ER-14-0174*	*0.631*	*(0.470—0.750)*
ER-14-0151	*Z112746*	*0.502*	*(0.271—0.648)*
Z112746	*Z112748*	*0.502*	*(0.347—0.695)*
ER-14-0156	*ER-14-0167*	*0.497*	*(0.322—0.654)*
ER-14-0162	*ER-14-0173*	*0.483*	*(0.260—0.678)*
ER-14-0159	*ER-14-0162*	*0.469*	*(0.286—0.632)*
ER-14-0149	*Z112746*	*0.467*	*(0.208—0.656)*
Z112746	*Z112747*	*0.459*	*(0.251—0.661)*
ER-14-0162	*ER-14-0174*	*0.458*	*(0.245—0.633)*
ER-14-0170	Z1127432	0.410	(0.193—0.573)
ER-14-0150	Z112745	0.398	(0.172—0.572)
ER-14-0167	ER-14-0155	0.393	(0.161—0.532)
ER-14-0175	Z112747	0.389	(0.158—0.572)
ER-14-0156	ER-14-0163	0.382	(0.199—0.575)

ER-14-0166	Z112747	0.376	(0.183—0.587)
ER-14-0167	ER-14-0171	0.359	(0.101—0.557)
ER-14-0148	ER-14-0151	0.357	(0.092—0.569)
ER-14-0148	Z112748	0.357	(0.084—0.570)
ER-14-0156	Z112745	0.338	(0.043—0.615)
ER-14-0149	ER-14-0151	0.328	(0.106—0.496)
ER-14-0149	Z112748	0.328	(0.121—0.568)
ER-14-0163	Z112745	0.326	(0.114—0.528)
Z112747	GFD02	0.326	(0.095—0.515)
ER-14-0157	ER-14-0149	0.314	(0.066—0.526)
ER-14-0164	ER-14-0149	0.306	(0.060—0.506)
ER-14-0150	ER-14-0171	0.301	(0.041—0.500)

Molecular sexing and haplotyping

Samples from the 29 individual gray whales were sexed using both our novel SNP assays and the traditional method using PCR and gel electrophoresis. The results of the two methods were in complete concordance with one another (see Figure 2), indicating that our samples were derived from 11 males and 18 females. These same samples were haplotyped using both our mtDNA SNP assays as well as traditional Sanger sequencing. Once again, the results of the two methods were in complete concordance (data not shown) and three distinct mitochondrial haplotypes were detected (Table 3).

Table 3. Haplotype and sex data. Genotypes for two mitochondrial (CR_82 and CR_104) and two sexing markers (ZFY_288 and ZFY_342). Missing genotypes are represented with a dash.

		mtDNA		**Sex chromosomes**		
Sample	**Population**	**CR_82**	**CR_104**	**ZFY_288**	**ZFY_342**	**Sex**
ER-14-0148	western	A:A	G:G	C:C	G:G	Female
ER-14-0149	western	A:A	G:G	C:C	G:G	Female
ER-14-0150	western	G:G	A:A	C:T	A:G	Male
ER-14-0153	western	G:G	G:G	C:C	G:G	Female
ER-14-0154	western	G:G	G:G	C:C	G:G	Female

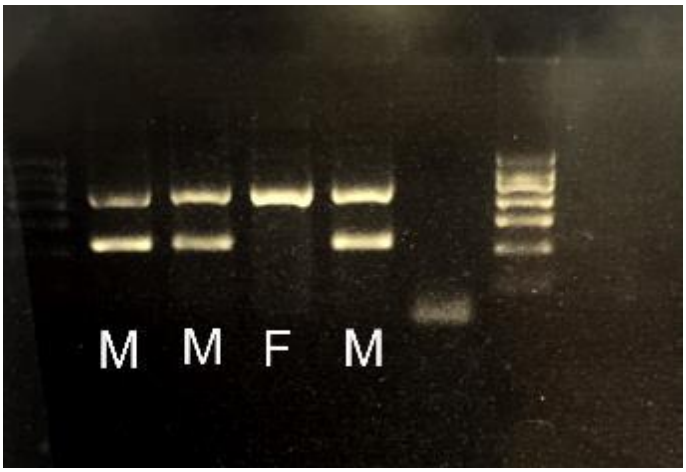
ER-14-0155	western	A:A	G:G	C:C	G:G	Female
ER-14-0156	western	A:A	G:G	C:T	A:G	Male
ER-14-0160	western	G:G	A:A	C:T	A:G	Male
ER-14-0161	western	G:G	A:A	C:C	G:G	Female
ER-14-0162	western	G:G	G:G	C:C	G:G	Female
ER-14-0163	western	G:G	G:G	C:C	G:G	Female
ER-14-0164	western	A:A	G:G	C:T	A:G	Male
ER-14-0165	western	A:A	G:G	C:T	A:G	Male
ER-14-0167	western	G:G	G:G	C:T	A:G	Male
ER-14-0168	western	G:G	G:G	C:T	A:G	Male
ER-14-0169	western	A:A	G:G	C:T	A:G	Male
ER-14-0170	western	G:G	A:A	C:T	A:G	Male
ER-14-0171	western	G:G	A:A	C:C	G:G	Female
ER-14-0172	western	G:G	G:G	C:C	G:G	Female
ER-14-0173	western	G:G	G:G	C:C	G:G	Female
ER-14-0174	western	G:G	G:G	C:C	G:G	Female
ER-14-0175	western	A:A	G:G	C:T	-	Male
Z112743	western	G:G	G:G	C:T	A:G	Male
Z112744	western	G:G	G:G	C:C	G:G	Female
Z112745	western	G:G	G:G	C:C	G:G	Female
Z112746	western	A:A	G:G	C:C	G:G	Female
Z112747	western	A:A	G:G	C:C	G:G	Female
Z112748	western	A:A	G:G	C:C	G:G	Female
GFD02	eastern	G:G	A:A	C:C	G:G	Female

Relatedness, effective population size, and genetic structure

Mean pairwise relatedness (r_{pop}) observed among all 29 individual gray whales (including one eastern individual) was -0.032 and the 95% confidence interval ranged from -0.055 to -0.009. This analysis of pairwise relatedness confirmed the allelematch results in that 7 of our

biopsies were duplicate samples from the same individual, and many dyads were likely first-degree relatives (e.g., full siblings or parent-offspring pairs) as indicated in Table 4. The

A.



B.

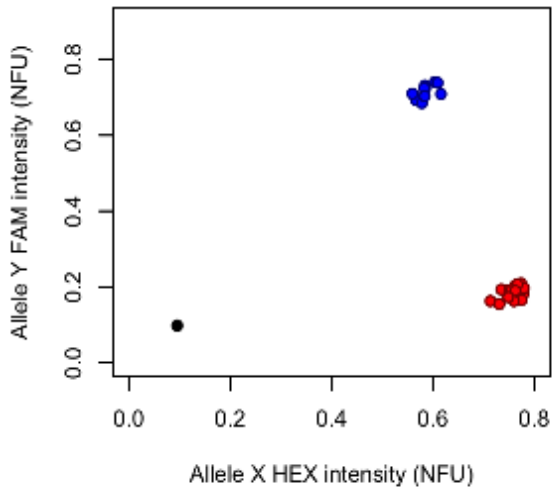


Figure 2. Concordance between A) traditional PCR/gel and B) our novel SNP sexing assays. Panel A demonstrates that the traditional method produces a single product in females (ZFX) and two products in males (ZFX and SRY); also shown are a no-template control and a size standard. Panel B demonstrates that males (blue) and females (red) can be distinguished from one another based on HEX and FAM intensity measured in normalized fluorescence units (NFU).

distribution of individual relatedness values (r_{pw}) is shown in Fig. 4. The CERVUS analyses identified two cow-calf pairs, one of which (ER14-0159/ER14-0173) confirmed a relationship suspected in the field whereas the other (ER14-0152/ER14-0172) overturned our field suppositions. No sires were identified in our sample but we identified two potential full sisters

(ER14-0162 and ER14-0173; pairwise r = 0.483). They apparently share the mother ER14-0174/ ER14-0159, r = 0.631 with ER14-0173 and r = 0.469 with ER14-0162; Table 4).

The N_e estimates of contemporary WGW were similar based on linkage disequilibrium (mean N_e=14.1; 95% CI from 12.1–16.7) and heterozygosity excess (mean N_e=14.4; 95% CI from 7.6–254.1). The effective number of breeders, based on individual coancestry, was only 1.3 (95% CI from 1.0–1.7).

Our analyses of population structure found the lone EGW in our survey to be genetically similar to the WGWs. The PCA revealed a single cluster of genotypes that include all the WGWs and the lone EGW; there was no differentiation between these two putative populations (Figure 3a). Our data contained signals of substructure in the gray whale gene pool and the most likely number of clusters was three (K = 3; ΔK = 27.00; Figure 3b).

DISCUSSION

Genome sequencing, assembly, and annotation

The gray whale genome assemblies we describe consist of ~22,700 genes (Tables 1 and 2) and contain ~95% of the genes known to be highly conserved among eukaryotes (Parra et al. 2007). These assemblies are relatively complete and reveal that the gray whale genome is fairly typical of cetaceans in terms of genome size and gene complement, which likely reflects their shared ancestry. Foote et al. (2015) have recently argued that the genomes of marine mammals have evolved in a convergent fashion, and future research will determine what proportion of the gray whale genes we annotated (Supplementary Table 1) are orthologues of the 16,878 genes shared by killer whales, manatees, walrus, and bottlenose dolphin (Foote et al. 2015). We expect that all of these species have undergone similar selection with regard to genes involved in osmoregulation (e.g., adaptation to a saline environment), oxygen binding affinities, and other aspects of marine life.

SNP identification and development

From the genomic sequence data, we identified hundreds of thousands of SNPs that can be used in future population genetic surveys. Of these, we evaluated 96 and found that 92 of these were polymorphic, had low error rates, and could be multiplexed in a single assay. This small panel of markers should be sufficient for investigations of genetic parentage, relatedness, individuality, demographic turnover, and population structure. However, the much larger set of SNPs we identified could inform future genome scans based on RAD-seq (Miller et al. 2007) or other queries of anonymous SNPs that might also be informative for studies of natural selection and/or demographic history.

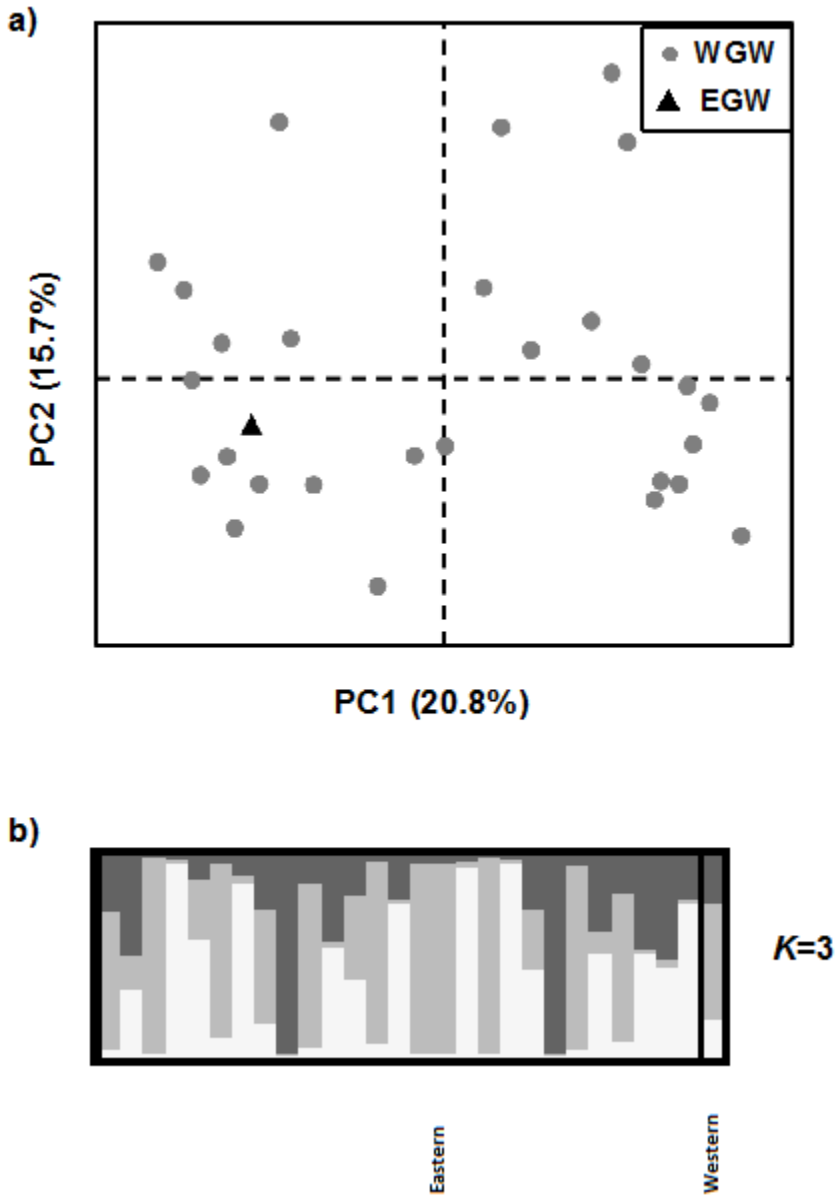


Figure 3. Gray whale population structure based on PCA (panel A) and Bayesian clustering (panel B). For panel B, each vertical bar represents an individual and its proportional ancestry one of K=3 clusters; this plot excludes first-degree relatives (including 'parent-offspring' and 'full-siblings' pairs; $r \geq 0.5$). A black line separates the eastern gray whale (EGW) from the western gray whale (WGW) samples.

SNP genotyping, variability, and error rates

The oligonucleotides we developed and the SNPs they query were assessed with the Fluidigm platform, but could instead be utilized with alternative genotyping technologies. Because these markers are polymorphic and have low error rates (~0.02%), we expect lab-to-lab variability should be low, as 99.98% of our replicate data were identical across independent genotyping runs. For example, a whale from the western Pacific that is genotyped with these SNPs could be identified as one also sampled in the eastern Pacific provided the genotypes are stored in a common database that could easily be queried by independent research groups (e.g., on the cloud).

From a large pool of candidates, genetic markers can be used to assign a) genotypes to individuals (e.g., forensic applications) and b) offspring to candidate parents (e.g., paternity). The power available for such analyses are captured by P_I and P_E, respectively. In our sample of whales, the mean $P_I = 1.6 \times 10^{-25}$. Thus trillions and trillions of whales would have to be sampled—far more than collectively ever roamed the oceans since the evolution of cetaceans—before two unrelated individuals would be expected to have the same multi-locus SNP genotype by chance alone. Indeed, our sampling yielded multiple biopsies from the same donor whales which were identified by their identical SNP genotypes (see below and Table 4). Similarly, a calf's unknown parentage could be determined among thousands of candidate parents with virtual certainty if all were genotyped with this SNP panel (P_E>0.9999).

Molecular sexing and haplotyping

Our novel SNP sexing assays performed well (i.e., were corroborated by conventional molecular sexing), as did the SNP mtDNA haplotyping assay. Although our marker set queries only two mtDNA sites, this marker panel could easily be extended to other SNP sites known to be variable in gray whales; we provide herein the first proof-of-concept data. We include these markers along with our autosomal SNPs because data on sex and matriline may ultimately reveal different aspects of cetacean biology, such as the female philopatry and male-biased dispersal observed in sperm whales (Alexander et al. 2016).

Relatedness, effective population size, and genetic structure

The WGW is considered critically endangered by the IUCN, and although our sample consisted of only 28 WGW individuals, this is ~20% of the entire population (Cooke et al. 2013). Our relatedness analysis indicated that a number of our biopsies came from the same whales; seven pairs of samples were found to have identical SNP genotypes across all loci (Table 4). Given the paucity of WGWs, it is not entirely surprising that we sampled 7 individuals twice. Furthermore, a number of individual pairs were apparently derived from close relatives (Table 4; Figure 4) that may represent parent-offspring pairs, full-siblings, half-siblings, and other close relatives. We identified two distinct cow/calf pairs and one ostensible full-sibling pair. This point illustrates the power of genetic analyses in corroborating or overturning relationships suspected based on field work. All of our population inferences (i.e., genetic structure and N_e)

are preliminary, but we include them here because of the keen interest in the conservation of the critically endangered WGW population.

Whether the population near Sakhalin Island is comprised of western gray whales, eastern gray whales, or is a mixed aggregation of the two stocks is under study by the IWC (2015). The lone EGW we sampled was no more or less related to the WGW population than expected by chance alone (Figure 4). If the EGW was derived from an independent gene pool, it should be more distantly related to the WGW population. Furthermore, the relatedness analysis (based on the proportion of alleles shared among loci by two individuals) corroborates the STRUCTURE analysis (based on minimizing population deviations from Hardy-Weinberg equilibrium).

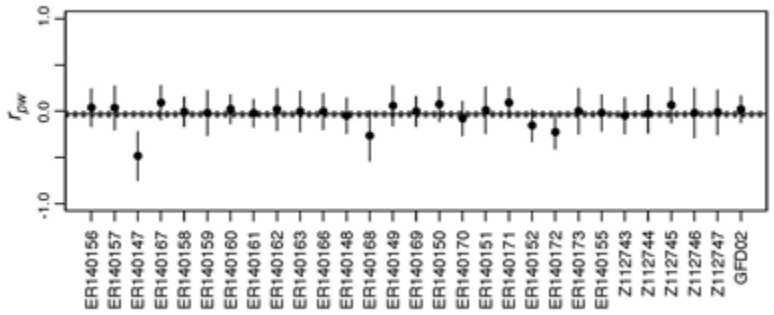


Figure 4. The distribution of individual relatedness values (r_{pw}) and their associated 95% confidence intervals (CI). The mean pairwise relatedness among all 29 individuals in the population (i.e., 406 pairwise comparisons where r_{pop} = -0.032) is shown as a solid black line and the 95% CI (from -0.055 to -0.009) is shown as a dashed line. For each individual, r_{pw} is indicated as a dot and the 95% CI is shown as a vertical bar. Note that GFD02, the lone EGW, is no more or less related to the population than expected based on chance alone.

STRUCTURE indicated the presence of three genetic groups within our sample set, but it seems unlikely that this differentiation is simply due to the presence of eastern and western gray whales in our sample because the single EGW we genotyped was genetically indistinguishable from the WGWs and appeared to be admixed from all three groups that STRUCTURE identified (Figure 3). Populations with small effective sizes diverge rapidly due to drift and inbreeding (Wang and Caballero 1999). Thus, our small estimates of gray whale N_e ($N_e \approx 14$ by both linkage disequilibrium and heterozygosity excess) are consistent with the idea of genetic structure in the gray whale and may explain, at least in part, the divergence between the samples we genotyped.

A panel of ~100 SNPs has substantial discriminatory power, even in a migratory species (e.g., Ruegg et al. 2014). The signals of genetic differentiation that we detected may be due to true population structure associated with divergent selection, genetic drift, and/or a lack of migration (gene flow) among gray whale populations. Alternatively, the structure may represent the presence of relatives within our sample of WGWs (Anderson and Dunham 2008; see Figure 3). Additional genotyping will be required to differentiate among these possibilities, but the genome sequence and the genotyping platform we describe herein should enable those efforts.

Conclusions

Herein, we describe the gray whale genome and the development of a gray whale genotyping assay that queries 92 autosomal nuclear SNPs (88 gene-associated markers), 2 mitochondrial markers, and 2 molecular-sexing markers. We validated these markers by repeated genotyping of 36 gray whale samples and determined that the error rates were low and the markers were polymorphic despite small effective population sizes. The single whale we sampled from the eastern population could not be genetically distinguished from the 28 gray whales we sampled near Sakhalin Island, but our markers provide a powerful platform for distinguishing among individuals and kin (e.g., identifying close relatives). Ultimately, the markers described herein should prove a valuable resource for biologists and for the broader conservation community given the difficulty and expense associated with sampling and identifying baleen whales, and the genome sequence will serve as a valuable resource for basic studies across a diversity of disciplines.

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Supplementary Table 1. Genomics of the gray whale compared to other cetaceans.

Species	Scientific Name	Assembly Size (bp)	Estimated # of genes	Mean gene length (bp)	Mean exons per gene (bp)	Mean exon length (bp)	Mean intron length (bp)	Citation
Western gray whale	*Eschrichtius robustus*	2,789,519,164	22,711	20,540	4.89	155	2,308	*this study*
Common minke whale	*Balaenoptera acutorostrata*	2,442,893,294	20,605	30,443	8.22	177	3,639	*Nature Genetics* 46: 88-92. (doi:10.1038/ng.2835)
Yangtze river dolphin	*Lipotes vexillifer*	2,565,001,670	22,168	22,385	7.66	195	3,135	*Nat. Comm.* 4: 2708. (doi:10.1038/ncomms3708)
Bowhead whale	*Balaena mysticetus*	2,313,241,988	22,672	-	-	-	-	*Cell Reports* 10: 112-122. (doi: 10.1016/j.celrep.2014.12.008)
Common bottlenose dolphin	*Tursiops truncatus*	2,551,996,573	-	-	-	-	-	*Nature Genetics 47*: 272-275. (doi:10.1038/ng.3198)
Killer whale	*Orcinus orca*	2,372,919,877	-	-	-	-	-	*Nature Genetics 47*: 272-275. (doi:10.1038/ng.3198)
Antartic minke whale	*Balaenoptera bonaerensis*	2,236,396,878	-	-	-	-	-	*Zoological Letters 1*: 1-10. (doi:10.1186/s40851-014-0002-z)

Supplementary Table 2. Description of 92 autosomal gray whale SNPs associated with genes under selection in different species.

Locus name	Scaffold_position	Gene	Species	Citation
SNPa01	scaffold.11536954_25317	CXCR6	*Tursiops truncatus*	Nery et al. 2013
SNPa02	scaffold.11735904_444349	DDX54	Cetacean species	Foote et al. 2015
SNPa03	scaffold.11736281_50014	EHD3	*Tursiops truncatus*	Nery et al. 2013
SNPa04	scaffold.11736296_10999	A4GNT	Cetacean species	Foote et al. 2015
SNPa05	scaffold.11737044_320147	EIF2AK3	*Tursiops truncatus*	Nery et al. 2013
SNPa06	scaffold.11737172_20296	ZNF350	Cetacean species	Foote et al. 2015
SNPa07	scaffold.11737380_10032	CHST4	Cetacean species	Foote et al. 2015
SNPa08	scaffold.11737602_84701	DNAAF2	Cetacean species	Foote et al. 2015
SNPa09	scaffold.11738347_39694	KRT12	Cetacean species	Foote et al. 2015
SNPa10	scaffold.11738506_64384	CELA1	Cetacean species	Foote et al. 2015
SNPa11	scaffold.11738733_493836	ORC3	Mammal species	Foote et al. 2015
SNPa12	scaffold.11739090_87350	STK32A	*Tursiops truncatus*	Nery et al. 2013
SNPa13	scaffold.11739349_25942	DSC2	Cetacean species	Foote et al. 2015
SNPa14	scaffold.11739454_17885	LRP2	Cetacean species	Foote et al. 2015
SNPa15	scaffold.11739933_438449	TSPEAR	Cetacean species	Foote et al. 2015
SNPa16	scaffold.11740012_261685	GTF3A	Cetacean species	Foote et al. 2015
SNPa17	scaffold.11740254_536576	GREB1	*Tursiops truncatus*	Nery et al. 2013

SNPa18	scaffold.11740933_43610	MED24	*Tursiops truncatus*	Nery et al. 2013
SNPa19	scaffold.11741143_43382	TAP1	*Tursiops truncatus*	Nery et al. 2013
SNPa20	scaffold.11741481_66438	NPC1	*Tursiops truncatus*	Nery et al. 2013
SNPa21	scaffold.11741578_148103	PLEKHM3	*Tursiops truncatus*	Nery et al. 2013
SNPa22	scaffold.11741679_87585	FAIM	*Tursiops truncatus*	Nery et al. 2013
SNPa23	scaffold.11741835_158331	ADRB1	Cetacean species	Foote et al. 2015
SNPa24	scaffold.11742233_4626	METAP2	*Tursiops truncatus*	Nery et al. 2013
SNPa25	scaffold.11743069_175244	AKAP12	*Balaenoptera acutorostrata*	Yim et al. 2014
SNPa26	scaffold.11743151_100410	PCNA	*Balaena mysticetus*	Keane et al. 2015
SNPa27	scaffold.11743395_82148	FAM208B	Cetacean species	Foote et al. 2015
SNPa28	scaffold.11744045_693644	TGM1	Cetacean species	Foote et al. 2015
SNPa29	scaffold.11744272_148545	CSAD	Cetacean species	Foote et al. 2015
SNPa30	scaffold.11744715_90499	ASXL2	Mammal species	Foote et al. 2015
SNPa31	scaffold.11744735_65250	DNAJC12	*Tursiops truncatus*	Nery et al. 2013
SNPa32	scaffold.11745014_206127	APP	*Tursiops truncatus*	Nery et al. 2013
SNPa33	scaffold.11746333_38747	FGL2	Mammal species	Foote et al. 2015
SNPa34	scaffold.11746591_75743	FYN	*Balaenoptera acutorostrata*	Yim et al. 2014
SNPa35	scaffold.11746662_39854	FTL	Cetacean species	Foote et al. 2015
SNPa36	scaffold.11747598_28366	ZP2	*Balaenoptera acutorostrata*	Yim et al. 2014

SNPa37	scaffold.11748090_33854	FSHR	Cetacean species	Foote et al. 2015
SNPa38	scaffold.11748750_317645	BANF2	Mammal species	Foote et al. 2015
SNPa39	scaffold.11748803_80903	URB2	*Tursiops truncatus*	Nery et al. 2013
SNPa40	scaffold.11748874_57596	CXCL16	Cetacean species	Foote et al. 2015
SNPa41	scaffold.11749393_90671	TRANK1	Cetacean species	Foote et al. 2015
SNPa42	scaffold.11749470_425713	MRPL37	*Tursiops truncatus*	Nery et al. 2013
SNPa43	scaffold.11749832_42839	COL4A1	Cetacean species	Foote et al. 2015
SNPa44	scaffold.11749879_224142	NFATC2	Cetacean species	Foote et al. 2015
SNPa45	scaffold.11750125_114033	IFNAR2	*Tursiops truncatus*	Nery et al. 2013
SNPa46	scaffold.11750164_91753	TCOF1	Cetacean species	Foote et al. 2015
SNPa47	scaffold.11750207_62583	FAM216B	Cetacean species	Foote et al. 2015
SNPa48	scaffold.11751039_1109476	DHX34	*Tursiops truncatus*	Nery et al. 2013
SNPa49	scaffold.11752282_69851	KCNA4	Cetacean species	Foote et al. 2015
SNPa50	scaffold.11752561_2913	EIF3D	Cetacean species	Foote et al. 2015
SNPa51	scaffold.11752861_99073	RASSF8	Mammal species	Foote et al. 2015
SNPa52	scaffold.11753412_66351	SYT15	Cetacean species	Foote et al. 2015
SNPa53	scaffold.11753778_108724	SLC13A4	Cetacean species	Foote et al. 2015
SNPa54	scaffold.11754344_203710	RSAD2	Cetacean species	Foote et al. 2015
SNPa55	scaffold.11754404_2015	TRAF6	Cetacean species	Foote et al. 2015

SNPa56	scaffold.11754570_267715	URB1	Cetacean species	Foote et al. 2015
SNPa57	scaffold.11754783_80109	MYOM3	Cetacean species	Foote et al. 2015
SNPa58	scaffold.11754987_568882	MRPS5	Cetacean species	Foote et al. 2015
SNPa59	scaffold.11755085_4735	UPP1	*Tursiops truncatus*	Nery et al. 2013
SNPa60	scaffold.11755210_62479	TTC28	*Tursiops truncatus*	Nery et al. 2013
SNPa61	scaffold.11755244_276808	PDCD11	*Tursiops truncatus*	Nery et al. 2013
SNPa62	scaffold.11755545_218706	FZD7	*Tursiops truncatus*	Nery et al. 2013
SNPa63	scaffold.11755611_176412	TCF4	*Tursiops truncatus*	Nery et al. 2013
SNPa64	scaffold.11755645_67192	SRCIN1	*Balaenoptera acutorostrata*	Yim et al. 2014
SNPa65	scaffold.11755774_306897	AGA	*Balaena mysticetus*	Seim et al. 2014
SNPa66	scaffold.11755803_5837	FBXO10	Cetacean species	Foote et al. 2015
SNPa67	scaffold.11755917_214282	FBXO24	Cetacean species	Foote et al. 2015
SNPa68	scaffold.11756180_10850	PRF1	Cetacean species	Foote et al. 2015
SNPa69	scaffold.11756216_155377	SLC46A3	Cetacean species	Foote et al. 2015
SNPa70	scaffold.11756371_25268	HARS2	Cetacean species	Foote et al. 2015
SNPa71	scaffold.11756557_399867	JAKMIP3	Cetacean species	Foote et al. 2015
SNPa72	scaffold.11756815_77279	GNB5	*Tursiops truncatus*	Nery et al. 2013
SNPa73	scaffold.11757048_34339	STK36	Cetacean species	Foote et al. 2015
SNPa74	scaffold.11757296_155545	ZNF483	Cetacean species	Foote et al. 2015

SNPa75	scaffold.11757844_2527	DNM1L	*Tursiops truncatus*	Nery et al. 2013
SNPa76	scaffold.11757856_112749	ZNF23	Mammal species	Foote et al. 2015
SNPa77	scaffold.11757988_79308	P2RY8	Cetacean species	Foote et al. 2015
SNPa78	scaffold.11758255_224148	ARHGAP29	*Tursiops truncatus*	Nery et al. 2013
SNPa79	scaffold.11758384_322538	LOXL2	*Tursiops truncatus*	Nery et al. 2013
SNPa80	scaffold.11758981_271647	CPXM2	Cetacean species	Foote et al. 2015
SNPa81	scaffold.11759377_41598	FXN	*Tursiops truncatus*	Nery et al. 2013
SNPa82	scaffold.11759415_54423	Tutr-DQB	*Tursiops truncatus*	Lindblad-Toh et al. 2011
SNPa83	scaffold.11759462_6297	GPR114	Cetacean species	Foote et al. 2015
SNPa84	scaffold.11759849_37766	DENND3	Cetacean species	Foote et al. 2015
SNPa85	scaffold.11760392_107360	UTP3	Cetacean species	Foote et al. 2015
SNPa86	scaffold.11761068_89831	MINA	Cetacean species	Foote et al. 2015
SNPa87	scaffold.11761623_163902	BRF2	*Balaenoptera acutorostrata*	Yim et al. 2014
SNPa88	scaffold.11761866_802497	CNTRL	Cetacean species	Foote et al. 2015
SNPa89	scaffold.11761886_1422673	EMC1	Mammal species	Foote et al. 2015
SNPa90	scaffold.11762666_47455	CECR2	Mammal species	Foote et al. 2015
SNPa91	scaffold.11762730_75642	CENPO	Mammal species	Foote et al. 2015
SNPa92	scaffold.11762835_85596	CCDC83	Cetacean species	Foote et al. 2015

Supplementary Table 3. Summary statistics for the 88 autosomal loci. Observed (H_O) and expected (H_E) heterozygosity, deviations from Hardy-Weinberg (F_{IS}) with *P*-values are given. None of the loci deviated form HWE following sequential Bonferroni correction.

SNP	Locus	Gene	H_O	H_E	F_{IS}	*P*-value
SNPa01	scaffold.11536954_25317	CXCR6	0.2	0.228	0.122	0.444
SNPa02	scaffold.11735904_444349	DDX54	0.457	0.457	0	0.635
SNPa03	scaffold.11736281_50014	EHD3	0.6	0.479	-0.253	0.112
SNPa04	scaffold.11736296_10999	A4GNT	0.371	0.373	0.005	0.657
SNPa05	scaffold.11737044_320147	EIF2AK3	0.486	0.447	-0.086	0.423
SNPa06	scaffold.11737172_20296	ZNF350	0.257	0.343	0.25	0.149
SNPa07	scaffold.11737380_10032	CHST4	0.514	0.473	-0.087	0.434
SNPa08	scaffold.11737602_84701	DNAAF2	0.2	0.344	0.418	0.029
SNPa09	scaffold.11738347_39694	KRT12	0.171	0.159	-0.079	0.786
SNPa10	scaffold.11738506_64384	CELA1	0.543	0.492	-0.104	0.396
SNPa11	scaffold.11738733_493836	ORC3	0.543	0.5	-0.086	0.459
SNPa12	scaffold.11739090_87350	STK32A	0.429	0.448	0.043	0.554
SNPa13	scaffold.11739349_25942	DSC2	0.057	0.056	-0.015	0.987
SNPa15	scaffold.11739933_438449	TSPEAR	0.371	0.467	0.205	0.193
SNPa16	scaffold.11740012_261685	GTF3A	0.257	0.227	-0.133	0.521
SNPa17	scaffold.11740254_536576	GREB1	0.257	0.308	0.164	0.309

SNPa18	scaffold.11740933_43610	MED24	0.176	0.163	-0.082	0.795
SNPa19	scaffold.11741143_43382	TAP1	0.086	0.083	-0.03	0.949
SNPa20	scaffold.11741481_66438	NPC1	0.457	0.437	-0.046	0.558
SNPa21	scaffold.11741578_148103	PLEKHM3	0.343	0.287	-0.193	0.365
SNPa22	scaffold.11741679_87585	FAIM	0.389	0.32	-0.214	0.476
SNPa23	scaffold.11741835_158331	ADRB1	0.343	0.287	-0.193	0.336
SNPa24	scaffold.11742233_4626	METAP2	0.4	0.414	0.034	0.587
SNPa25	scaffold.11743069_175244	AKAP12	0.686	0.494	-0.388	0.026
SNPa26	scaffold.11743151_100410	PCNA	0.371	0.306	-0.214	0.234
SNPa27	scaffold.11743395_82148	FAM208B	0.2	0.182	-0.097	0.711
SNPa28	scaffold.11744045_693644	TGM1	0.086	0.083	-0.03	0.965
SNPa29	scaffold.11744272_148545	CSAD	0.486	0.501	0.03	0.597
SNPa30	scaffold.11744715_90499	ASXL2	0.114	0.109	-0.046	0.912
SNPa31	scaffold.11744735_65250	DNAJC12	0.4	0.458	0.127	0.349
SNPa32	scaffold.11745014_206127	APP	0.029	0.029	0	1.001
SNPa34	scaffold.11746591_75743	FYN	0.286	0.359	0.204	0.237
SNPa35	scaffold.11746662_39854	FTL	0.314	0.468	0.329	0.064
SNPa36	scaffold.11747598_28366	ZP2	0.657	0.478	-0.374	0.027

SNPa37	scaffold.11748090_33854	FSHR	0.571	0.435	-0.313	0.051
SNPa38	scaffold.11748750_317645	BANF2	0.2	0.228	0.122	0.441
SNPa39	scaffold.11748803_80903	URB2	0.4	0.387	-0.033	0.617
SNPa40	scaffold.11748874_57596	CXCL16	0.286	0.248	-0.153	0.484
SNPa41	scaffold.11749393_90671	TRANK1	0.543	0.5	-0.086	0.436
SNPa42	scaffold.11749470_425713	MRPL37	0.286	0.325	0.121	0.427
SNPa43	scaffold.11749832_42839	COL4A1	0.4	0.505	0.208	0.182
SNPa44	scaffold.11749879_224142	NFATC2	0.6	0.499	-0.202	0.202
SNPa46	scaffold.11750164_91753	TCOF1	0.171	0.159	-0.079	0.818
SNPa47	scaffold.11750207_62583	FAM216B	0.143	0.134	-0.063	0.845
SNPa48	scaffold.11751039_1109476	DHX34	0.543	0.492	-0.104	0.405
SNPa49	scaffold.11752282_69851	KCNA4	0.457	0.504	0.093	0.418
SNPa50	scaffold.11752561_2913	EIF3D	0.143	0.134	-0.063	0.866
SNPa51	scaffold.11752861_99073	RASSF8	0.429	0.34	-0.259	0.147
SNPa52	scaffold.11753412_66351	SYT15	0.143	0.134	-0.063	0.871
SNPa53	scaffold.11753778_108724	SLC13A4	0.353	0.332	-0.065	0.58
SNPa54	scaffold.11754344_203710	RSAD2	0.457	0.413	-0.106	0.434
SNPa55	scaffold.11754404_2015	TRAF6	0.429	0.34	-0.259	0.142

SNPa56	scaffold.11754570_267715	URB1	0.167	0.157	-0.063	0.929
SNPa57	scaffold.11754783_80109	MYOM3	0.114	0.109	-0.046	0.914
SNPa58	scaffold.11754987_568882	MRPS5	0.563	0.434	-0.295	0.097
SNPa59	scaffold.11755085_4735	UPP1	0.086	0.083	-0.03	0.958
SNPa60	scaffold.11755210_62479	TTC28	0.086	0.083	-0.03	0.964
SNPa61	scaffold.11755244_276808	PDCD11	0.6	0.464	-0.293	0.076
SNPa62	scaffold.11755545_218706	FZD7	0.371	0.482	0.23	0.156
SNPa63	scaffold.11755611_176412	TCF4	0.086	0.083	-0.03	0.962
SNPa64	scaffold.11755645_67192	SRCIN1	0.257	0.308	0.164	0.299
SNPa65	scaffold.11755774_306897	AGA	0.543	0.5	-0.086	0.445
SNPa66	scaffold.11755803_5837	FBXO10	0.543	0.465	-0.168	0.281
SNPa67	scaffold.11755917_214282	FBXO24	0.286	0.288	0.009	0.708
SNPa68	scaffold.11756180_10850	PRF1	0.657	0.478	-0.374	0.024
SNPa69	scaffold.11756216_155377	SLC46A3	0.286	0.325	0.121	0.394
SNPa70	scaffold.11756371_25268	HARS2	0.171	0.159	-0.079	0.784
SNPa71	scaffold.11756557_399867	JAKMIP3	0.229	0.36	0.364	0.055
SNPa72	scaffold.11756815_77279	GNB5	0.457	0.413	-0.106	0.408
SNPa73	scaffold.11757048_34339	STK36	0.333	0.284	-0.172	0.616

SNPa74	scaffold.11757296_155545	ZNF483	0.229	0.249	0.081	0.525
SNPa75	scaffold.11757844_2527	DNM1L	0.029	0.029	0	1.001
SNPa76	scaffold.11757856_112749	ZNF23	0.486	0.508	0.043	0.525
SNPa77	scaffold.11757988_79308	P2RY8	0.143	0.134	-0.063	0.839
SNPa78	scaffold.11758255_224148	ARHGAP29	0.457	0.356	-0.283	0.104
SNPa79	scaffold.11758384_322538	LOXL2	0.029	0.029	0	1.001
SNPa80	scaffold.11758981_271647	CPXM2	0.086	0.083	-0.03	0.961
SNPa81	scaffold.11759377_41598	FXN	0.143	0.134	-0.063	0.862
SNPa82	scaffold.11759415_54423	Tutr-DQB	0.343	0.287	-0.193	0.331
SNPa83	scaffold.11759462_6297	GPR114	0.171	0.206	0.167	0.397
SNPa85	scaffold.11760392_107360	UTP3	0.371	0.482	0.23	0.144
SNPa86	scaffold.11761068_89831	MINA	0.686	0.501	-0.369	0.028
SNPa87	scaffold.11761623_163902	BRF2	0.171	0.159	-0.079	0.784
SNPa88	scaffold.11761866_802497	CNTRL	0.286	0.248	-0.153	0.492
SNPa89	scaffold.11761886_1422673	EMC1	0.486	0.4	-0.214	0.183
SNPa90	scaffold.11762666_47455	CECR2	0.457	0.413	-0.106	0.447
SNPa91	scaffold.11762730_75642	CENPO	0.029	0.029	0	1.001
SNPa92	scaffold.11762835_85596	CCDC83	0.4	0.438	0.086	0.434

Overall	*0.329*	*0.313*	*-0.051*	*0.009*

Supplementary Table 4. Pairwise relatedness estimates (*r*) among each possible pair of individual gray whales in our sample. See the table in the main text for estimates of mean *r* > 0.30 (i.e., close relatives).

ER-14-0171	Z112745	0.298	(0.057—0.556)
ER-14-0149	Z112747	0.295	(-0.032—0.594)
ER-14-0158	Z112746	0.292	(0.044—0.478)
ER-14-0165	Z112746	0.292	(0.062—0.519)
ER-14-0163	ER-14-0155	0.292	(0.045—0.519)
ER-14-0160	ER-14-0174	0.289	(0.023—0.447)
ER-14-0159	ER-14-0160	0.289	(0.062—0.441)
ER-14-0164	ER-14-0175	0.288	(0.030—0.524)
ER-14-0156	ER-14-0169	0.288	(0.039—0.562)
ER-14-0157	ER-14-0166	0.283	(0.075—0.521)
ER-14-0157	ER-14-0175	0.283	(0.032—0.510)
ER-14-0161	Z112745	0.282	(-0.021—0.541)
ER-14-0164	ER-14-0166	0.277	(0.090—0.506)
ER-14-0164	Z112746	0.275	(0.063—0.489)
ER-14-0175	Z112746	0.275	(0.093—0.496)
ER-14-0171	Z1127432	0.273	(0.005—0.473)
ER-14-0157	ER-14-0171	0.270	(0.037—0.473)
ER-14-0157	Z112746	0.268	(0.019—0.526)
ER-14-0166	Z112746	0.264	(0.045—0.462)
ER-14-0164	ER-14-0171	0.264	(0.021—0.443)
ER-14-0167	ER-14-0164	0.263	(0.019—0.477)
ER-14-0157	ER-14-0167	0.257	(0.048—0.462)
ER-14-0151	Z112747	0.251	(0.032—0.450)
Z112747	Z112748	0.251	(0.010—0.494)
ER-14-0150	ER-14-0173	0.249	(0.000—0.450)

ER-14-0162	ER-14-0151	0.245	(-0.063—0.475)
ER-14-0162	Z112748	0.245	(0.005—0.484)
ER-14-0163	ER-14-0169	0.244	(-0.054—0.487)
ER-14-0162	ER-14-0148	0.238	(-0.024—0.446)
ER-14-0149	ER-14-0150	0.238	(-0.002—0.490)
ER-14-0166	ER-14-0149	0.235	(-0.004—0.498)
ER-14-0169	Z112745	0.231	(0.000—0.422)
ER-14-0157	ER-14-0150	0.231	(-0.140—0.512)
ER-14-0151	ER-14-0173	0.220	(-0.004—0.478)
ER-14-0173	Z112748	0.220	(0.037—0.486)
Z112745	GFD02	0.219	(-0.073—0.489)
ER-14-0167	Z112745	0.219	(-0.025—0.458)
ER-14-0159	ER-14-0150	0.218	(0.030—0.473)
ER-14-0149	ER-14-0174	0.216	(-0.009—0.425)
ER-14-0167	ER-14-0149	0.213	(-0.082—0.498)
ER-14-0150	ER-14-0170	0.210	(-0.030—0.432)
ER-14-0148	ER-14-0171	0.209	(-0.079—0.544)
ER-14-0151	ER-14-0155	0.208	(-0.030—0.434)
ER-14-0155	Z112748	0.208	(-0.061—0.434)
ER-14-0149	ER-14-0175	0.204	(-0.013—0.440)
ER-14-0150	ER-14-0174	0.204	(-0.024—0.448)
ER-14-0167	ER-14-0162	0.203	(-0.029—0.405)
ER-14-0148	ER-14-0155	0.202	(-0.038—0.433)
ER-14-0156	ER-14-0158	0.202	(-0.007—0.389)
ER-14-0156	ER-14-0165	0.202	(-0.002—0.403)
ER-14-0167	ER-14-0150	0.200	(-0.032—0.429)
ER-14-0164	ER-14-0150	0.199	(-0.102—0.500)

ER-14-0156	ER-14-0161	0.195	(-0.064—0.388)
ER-14-0167	ER-14-0163	0.195	(-0.080—0.403)
ER-14-0159	ER-14-0149	0.194	(-0.115—0.423)
ER-14-0156	Z1127432	0.194	(-0.100—0.451)
ER-14-0160	ER-14-0173	0.184	(-0.095—0.466)
ER-14-0160	ER-14-0161	0.183	(-0.104—0.426)
ER-14-0158	Z112745	0.182	(-0.061—0.447)
ER-14-0165	Z112745	0.182	(-0.045—0.443)
ER-14-0149	Z112744	0.182	(-0.116—0.483)
ER-14-0164	Z112747	0.177	(-0.053—0.415)
ER-14-0158	ER-14-0164	0.175	(-0.069—0.425)
ER-14-0164	ER-14-0165	0.175	(-0.101—0.464)
ER-14-0171	GFD02	0.172	(-0.056—0.425)
ER-14-0148	GFD02	0.172	(-0.057—0.388)
ER-14-0157	Z112747	0.170	(-0.062—0.407)
ER-14-0150	Z112744	0.170	(-0.102—0.342)
ER-14-0157	ER-14-0158	0.168	(-0.131—0.379)
ER-14-0157	ER-14-0165	0.168	(-0.133—0.542)
ER-14-0163	ER-14-0168	0.167	(-0.171—0.380)
Z112746	GFD02	0.167	(-0.047—0.426)
ER-14-0160	ER-14-0171	0.167	(-0.163—0.364)
ER-14-0158	ER-14-0175	0.166	(-0.104—0.383)
ER-14-0165	ER-14-0175	0.166	(-0.070—0.439)
ER-14-0149	GFD02	0.165	(-0.059—0.432)
ER-14-0173	Z112744	0.165	(-0.093—0.367)
ER-14-0149	ER-14-0171	0.164	(-0.060—0.408)
ER-14-0169	ER-14-0150	0.163	(-0.113—0.418)

Z1127432	GFD02	0.163	(-0.082—0.445)
ER-14-0160	ER-14-0149	0.162	(-0.074—0.456)
ER-14-0162	ER-14-0155	0.160	(-0.092—0.360)
ER-14-0158	ER-14-0166	0.158	(-0.056—0.391)
ER-14-0165	ER-14-0166	0.158	(-0.088—0.403)
ER-14-0150	GFD02	0.155	(-0.155—0.413)
ER-14-0170	ER-14-0171	0.154	(-0.122—0.417)
ER-14-0167	Z1127432	0.153	(-0.086—0.386)
ER-14-0162	ER-14-0171	0.151	(-0.114—0.444)
ER-14-0171	ER-14-0173	0.150	(-0.115—0.380)
ER-14-0159	Z112747	0.148	(-0.122—0.342)
ER-14-0162	ER-14-0150	0.147	(-0.075—0.400)
ER-14-0151	Z112744	0.145	(-0.100—0.372)
Z112744	Z112748	0.145	(-0.049—0.320)
ER-14-0174	Z112747	0.145	(-0.091—0.388)
ER-14-0166	Z112744	0.143	(-0.133—0.420)
ER-14-0163	Z112744	0.141	(-0.129—0.379)
ER-14-0151	ER-14-0174	0.139	(-0.094—0.380)
ER-14-0174	Z112748	0.139	(-0.171—0.360)
ER-14-0166	ER-14-0169	0.137	(-0.097—0.438)
ER-14-0167	ER-14-0169	0.136	(-0.207—0.419)
ER-14-0169	Z1127432	0.135	(-0.089—0.395)
Z112744	Z112747	0.134	(-0.072—0.336)
ER-14-0164	ER-14-0148	0.131	(-0.208—0.454)
ER-14-0157	Z112745	0.131	(-0.062—0.353)
ER-14-0156	GFD02	0.131	(-0.123—0.432)
ER-14-0163	ER-14-0171	0.129	(-0.082—0.405)

ER-14-0160	ER-14-0151	0.127	(-0.103—0.374)
ER-14-0160	Z112748	0.127	(-0.095—0.329)
ER-14-0162	Z112744	0.127	(-0.110—0.403)
ER-14-0150	ER-14-0175	0.126	(-0.177—0.423)
ER-14-0171	ER-14-0155	0.126	(-0.162—0.454)
ER-14-0166	ER-14-0150	0.126	(-0.136—0.399)
ER-14-0158	ER-14-0163	0.126	(-0.153—0.369)
ER-14-0163	ER-14-0165	0.126	(-0.112—0.429)
ER-14-0151	ER-14-0171	0.125	(-0.155—0.393)
ER-14-0171	Z112748	0.125	(-0.124—0.422)
ER-14-0157	ER-14-0148	0.124	(-0.167—0.393)
ER-14-0160	ER-14-0163	0.124	(-0.150—0.380)
ER-14-0167	ER-14-0161	0.123	(-0.164—0.384)
ER-14-0161	ER-14-0172	0.122	(-0.123—0.360)
ER-14-0164	ER-14-0155	0.122	(-0.167—0.427)
ER-14-0159	ER-14-0151	0.121	(-0.116—0.312)
ER-14-0159	Z112748	0.121	(-0.130—0.325)
ER-14-0164	ER-14-0151	0.121	(-0.183—0.394)
ER-14-0164	Z112748	0.121	(-0.178—0.369)
ER-14-0175	Z112744	0.121	(-0.161—0.406)
ER-14-0169	ER-14-0175	0.120	(-0.141—0.390)
ER-14-0157	ER-14-0155	0.116	(-0.202—0.377)
ER-14-0160	ER-14-0150	0.115	(-0.186—0.422)
ER-14-0150	ER-14-0152	0.114	(-0.146—0.391)
ER-14-0150	ER-14-0153	0.114	(-0.098—0.349)
ER-14-0157	ER-14-0151	0.114	(-0.175—0.387)
ER-14-0157	Z112748	0.114	(-0.115—0.378)

ER-14-0159	ER-14-0171	0.112	(-0.143—0.325)
ER-14-0171	ER-14-0174	0.112	(-0.157—0.406)
ER-14-0160	ER-14-0162	0.108	(-0.117—0.363)
ER-14-0157	Z112744	0.106	(-0.108—0.345)
ER-14-0152	ER-14-0154	0.106	(-0.226—0.354)
ER-14-0153	ER-14-0154	0.106	(-0.235—0.320)
ER-14-0171	ER-14-0152	0.104	(-0.248—0.378)
ER-14-0171	ER-14-0153	0.104	(-0.154—0.373)
ER-14-0156	ER-14-0166	0.103	(-0.123—0.357)
ER-14-0160	Z112745	0.103	(-0.143—0.363)
ER-14-0164	Z112744	0.103	(-0.209—0.373)
ER-14-0162	ER-14-0164	0.101	(-0.131—0.335)
ER-14-0164	Z112745	0.100	(-0.140—0.316)
ER-14-0149	ER-14-0155	0.100	(-0.136—0.350)
ER-14-0157	GFD02	0.100	(-0.143—0.328)
ER-14-0149	ER-14-0173	0.100	(-0.199—0.330)
ER-14-0155	Z112745	0.099	(-0.143—0.449)
ER-14-0167	ER-14-0173	0.099	(-0.171—0.382)
ER-14-0147	ER-14-0152	0.098	(-0.246—0.322)
ER-14-0147	ER-14-0153	0.098	(-0.253—0.335)
ER-14-0164	GFD02	0.097	(-0.097—0.418)
ER-14-0147	ER-14-0172	0.096	(-0.216—0.361)
ER-14-0161	ER-14-0171	0.094	(-0.149—0.316)
ER-14-0156	ER-14-0175	0.094	(-0.155—0.326)
ER-14-0157	ER-14-0162	0.093	(-0.180—0.324)
ER-14-0162	Z112746	0.091	(-0.151—0.355)
ER-14-0156	ER-14-0171	0.089	(-0.243—0.325)

ER-14-0170	Z112745	0.088	(-0.235—0.327)
ER-14-0167	ER-14-0160	0.086	(-0.143—0.303)
ER-14-0158	ER-14-0149	0.083	(-0.207—0.320)
ER-14-0165	ER-14-0149	0.083	(-0.202—0.337)
ER-14-0161	Z1127432	0.082	(-0.164—0.282)
ER-14-0173	Z112745	0.081	(-0.207—0.326)
Z112744	Z112745	0.080	(-0.230—0.305)
ER-14-0167	ER-14-0159	0.079	(-0.263—0.342)
ER-14-0172	ER-14-0154	0.079	(-0.200—0.322)
ER-14-0156	ER-14-0164	0.077	(-0.139—0.294)
ER-14-0169	ER-14-0152	0.077	(-0.208—0.307)
ER-14-0169	ER-14-0153	0.077	(-0.229—0.397)
ER-14-0158	ER-14-0150	0.075	(-0.139—0.363)
ER-14-0165	ER-14-0150	0.075	(-0.134—0.329)
ER-14-0164	Z1127432	0.075	(-0.162—0.261)
ER-14-0169	ER-14-0171	0.074	(-0.169—0.429)
ER-14-0162	ER-14-0149	0.073	(-0.177—0.355)
ER-14-0166	GFD02	0.070	(-0.189—0.400)
ER-14-0156	ER-14-0157	0.070	(-0.193—0.280)
ER-14-0161	ER-14-0162	0.070	(-0.221—0.376)
ER-14-0157	Z1127432	0.068	(-0.215—0.271)
ER-14-0163	ER-14-0173	0.067	(-0.156—0.289)
ER-14-0167	ER-14-0170	0.065	(-0.204—0.305)
ER-14-0167	ER-14-0174	0.061	(-0.186—0.318)
ER-14-0149	ER-14-0169	0.061	(-0.187—0.284)
ER-14-0152	ER-14-0172	0.060	(-0.218—0.360)
ER-14-0172	ER-14-0153	0.060	(-0.288—0.322)

ER-14-0167	ER-14-0175	0.056	(-0.168—0.290)
ER-14-0167	ER-14-0151	0.056	(-0.210—0.318)
ER-14-0167	Z112748	0.056	(-0.210—0.327)
ER-14-0162	Z112747	0.056	(-0.185—0.260)
ER-14-0150	ER-14-0155	0.056	(-0.193—0.302)
Z1127432	Z112745	0.056	(-0.231—0.310)
ER-14-0159	Z112744	0.054	(-0.216—0.297)
ER-14-0158	ER-14-0160	0.053	(-0.203—0.313)
ER-14-0160	ER-14-0165	0.053	(-0.261—0.376)
ER-14-0175	GFD02	0.052	(-0.220—0.313)
ER-14-0173	Z112746	0.050	(-0.283—0.325)
Z112744	Z112746	0.050	(-0.258—0.322)
ER-14-0156	ER-14-0150	0.049	(-0.210—0.325)
ER-14-0174	Z112744	0.048	(-0.257—0.337)
ER-14-0169	GFD02	0.047	(-0.225—0.311)
ER-14-0160	ER-14-0148	0.047	(-0.255—0.297)
ER-14-0169	Z112744	0.046	(-0.189—0.239)
ER-14-0173	GFD02	0.044	(-0.212—0.348)
ER-14-0159	ER-14-0161	0.044	(-0.189—0.330)
ER-14-0161	ER-14-0170	0.041	(-0.305—0.293)
ER-14-0161	ER-14-0174	0.038	(-0.153—0.385)
ER-14-0162	GFD02	0.037	(-0.266—0.279)
ER-14-0163	ER-14-0150	0.037	(-0.222—0.288)
ER-14-0166	Z112745	0.035	(-0.203—0.253)
ER-14-0167	Z112747	0.034	(-0.254—0.355)
ER-14-0160	Z112747	0.034	(-0.197—0.292)
ER-14-0158	ER-14-0169	0.033	(-0.214—0.274)

ER-14-0165	ER-14-0169	0.033	(-0.139—0.268)
ER-14-0160	ER-14-0169	0.033	(-0.239—0.286)
ER-14-0161	ER-14-0173	0.033	(-0.270—0.292)
ER-14-0167	ER-14-0166	0.032	(-0.207—0.290)
ER-14-0163	GFD02	0.032	(-0.147—0.316)
ER-14-0169	ER-14-0155	0.032	(-0.241—0.258)
ER-14-0156	ER-14-0155	0.030	(-0.225—0.334)
ER-14-0150	Z1127432	0.028	(-0.185—0.258)
ER-14-0156	Z112744	0.028	(-0.180—0.283)
ER-14-0156	Z112746	0.025	(-0.222—0.262)
ER-14-0151	GFD02	0.024	(-0.270—0.307)
Z112748	GFD02	0.024	(-0.214—0.291)
ER-14-0158	ER-14-0171	0.022	(-0.231—0.204)
ER-14-0165	ER-14-0171	0.022	(-0.200—0.304)
ER-14-0167	GFD02	0.020	(-0.225—0.295)
ER-14-0159	ER-14-0170	0.019	(-0.231—0.255)
ER-14-0170	ER-14-0174	0.019	(-0.203—0.347)
ER-14-0170	GFD02	0.018	(-0.285—0.293)
ER-14-0156	ER-14-0149	0.017	(-0.184—0.287)
ER-14-0158	ER-14-0155	0.015	(-0.279—0.273)
ER-14-0165	ER-14-0155	0.015	(-0.213—0.298)
ER-14-0175	Z112745	0.015	(-0.243—0.232)
ER-14-0163	ER-14-0148	0.015	(-0.281—0.337)
ER-14-0156	ER-14-0160	0.015	(-0.237—0.300)
ER-14-0158	ER-14-0148	0.015	(-0.240—0.332)
ER-14-0165	ER-14-0148	0.015	(-0.239—0.313)
ER-14-0159	Z112746	0.014	(-0.218—0.292)

ER-14-0174	Z112746	0.014	(-0.306—0.340)
ER-14-0168	ER-14-0150	0.012	(-0.297—0.273)
ER-14-0161	ER-14-0150	0.012	(-0.338—0.245)
ER-14-0173	Z112747	0.011	(-0.297—0.249)
ER-14-0168	ER-14-0169	0.008	(-0.294—0.328)
ER-14-0158	ER-14-0151	0.007	(-0.213—0.267)
ER-14-0158	Z112748	0.007	(-0.298—0.343)
ER-14-0165	ER-14-0151	0.007	(-0.255—0.311)
ER-14-0165	Z112748	0.007	(-0.261—0.262)
ER-14-0158	Z1127432	0.006	(-0.250—0.306)
ER-14-0165	Z1127432	0.006	(-0.180—0.278)
ER-14-0148	Z1127432	0.005	(-0.260—0.234)
ER-14-0155	Z112744	0.002	(-0.272—0.183)
ER-14-0160	ER-14-0170	0.001	(-0.288—0.268)
ER-14-0160	ER-14-0166	0.000	(-0.211—0.274)
ER-14-0152	GFD02	0.000	(-0.280—0.258)
ER-14-0153	GFD02	0.000	(-0.210—0.241)
ER-14-0160	ER-14-0175	0.000	(-0.219—0.295)
ER-14-0158	Z112747	-0.002	(-0.351—0.226)
ER-14-0165	Z112747	-0.002	(-0.265—0.249)
ER-14-0158	GFD02	-0.003	(-0.236—0.204)
ER-14-0165	GFD02	-0.003	(-0.264—0.219)
ER-14-0160	ER-14-0164	-0.004	(-0.243—0.250)
ER-14-0163	ER-14-0166	-0.006	(-0.322—0.277)
ER-14-0161	Z112744	-0.007	(-0.360—0.205)
ER-14-0160	ER-14-0155	-0.009	(-0.264—0.261)
ER-14-0156	ER-14-0170	-0.009	(-0.312—0.279)

ER-14-0166	ER-14-0152	-0.009	(-0.256—0.214)
ER-14-0166	ER-14-0153	-0.009	(-0.260—0.290)
ER-14-0157	ER-14-0160	-0.011	(-0.284—0.213)
ER-14-0150	Z112747	-0.012	(-0.274—0.233)
ER-14-0169	ER-14-0151	-0.012	(-0.290—0.243)
ER-14-0169	Z112748	-0.012	(-0.180—0.313)
ER-14-0162	Z112745	-0.012	(-0.255—0.300)
ER-14-0160	Z112744	-0.014	(-0.253—0.285)
ER-14-0148	Z112744	-0.016	(-0.279—0.304)
ER-14-0167	Z112744	-0.017	(-0.241—0.275)
ER-14-0149	Z112745	-0.024	(-0.341—0.220)
ER-14-0167	Z112746	-0.025	(-0.289—0.287)
ER-14-0163	ER-14-0175	-0.026	(-0.300—0.206)
ER-14-0152	ER-14-0175	-0.026	(-0.298—0.219)
ER-14-0153	ER-14-0175	-0.026	(-0.286—0.229)
Z112744	GFD02	-0.027	(-0.267—0.236)
ER-14-0170	ER-14-0173	-0.027	(-0.314—0.215)
ER-14-0155	Z112747	-0.029	(-0.307—0.201)
ER-14-0169	Z112746	-0.029	(-0.294—0.152)
ER-14-0163	ER-14-0151	-0.029	(-0.247—0.307)
ER-14-0163	Z112748	-0.029	(-0.277—0.284)
ER-14-0161	GFD02	-0.029	(-0.393—0.209)
ER-14-0160	Z1127432	-0.031	(-0.323—0.244)
ER-14-0166	ER-14-0171	-0.034	(-0.349—0.279)
ER-14-0147	ER-14-0161	-0.034	(-0.348—0.233)
ER-14-0171	Z112747	-0.036	(-0.254—0.254)
ER-14-0160	GFD02	-0.036	(-0.311—0.209)

ER-14-0157	ER-14-0173	-0.037	(-0.316—0.247)
ER-14-0161	Z112747	-0.037	(-0.236—0.208)
ER-14-0161	ER-14-0164	-0.037	(-0.300—0.273)
ER-14-0164	ER-14-0173	-0.037	(-0.351—0.296)
ER-14-0158	ER-14-0170	-0.037	(-0.292—0.175)
ER-14-0165	ER-14-0170	-0.037	(-0.351—0.196)
ER-14-0167	ER-14-0158	-0.038	(-0.234—0.207)
ER-14-0167	ER-14-0165	-0.038	(-0.309—0.149)
ER-14-0162	ER-14-0170	-0.040	(-0.346—0.271)
ER-14-0171	Z112744	-0.041	(-0.268—0.239)
ER-14-0151	ER-14-0175	-0.042	(-0.369—0.263)
ER-14-0175	Z112748	-0.042	(-0.348—0.211)
ER-14-0175	Z1127432	-0.043	(-0.279—0.184)
ER-14-0157	ER-14-0161	-0.045	(-0.256—0.204)
ER-14-0156	Z112747	-0.046	(-0.326—0.210)
ER-14-0163	Z112746	-0.048	(-0.330—0.260)
ER-14-0156	ER-14-0172	-0.048	(-0.392—0.281)
ER-14-0166	Z1127432	-0.049	(-0.293—0.240)
ER-14-0160	Z112746	-0.050	(-0.257—0.322)
ER-14-0148	Z112747	-0.050	(-0.446—0.204)
ER-14-0159	GFD02	-0.053	(-0.311—0.252)
ER-14-0174	GFD02	-0.053	(-0.294—0.236)
ER-14-0148	Z112746	-0.054	(-0.377—0.168)
ER-14-0161	ER-14-0148	-0.054	(-0.274—0.287)
ER-14-0148	Z112745	-0.054	(-0.320—0.198)
ER-14-0156	ER-14-0151	-0.054	(-0.329—0.228)
ER-14-0156	Z112748	-0.054	(-0.306—0.145)

ER-14-0167	ER-14-0172	-0.054	(-0.327—0.142)
ER-14-0171	ER-14-0175	-0.054	(-0.269—0.224)
ER-14-0161	ER-14-0166	-0.055	(-0.319—0.193)
ER-14-0166	ER-14-0174	-0.055	(-0.294—0.203)
ER-14-0161	ER-14-0175	-0.057	(-0.285—0.230)
ER-14-0166	ER-14-0151	-0.059	(-0.321—0.150)
ER-14-0166	Z112748	-0.059	(-0.274—0.277)
ER-14-0157	ER-14-0170	-0.059	(-0.278—0.168)
ER-14-0162	ER-14-0163	-0.062	(-0.315—0.210)
ER-14-0156	ER-14-0148	-0.064	(-0.285—0.153)
ER-14-0155	ER-14-0175	-0.064	(-0.330—0.175)
ER-14-0148	ER-14-0149	-0.065	(-0.284—0.181)
ER-14-0158	ER-14-0162	-0.066	(-0.426—0.200)
ER-14-0162	ER-14-0165	-0.066	(-0.299—0.235)
ER-14-0164	ER-14-0170	-0.067	(-0.416—0.212)
ER-14-0161	ER-14-0154	-0.067	(-0.411—0.187)
ER-14-0164	ER-14-0169	-0.068	(-0.286—0.212)
ER-14-0157	ER-14-0169	-0.069	(-0.276—0.227)
ER-14-0159	ER-14-0166	-0.069	(-0.271—0.188)
ER-14-0152	Z1127432	-0.071	(-0.285—0.295)
ER-14-0153	Z1127432	-0.071	(-0.456—0.221)
ER-14-0167	ER-14-0148	-0.071	(-0.436—0.237)
ER-14-0174	ER-14-0155	-0.073	(-0.296—0.173)
ER-14-0162	ER-14-0175	-0.073	(-0.281—0.115)
ER-14-0156	ER-14-0168	-0.076	(-0.368—0.207)
ER-14-0159	ER-14-0175	-0.077	(-0.350—0.206)
ER-14-0174	ER-14-0175	-0.077	(-0.294—0.156)

Z112745	Z112747	-0.079	(-0.389—0.161)
ER-14-0166	ER-14-0155	-0.079	(-0.286—0.131)
ER-14-0148	ER-14-0169	-0.079	(-0.341—0.246)
ER-14-0161	ER-14-0163	-0.080	(-0.342—0.169)
ER-14-0163	Z112747	-0.083	(-0.314—0.131)
ER-14-0158	ER-14-0161	-0.084	(-0.307—0.151)
ER-14-0161	ER-14-0165	-0.084	(-0.332—0.220)
ER-14-0159	ER-14-0155	-0.084	(-0.280—0.140)
ER-14-0149	ER-14-0172	-0.085	(-0.379—0.221)
ER-14-0167	ER-14-0168	-0.085	(-0.439—0.243)
ER-14-0167	ER-14-0152	-0.085	(-0.321—0.125)
ER-14-0167	ER-14-0153	-0.085	(-0.350—0.135)
ER-14-0173	ER-14-0155	-0.085	(-0.303—0.170)
ER-14-0155	Z112746	-0.088	(-0.344—0.179)
ER-14-0158	Z112744	-0.088	(-0.355—0.198)
ER-14-0165	Z112744	-0.088	(-0.346—0.231)
ER-14-0172	Z1127432	-0.088	(-0.535—0.174)
ER-14-0158	ER-14-0173	-0.091	(-0.393—0.255)
ER-14-0165	ER-14-0173	-0.091	(-0.357—0.166)
ER-14-0162	ER-14-0166	-0.095	(-0.337—0.156)
ER-14-0164	ER-14-0152	-0.096	(-0.332—0.118)
ER-14-0164	ER-14-0153	-0.096	(-0.333—0.153)
ER-14-0157	ER-14-0152	-0.097	(-0.349—0.128)
ER-14-0157	ER-14-0153	-0.097	(-0.347—0.145)
ER-14-0150	ER-14-0151	-0.098	(-0.291—0.154)
ER-14-0150	Z112748	-0.098	(-0.358—0.123)
ER-14-0158	ER-14-0152	-0.100	(-0.336—0.183)

ER-14-0158	ER-14-0153	-0.100	(-0.405—0.182)
ER-14-0165	ER-14-0152	-0.100	(-0.367—0.216)
ER-14-0165	ER-14-0153	-0.100	(-0.343—0.207)
ER-14-0151	Z112745	-0.100	(-0.343—0.139)
Z112745	Z112748	-0.100	(-0.363—0.131)
ER-14-0168	Z112745	-0.100	(-0.496—0.174)
ER-14-0171	ER-14-0172	-0.101	(-0.409—0.174)
ER-14-0168	ER-14-0155	-0.102	(-0.436—0.125)
ER-14-0172	Z112745	-0.104	(-0.368—0.149)
ER-14-0170	Z112747	-0.104	(-0.457—0.165)
ER-14-0163	ER-14-0149	-0.107	(-0.347—0.186)
ER-14-0159	Z112745	-0.107	(-0.430—0.196)
ER-14-0174	Z112745	-0.107	(-0.369—0.119)
ER-14-0158	ER-14-0168	-0.109	(-0.417—0.166)
ER-14-0165	ER-14-0168	-0.109	(-0.491—0.244)
ER-14-0168	ER-14-0175	-0.111	(-0.344—0.111)
ER-14-0150	Z112746	-0.112	(-0.334—0.135)
ER-14-0159	ER-14-0164	-0.112	(-0.360—0.193)
ER-14-0164	ER-14-0174	-0.112	(-0.369—0.138)
ER-14-0157	ER-14-0159	-0.114	(-0.381—0.163)
ER-14-0157	ER-14-0174	-0.114	(-0.333—0.197)
ER-14-0161	ER-14-0151	-0.114	(-0.364—0.131)
ER-14-0161	Z112748	-0.114	(-0.385—0.134)
ER-14-0170	ER-14-0152	-0.116	(-0.457—0.167)
ER-14-0170	ER-14-0153	-0.116	(-0.515—0.217)
ER-14-0148	ER-14-0170	-0.117	(-0.320—0.106)
ER-14-0156	ER-14-0152	-0.117	(-0.421—0.143)

ER-14-0156	ER-14-0153	-0.117	(-0.406—0.149)
ER-14-0166	ER-14-0168	-0.118	(-0.367—0.105)
ER-14-0151	Z1127432	-0.118	(-0.380—0.196)
Z1127432	Z112748	-0.118	(-0.428—0.173)
ER-14-0149	ER-14-0152	-0.119	(-0.338—0.165)
ER-14-0149	ER-14-0153	-0.119	(-0.414—0.159)
ER-14-0170	ER-14-0175	-0.123	(-0.357—0.123)
ER-14-0169	ER-14-0172	-0.127	(-0.417—0.142)
ER-14-0169	ER-14-0170	-0.127	(-0.436—0.107)
ER-14-0168	ER-14-0170	-0.128	(-0.440—0.140)
ER-14-0163	ER-14-0164	-0.131	(-0.326—0.207)
ER-14-0157	ER-14-0163	-0.132	(-0.331—0.162)
ER-14-0161	ER-14-0155	-0.133	(-0.387—0.092)
ER-14-0152	Z112745	-0.134	(-0.445—0.150)
ER-14-0153	Z112745	-0.134	(-0.461—0.173)
ER-14-0155	GFD02	-0.134	(-0.362—0.123)
ER-14-0152	ER-14-0173	-0.135	(-0.393—0.146)
ER-14-0153	ER-14-0173	-0.135	(-0.417—0.123)
ER-14-0148	ER-14-0173	-0.135	(-0.396—0.146)
ER-14-0163	ER-14-0170	-0.144	(-0.449—0.111)
ER-14-0159	ER-14-0163	-0.145	(-0.375—0.073)
ER-14-0163	ER-14-0174	-0.145	(-0.403—0.094)
ER-14-0169	ER-14-0173	-0.145	(-0.400—0.125)
ER-14-0160	ER-14-0168	-0.152	(-0.476—0.103)
ER-14-0166	ER-14-0170	-0.152	(-0.376—0.081)
ER-14-0160	ER-14-0172	-0.155	(-0.504—0.162)
ER-14-0168	GFD02	-0.161	(-0.431—0.112)

ER-14-0159	Z1127432	-0.162	(-0.363—0.099)
ER-14-0174	Z1127432	-0.162	(-0.435—0.146)
ER-14-0149	Z1127432	-0.163	(-0.421—0.071)
ER-14-0162	Z1127432	-0.164	(-0.453—0.094)
ER-14-0159	ER-14-0169	-0.164	(-0.351—0.102)
ER-14-0164	ER-14-0168	-0.164	(-0.474—0.150)
ER-14-0169	ER-14-0174	-0.164	(-0.419—0.152)
ER-14-0162	ER-14-0169	-0.166	(-0.378—0.146)
ER-14-0161	ER-14-0169	-0.166	(-0.420—0.141)
ER-14-0171	Z112746	-0.167	(-0.422—0.086)
ER-14-0161	ER-14-0152	-0.173	(-0.476—0.050)
ER-14-0161	ER-14-0153	-0.173	(-0.408—0.068)
Z112745	Z112746	-0.174	(-0.407—0.050)
ER-14-0157	ER-14-0168	-0.176	(-0.452—0.119)
ER-14-0159	ER-14-0148	-0.181	(-0.453—0.137)
ER-14-0173	Z1127432	-0.182	(-0.436—0.099)
ER-14-0148	ER-14-0150	-0.182	(-0.368—0.100)
Z1127432	Z112747	-0.186	(-0.435—0.102)
ER-14-0161	ER-14-0149	-0.192	(-0.439—0.093)
ER-14-0148	ER-14-0174	-0.194	(-0.465—0.126)
ER-14-0172	GFD02	-0.194	(-0.511—0.095)
ER-14-0168	Z112744	-0.195	(-0.595—0.057)
ER-14-0166	ER-14-0173	-0.204	(-0.380—0.055)
ER-14-0149	ER-14-0170	-0.205	(-0.496—0.028)
ER-14-0163	Z1127432	-0.214	(-0.458—0.004)
Z1127432	Z112744	-0.217	(-0.493—0.044)
ER-14-0156	ER-14-0173	-0.226	(-0.510—0.055)

ER-14-0160	ER-14-0152	-0.229	(-0.463—0.043)
ER-14-0160	ER-14-0153	-0.229	(-0.530—0.054)
ER-14-0173	ER-14-0175	-0.229	(-0.450—0.074)
ER-14-0152	ER-14-0174	-0.235	(-0.457—0.028)
ER-14-0153	ER-14-0174	-0.235	(-0.455—0.072)
ER-14-0168	ER-14-0171	-0.235	(-0.547—0.035)
ER-14-0161	Z112746	-0.236	(-0.441—0.064)
ER-14-0170	ER-14-0151	-0.237	(-0.519—-0.007)
ER-14-0170	Z112748	-0.237	(-0.471—0.006)
ER-14-0159	ER-14-0152	-0.238	(-0.505—0.055)
ER-14-0159	ER-14-0153	-0.238	(-0.440—0.073)
ER-14-0158	ER-14-0172	-0.240	(-0.532—0.044)
ER-14-0165	ER-14-0172	-0.240	(-0.557—0.101)
ER-14-0156	ER-14-0174	-0.241	(-0.472—-0.033)
ER-14-0155	Z1127432	-0.247	(-0.463—0.035)
ER-14-0170	ER-14-0155	-0.249	(-0.545—-0.023)
ER-14-0162	ER-14-0152	-0.251	(-0.515—0.009)
ER-14-0162	ER-14-0153	-0.251	(-0.577—-0.013)
ER-14-0156	ER-14-0159	-0.254	(-0.429—-0.059)
ER-14-0170	Z112744	-0.258	(-0.442—-0.001)
ER-14-0158	ER-14-0159	-0.262	(-0.492—0.068)
ER-14-0158	ER-14-0174	-0.262	(-0.482—0.137)
ER-14-0159	ER-14-0165	-0.262	(-0.495—0.043)
ER-14-0165	ER-14-0174	-0.262	(-0.488—-0.031)
ER-14-0166	ER-14-0148	-0.264	(-0.460—-0.044)
ER-14-0172	ER-14-0155	-0.264	(-0.504—-0.063)
ER-14-0168	Z1127432	-0.266	(-0.508—0.037)

ER-14-0169	Z112747	-0.268	(-0.457—0.011)
ER-14-0156	ER-14-0162	-0.269	(-0.471—-0.080)
ER-14-0162	ER-14-0172	-0.270	(-0.575—-0.007)
ER-14-0148	ER-14-0175	-0.274	(-0.483—-0.022)
ER-14-0168	ER-14-0149	-0.274	(-0.645—0.010)
Z1127432	Z112746	-0.279	(-0.489—-0.052)
ER-14-0148	ER-14-0152	-0.281	(-0.532—-0.007)
ER-14-0148	ER-14-0153	-0.281	(-0.545—-0.055)
ER-14-0152	Z112747	-0.285	(-0.495—0.041)
ER-14-0153	Z112747	-0.285	(-0.610—0.033)
ER-14-0159	ER-14-0172	-0.290	(-0.522—-0.077)
ER-14-0172	ER-14-0174	-0.290	(-0.531—0.024)
ER-14-0157	ER-14-0172	-0.292	(-0.609—0.030)
ER-14-0150	ER-14-0172	-0.293	(-0.540—-0.069)
ER-14-0166	ER-14-0172	-0.296	(-0.566—-0.053)
ER-14-0172	ER-14-0175	-0.296	(-0.575—-0.009)
ER-14-0148	ER-14-0168	-0.308	(-0.624—-0.027)
ER-14-0164	ER-14-0172	-0.311	(-0.651—-0.045)
ER-14-0168	Z112747	-0.317	(-0.761—-0.013)
ER-14-0152	Z112746	-0.324	(-0.546—-0.066)
ER-14-0153	Z112746	-0.324	(-0.575—-0.135)
ER-14-0168	Z112746	-0.327	(-0.662—-0.012)
ER-14-0148	ER-14-0172	-0.330	(-0.592—-0.022)
ER-14-0163	ER-14-0172	-0.342	(-0.618—-0.053)
ER-14-0152	Z112744	-0.348	(-0.587—-0.121)
ER-14-0153	Z112744	-0.348	(-0.589—-0.103)
ER-14-0172	Z112746	-0.349	(-0.643—-0.094)

ER-14-0170	ER-14-0172	-0.354	(-0.618—-0.048)
ER-14-0168	ER-14-0151	-0.360	(-0.699—-0.089)
ER-14-0168	Z112748	-0.360	(-0.626—-0.139)
ER-14-0163	ER-14-0152	-0.364	(-0.649—-0.128)
ER-14-0163	ER-14-0153	-0.364	(-0.619—-0.137)
ER-14-0170	Z112746	-0.367	(-0.588—-0.125)
ER-14-0147	ER-14-0159	-0.372	(-0.687—-0.046)
ER-14-0147	ER-14-0174	-0.372	(-0.619—-0.135)
ER-14-0154	ER-14-0174	-0.372	(-0.633—-0.061)
ER-14-0147	GFD02	-0.374	(-0.634—-0.143)
ER-14-0159	ER-14-0154	-0.374	(-0.712—-0.107)
ER-14-0147	ER-14-0171	-0.374	(-0.710—-0.065)
ER-14-0151	ER-14-0172	-0.374	(-0.632—-0.091)
ER-14-0172	Z112748	-0.374	(-0.665—-0.058)
ER-14-0154	GFD02	-0.383	(-0.715—-0.079)
ER-14-0171	ER-14-0154	-0.385	(-0.713—-0.083)
ER-14-0151	ER-14-0152	-0.388	(-0.645—-0.130)
ER-14-0151	ER-14-0153	-0.388	(-0.603—-0.101)
ER-14-0152	Z112748	-0.388	(-0.643—-0.113)
ER-14-0153	Z112748	-0.388	(-0.631—-0.171)
ER-14-0152	ER-14-0155	-0.391	(-0.631—-0.146)
ER-14-0153	ER-14-0155	-0.391	(-0.637—-0.131)
ER-14-0162	ER-14-0168	-0.399	(-0.789—-0.099)
ER-14-0168	ER-14-0173	-0.401	(-0.792—-0.051)
ER-14-0173	ER-14-0154	-0.416	(-0.696—-0.204)
ER-14-0156	ER-14-0147	-0.423	(-0.742—-0.103)
ER-14-0156	ER-14-0154	-0.433	(-0.744—-0.179)

ER-14-0161	ER-14-0168	-0.434	(-0.720—-0.112)
ER-14-0147	ER-14-0169	-0.449	(-0.811—-0.167)
ER-14-0172	ER-14-0173	-0.450	(-0.649—-0.132)
ER-14-0147	ER-14-0173	-0.451	(-0.781—-0.142)
ER-14-0159	ER-14-0168	-0.452	(-0.758—-0.229)
ER-14-0168	ER-14-0174	-0.452	(-0.737—-0.138)
ER-14-0169	ER-14-0154	-0.459	(-0.817—-0.151)
ER-14-0147	Z112745	-0.460	(-0.777—-0.225)
ER-14-0154	Z112745	-0.460	(-0.762—-0.203)
ER-14-0147	ER-14-0155	-0.460	(-0.782—-0.123)
ER-14-0147	ER-14-0162	-0.473	(-0.771—-0.196)
ER-14-0162	ER-14-0154	-0.474	(-0.899—-0.145)
ER-14-0172	Z112747	-0.479	(-0.753—-0.223)
ER-14-0172	Z112744	-0.482	(-0.740—-0.201)
ER-14-0147	ER-14-0167	-0.498	(-0.784—-0.240)
ER-14-0147	ER-14-0158	-0.505	(-0.875—-0.183)
ER-14-0147	ER-14-0165	-0.505	(-0.762—-0.209)
ER-14-0158	ER-14-0154	-0.505	(-0.802—-0.234)
ER-14-0165	ER-14-0154	-0.505	(-0.821—-0.151)
ER-14-0154	ER-14-0155	-0.508	(-0.795—-0.244)
ER-14-0167	ER-14-0154	-0.508	(-0.750—-0.183)
ER-14-0147	ER-14-0170	-0.513	(-0.762—-0.272)
ER-14-0147	Z1127432	-0.515	(-1.075—-0.164)
ER-14-0147	ER-14-0150	-0.515	(-0.818—-0.231)
ER-14-0147	ER-14-0148	-0.521	(-0.863—-0.208)
ER-14-0170	ER-14-0154	-0.523	(-0.817—-0.271)
ER-14-0150	ER-14-0154	-0.524	(-0.875—-0.208)

ER-14-0154	Z1127432	-0.524	(-0.875—-0.205)
ER-14-0147	ER-14-0149	-0.530	(-0.840—-0.205)
ER-14-0148	ER-14-0154	-0.531	(-0.928—-0.146)
ER-14-0147	ER-14-0160	-0.531	(-0.845—-0.307)
ER-14-0149	ER-14-0154	-0.537	(-0.853—-0.240)
ER-14-0160	ER-14-0154	-0.549	(-0.901—-0.279)
ER-14-0147	Z112746	-0.562	(-0.929—-0.311)
ER-14-0147	ER-14-0175	-0.566	(-0.811—-0.292)
ER-14-0147	ER-14-0166	-0.567	(-0.810—-0.324)
ER-14-0168	ER-14-0152	-0.568	(-0.899—-0.263)
ER-14-0168	ER-14-0153	-0.568	(-0.995—-0.274)
ER-14-0166	ER-14-0154	-0.572	(-0.778—-0.377)
ER-14-0154	Z112746	-0.573	(-0.922—-0.307)
ER-14-0154	ER-14-0175	-0.574	(-0.839—-0.293)
ER-14-0168	ER-14-0172	-0.600	(-0.995—-0.162)
ER-14-0147	Z112747	-0.608	(-0.915—-0.296)
ER-14-0147	ER-14-0151	-0.613	(-0.970—-0.335)
ER-14-0147	Z112748	-0.613	(-1.016—-0.322)
ER-14-0147	ER-14-0163	-0.620	(-0.937—-0.347)
ER-14-0163	ER-14-0154	-0.620	(-0.947—-0.312)
ER-14-0154	Z112747	-0.627	(-0.921—-0.324)
ER-14-0147	Z112744	-0.660	(-1.081—-0.272)
ER-14-0151	ER-14-0154	-0.660	(-1.042—-0.351)
ER-14-0154	Z112748	-0.660	(-1.085—-0.356)
ER-14-0154	Z112744	-0.666	(-1.153—-0.360)
ER-14-0157	ER-14-0147	-0.878	(-1.171—-0.570)
ER-14-0157	ER-14-0154	-0.886	(-1.256—-0.572)

ER-14-0147	ER-14-0164	-0.899	(-1.249—-0.618)
ER-14-0164	ER-14-0154	-0.907	(-1.211—-0.616)
ER-14-0147	ER-14-0168	-1.326	(-1.861—-0.954)
ER-14-0168	ER-14-0154	-1.328	(-1.940—-0.910)

SC/67A/SDDNA/02

Characterization of the gray whale (Eschrichtius robustus) genome and a genotyping array based on single nucleotide polymorphisms in candidate genes: update of SC/66b/DNA04

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Characterization of the gray whale (*Eschrichtius robustus*) genome and a genotyping array based on single nucleotide polymorphisms in candidate genes: update of SC/66b/DNA04

J. Andrew DeWoody[1,2], Nadia B. Fernandez[1], Anna Brüniche-Olsen[1], Jennifer D. Antonides[1], Jacqueline M. Doyle[1], Phillip San Miguel[3], Rick Westerman[3], Vladimir V. Vertyankin[4], Céline Godard-Codding[5], and John W. Bickham[6]

Departments of Forestry and Natural Resources[1], Biological Sciences[2], and Horticulture and Landscape Architecture[3], Purdue University, West Lafayette, IN 47907

[4]Kronotsky State Nature Biosphere Reserve, Elizovo, Kamchatka 684100 Russia

[5]The Institute of Environmental and Human Health, Texas Tech University and TTU Health Sciences Center, Box 41163, Lubbock, Texas 79409-1163

[6] Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77845

ABSTRACT

Paper SC/66b/DNA/04 reported the results of the genome sequences of 2 western gray whales from Sakhalin Island and 1 eastern gray whale from northern Alaska. A modified version of that paper has been accepted for publication in the journal Biological Bulletin. Herein we provide a summary of the paper, the links to the data archives, and a discussion of the ongoing research program.

INTRODUCTION

The following is the abstract of the paper: *Genetic and genomic approaches have much to offer in terms of ecology, evolution, and conservation. To help better understand the biology of the gray whale, we sequenced the genome and produced an assembly that contains ~95% of the genes known to be highly conserved among eukaryotes. From this assembly, we annotated 22,711 genes and identified 2,057,254 single nucleotide polymorphisms (SNPs). Using this assembly, we generated a curated list of candidate genes potentially subject to strong natural selection, including genes associated with osmoregulation, oxygen binding/delivery, and other aspects of marine life. From these candidate genes, we queried 88 autosomal protein-coding markers with a panel of 92 SNPs that also included two sexing and two mitochondrial markers. Genotyping error rates, calculated across loci and across 69 intentional replicate samples, were low (0.021%) and observed heterozygosity was 0.33 averaged over all autosomal markers. This level of variability provides substantial discriminatory power across loci (mean probability of identity of 1.6 x 10^{-25} and a mean probability of exclusion >0.999 with neither parent known), indicating that these markers provide a powerful means to assess parentage and relatedness in gray whales. We found 29 unique multilocus genotypes represented among our 36 biopsies (indicating that we inadvertently sampled 7 whales twice). In total, we compiled an individual dataset of 28 Western gray whales (WGSs) and 1 presumptive Eastern gray whale (EGW). The*

lone EGW we sampled was no more or less related to the WGWs than expected by chance alone. The gray whale genomes reported herein will enable comparative studies of natural selection in cetaceans and the SNP markers should be highly informative for future studies of gray whale evolution, population structure, demography, and relatedness.

AVAILABILITY OF THE GENOME SEQUENCES AND SNP DATA

Upon official publication of the paper, genome data will be available from NCBI and SNP data will be archived by the journal.

ONGOING STUDIES

Additional biopsies of western gray whales were collected as part of the Joint Program in 2015 and 2016. Those samples are currently being imported from Russia into the US to be analyzed for SNPs. In addition, we are collaborating with Jorge Urban to analyze SNPs from gray whales from the Mexican wintering lagoons, and with the North Slope Borough Department of Wildlife Management to analyze SNPs from stranded gray whales from northern Alaska. And a request for samples from gray whales from Japan is presently being proposed.

The genome sequence and SNP panel reported in this paper and the ongoing collection of a larger dataset of SNPs from western and eastern gray whales will provide a test of the hypotheses of gray whale stock structure currently being considered under the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales. Other useful applications include genetic fingerprinting for the identification of individual whales from their biopsies, estimates of relatedness and other population genetics parameters that inform of structure, genetic diversity, and aspects of behavior and reproduction. The SNP panel will provide a useful platform for future studies of gray whales because the results are directly comparable from lab to lab and study to study.

LITERATURE CITED

DeWoody, J. A., N. B. Fernandez, A. Brüniche-Olsen, J. D. Antonides, J. M. Doyle, P. San Miguel, R. Westerman, C. Godard-Codding, and J. W. Bickham. 2016. Novel single nucleotide polymorphisms from functional genes in the gray whale (*Eschrichtius robustus*) genome provide a powerful genotyping platform. Paper SC/66b/DNA04 submitted to the International Whaling Commission Scientific Committee. 57 pp.

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Characterization of the Gray Whale *Eschrichtius robustus* Genome and a Genotyping Array Based on Single-Nucleotide Polymorphisms in Candidate Genes

J. ANDREW DEWOODY[1,2,*], NADIA B. FERNANDEZ[1], ANNA BRÜNICHE-OLSEN[1], JENNIFER D. ANTONIDES[1], JACQUELINE M. DOYLE[1,3], PHILLIP SAN MIGUEL[4], RICK WESTERMAN[4], VLADIMIR V. VERTYANKIN[5], CÉLINE A. J. GODARD-CODDING[6], AND JOHN W. BICKHAM[7]

[1]*Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana 47907;* [2]*Department of Biological Sciences, Purdue University, West Lafayette, Indiana 47907;* [3]*Department of Biological Sciences, Towson University, Towson, Maryland 21252;* [4]*Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, Indiana 47907;* [5]*Kronotsky State Nature Biosphere Reserve, Elizovo, Kamchatka 684100, Russia;* [6]*Institute of Environmental and Human Health, Texas Tech University (TTU) and TTU Health Sciences Center, Box 41163, Lubbock, Texas 79409-1163; and* [7]*Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas 77845*

Abstract. Genetic and genomic approaches have much to offer in terms of ecology, evolution, and conservation. To better understand the biology of the gray whale *Eschrichtius robustus* (Lilljeborg, 1861), we sequenced the genome and produced an assembly that contains ~95% of the genes known to be highly conserved among eukaryotes. From this assembly, we annotated 22,711 genes and identified 2,057,254 single-nucleotide polymorphisms (SNPs). Using this assembly, we generated a curated list of candidate genes potentially subject to strong natural selection, including genes associated with osmoregulation, oxygen binding and delivery, and other aspects of marine life. From these candidate genes, we queried 92 autosomal protein-coding markers with a panel of 96 SNPs that also included 2 sexing and 2 mitochondrial markers. Genotyping error rates, calculated across loci and across 69 intentional replicate samples, were low (0.021%), and observed heterozygosity was 0.33 averaged over all autosomal markers. This level of variability provides substantial discriminatory power across loci (mean probability of identity of 1.6×10^{-25} and mean probability of exclusion >0.999 with neither parent known), indicating that these markers provide a powerful means to assess parentage and relatedness in gray whales. We found 29 unique multilocus genotypes represented among our 36 biopsies (indicating that we inadvertently sampled 7 whales twice). In total, we compiled an individual data set of 28 western gray whales (WGSs) and 1 presumptive eastern gray whale (EGW). The lone EGW we sampled was no more or less related to the WGWs than expected by chance alone. The gray whale genomes reported here will enable comparative studies of natural selection in cetaceans, and the SNP markers should be highly informative for future studies of gray whale evolution, population structure, demography, and relatedness.

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* To whom correspondence should be addressed. E-mail: dewoody@purdue.edu.

Abbreviations: EGW, eastern gray whale; EST, expressed sequence tag; HWE, Hardy-Weinberg equilibrium; IUCN, International Union for Conservation of Nature; IWC, International Whaling Commission; LD, linkage disequilibrium; MP, mate paired; PCR, polymerase chain reaction; PE, paired end; SNP, single-nucleotide polymorphism; STA, specific target amplification; WGW, western gray whale.

Introduction

The gray whale *Eschrichtius robustus* (Lilljeborg, 1861) was once common in both the North Pacific and the North

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Atlantic Ocean but disappeared from the Atlantic by the early 1700s because of overhunting (Mead and Mitchell, 1984). Contemporary gray whales are found only along the eastern and western coasts of the North Pacific Ocean (Andrews, 1914; Rice and Wolman, 1971; Fig. 1). Here, we follow the convention established by the International Union for Conservation of Nature (IUCN, 2008; Reilly *et al.*, 2008) and refer to an eastern gray whale (EGW) population and a western gray whale (WGW) population. We use WGW to refer to the gray whales that feed in the western North Pacific off the coast of Sakhalin Island, Russia (Fig. 1). The IUCN considers the extant WGW population to be critically endangered (IUCN, 2008; Reilly *et al.*, 2008), as there were only about 140 WGW adults in 2012 (Cooke *et al.*, 2013), and the population was previously believed to be extinct (Bowen, 1974; Weller *et al.*, 2002). The EGW population was reduced to a low of about 2000 individuals and has since made a strong recovery; the contemporary population numbers about 19,000 individuals (Laake *et al.*, 2009; Durban *et al.*, 2015).

Like so many of the great whales, modern gray whale populations declined steeply during the commercial whaling era (Mead and Mitchell, 1984; Alter *et al.*, 2012). On the basis of whaling records, Henderson (1984) estimated the size of the EGW population at 15,000–20,000 individuals prior to commercial hunting. The prewhaling WGW population is thought to have been much smaller (see Berzin and Vladimirov, 1981), but they were apparently not as restricted in geographic range as they are today (Reeves *et al.*, 2008).

Gray whales are occasionally sighted along a historical western migration corridor that includes waters near Russia's Sakhalin Island in the Sea of Okhotsk (Weller *et al.*, 2008; Weller and Brownell, 2012; Fig. 1). Studies based on the maternally inherited mitochrondrial DNA (mtDNA) genome have documented genetic differentiation between the WGWs sampled near Sakhalin and the EGW population (LeDuc *et al.*, 2002; Alter *et al.*, 2012; Meschersky *et al.*, 2015). Geospatial and genetic data (*e.g.*, Alter *et al.*, 2015; Mate *et al.*, 2015) suggest that the extant WGW and EGW populations have the potential to mix, and thus contemporary signals of population differentiation may represent historical patterns. Gray whales have great capacity to travel long distances (>22,000 km; Scheinin *et al.*, 2011; Shpak *et al.*, 2013), and in other great whales (*e.g.*, sperm whales; Alexander *et al.*, 2016) nuclear gene pools are nearly homogenous across vast geographic scales. The development of additional, more powerful genetic assays would be a boon to global gray whale conservation, as the ability to identify individuals and family groups, delineate populations, and track patterns of genetic diversity over space and time would result in more informed management decisions.

Suites of single-nucleotide polymorphisms (SNPs) can be used to delineate breaks in genetic structure, but they can also be used for definitive individual identifications (*e.g.*, from biopsies) and for categorical assignment of parentage or relatedness (*e.g.*, Ruegg *et al.*, 2014; Doyle *et al.*, 2016). Here, we developed a gray whale SNP panel to facilitate genetic stud-

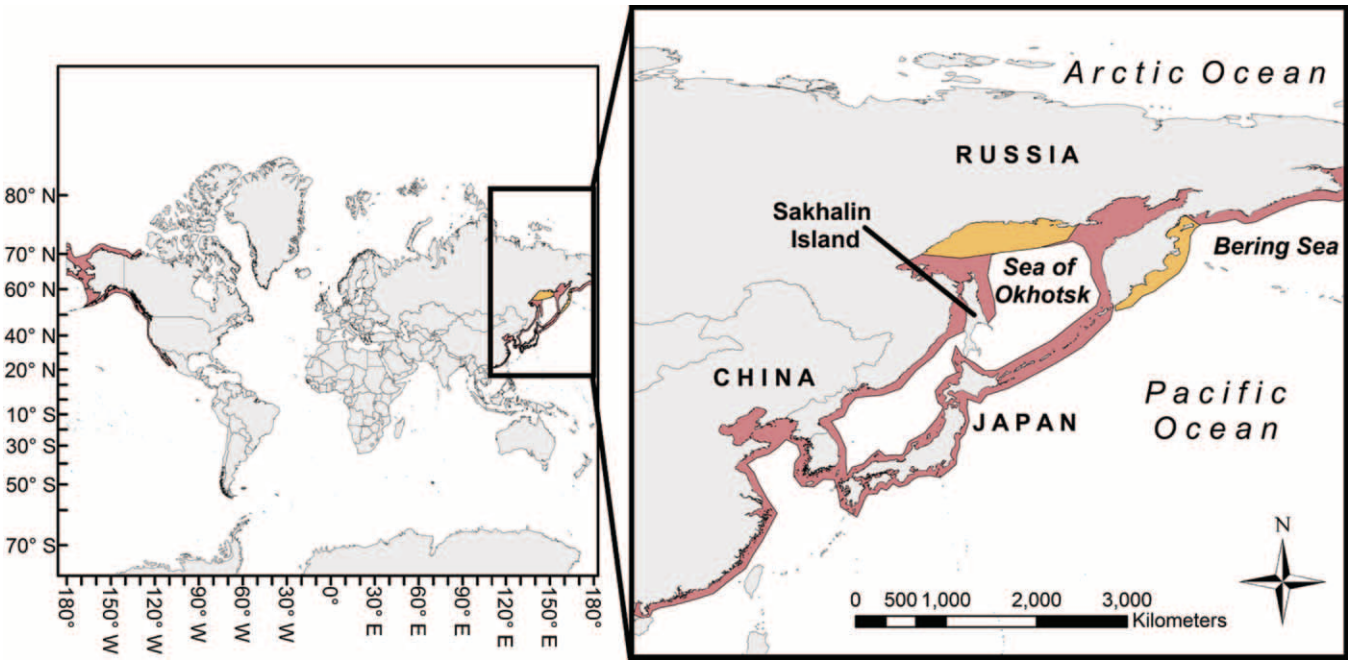

Figure 1. Range map of the gray whale according to 2008 International Union for Conservation of Nature (IUCN) data (which may not perfectly mirror the current range, particularly in the western Pacific). The red shading represents the "extant" portion of the range, and the orange shading represents the "probably extant" portion, according to the IUCN. *Inset:* presumptive range of the western gray whale.

ies of population differentiation, parentage, and individual identity. Instead of using anonymous SNP markers, we used SNPs from protein-coding genes thought to be targets of selection in other marine mammals because, in addition to providing a rich source of targets for future evolutionary genetic studies, they also have the potential to reveal subtle genetic differentiation sooner than neutral markers because of selection (Hoban *et al.*, 2016; Schweizer *et al.*, 2016).

To develop our SNP panel, we sequenced the genomes of two Sakhalin Island gray whales (a male and a female WGW) and a female EGW from Barrow, Alaska. Subsequently, multilocus SNP genotypes were generated for the single EGW plus a set of WGW biopsy samples ($n = 35$) collected near Sakhalin Island to provide a preliminary estimate of genomic diversity in gray whales. Our sample sizes are small despite three years of effort because these whales are rare and, like other baleen whales, difficult to sample because of both the expense involved and their extensive movements. However, the genome we describe here will allow researchers to explore evolutionary aspects of gray whales (*e.g.*, rates of nucleotide substitution) and perhaps identify genes and pathways unique to the species.

Materials and Methods

Sample collection and DNA extraction

Skin biopsies were obtained from WGWs on their summer feeding grounds near Sakhalin Island using methods approved by the Scientific Committee of the International Whaling Commission. These include samples from six calves as well as adults. Biopsy samples were frozen and shipped to Purdue University for processing. Skin samples from putative EGWs ($n = 2$) were cut from two dead gray whales that beached near Barrow, Alaska, and then frozen until processing at Purdue University. Genomic DNA was extracted using a standard potassium acetate protocol (Sambrook and Russell, 2001).

Genome sequencing, assembly, and annotation

The quality and quantity of DNA were greatest from the two WGWs (male ER-14-168 and female ER-14-0147), but we also sequenced one EGW (female GFD-02). For the male WGW, we constructed one paired-end (PE) library without polymerase chain reaction (PCR) amplification and one mate-paired (MP) no-gel library. For the two female gray whales (WGW and EGW), we constructed both MP and PE libraries. PE libraries were constructed per the instructions from the TruSeq DNA PCR-Free Library Preparation Kit (Illumina, San Diego, CA) using the 550-bp insert size method, whereas MP libraries were constructed per the instructions from the Nextera Mate Pair Library Preparation Kit (Illumina) using the "no gel size selection" method. In total, we sequenced 7 lanes of the PE libraries and 1 lane of the MP libraries using an Illumina HiSeq 2500 sequencing system (2×100).

We used FastQC software (ver. 0.11.2; Babraham Bioinformatics, 2016) to generate summary statistics for the sequencing data. Trimmomatic software (ver. 0.32; Bolger *et al.*, 2014) was used to remove adaptor sequences and low-quality bases (Phred scores <20). Multiple genome assemblies were generated using ABySS software (ver. 1.9.0; Simpson *et al.*, 2009) with a variety of *k*-mer values to produce the most comprehensive assemblies. We used the PE data during the contig-building steps and MP data during the scaffold-building steps.

Genome annotation was based on the male WGW to include genes found on the Y chromosome (*Zfy*) and the X chromosome (*Zfx*). We used the MAKER pipeline (ver. 2.28; Cantarel *et al.*, 2008) for annotation, following Doyle *et al.* (2014). Briefly, RepeatMasker software was used to identify and mask stretches of repetitive DNA. We subsequently used SNAP software (ver. 2013-02-16; Korf, 2004) to generate *ab initio* gene predictions. SNAP was trained (*i.e.*, gray whale gene models were generated) using cetacean protein sequences from the UniProtKB/Swiss-Prot database. SNAP gene predictions supported by expressed sequence tag (EST), protein, or InterProScan evidence were elevated to gene annotations. Cetacean protein data were downloaded from the UniProt Knowledgebase (Uniprot Consortium, 2017), and the manually annotated sequences were used with EST evidence derived from an assembled transcriptome of an Alaskan bowhead whale (Keane *et al.*, 2015). We used CEGMA software to assess the completeness of our genome assemblies (Parra *et al.*, 2007).

SNP identification and development

From published cetacean data, we generated a manually curated list of candidate genes potentially subject to strong natural selection. These include genes associated with osmoregulation, oxygen binding and delivery, and many other aspects of marine life (hereafter referred to as "nonneutral" or "candidate" genes; see Table S1 [available online], Table S2 [available online], and Kosiol *et al.*, 2008). We targeted SNPs from these genes because they can provide insights into adaptive divergence (Rico *et al.*, 2016), because they can help determine the biological significance of population genetic structure (Miller *et al.*, 2010), and because they can provide more power for population assignments (Freamo *et al.*, 2011; Helyar *et al.*, 2011). Using the MAKER transcripts from our genome annotation, we used BLAST software (ver. 2.2.31+) to annotate these candidate genes in the gray whale genome. For SNP identification, we used BWA software (ver. 0.7.12; Li and Durbin, 2009) to map all PE reads to the male assembly. We used GATK software (ver. 3.4; DePristo *et al.*, 2011; Van der Auwera *et al.*, 2013) to (1) identify and realign reads around insertions/deletions (indels), (2) identify SNPs with a minimum Phred quality score of 30 and a minimum depth of 10 reads, and (3) disregard SNPs within 20 bp of each other.

BEDOPS software (ver. 2.0; Neph *et al.*, 2012) was used to identify variable sites (*i.e.*, SNPs) within nonneutral genes. We used IGV software (ver. 2.3; Thorvaldsdóttir *et al.*, 2013) to identify target SNPs with at least 60 nucleotides (nt) of high-quality flanking sequence upstream and downstream and guanine and cytosine (GC) content less than 65%. We deliberately minimized linkage disequilibrium (LD) by choosing only single SNPs from a given scaffold.

Ultimately, we attempted to develop 92 autosomal nuclear markers from protein-coding genes specifically targeted because of evidence for selection in other marine mammals. Following preliminary population surveys *via* dideoxy sequencing (Alter and Palumbi 2009), we designed two mtDNA markers for haplotyping. For sexing, we designed two redundant SNP assays to assess differences in nucleotide sequence between the *Zfx* and *Zfy* genes, as reported in GenBank entries AF260789.1, AF260790.1, and AF260791.1.

SNP genotyping, error rates, and variability

We genotyped 36 gray whale biopsy samples at the 96 candidate SNP markers. Samples were genotyped using a Fluidigm Juno Genotyping System (Fluidigm, South San Francisco, CA), and a specific target amplification (STA) step was incorporated to facilitate genotyping of the low-quantity DNA samples that are often associated with endangered species. The STA step refers to Fluidigm's multiplex PCR, which uses a low molar concentration of each primer and limited thermal cycles to increase template material for downstream amplification. Individual SNP calls were visualized and edited using Fluidigm's genotyping analysis software; data from nuclear loci that did not produce obvious clusters of homozygotes and heterozygotes (see Fig. 2) were excluded from further analyses.

In theory, our 35 WGW biopsies could include whales that were inadvertently sampled more than once (*e.g.*, in subsequent years). We used allelematch in R software (Galpern *et al.*, 2012; R Development Core Team, 2008) to group replicate genotypes into unique records that represent individual whales, allowing for a maximum of two mismatches between replicates. Preliminary analyses conducted with the diagnostic function amUniqueProfile were used to determine the number of mismatches most appropriate for clustering replicate genotypes into groups (Galpern *et al.*, 2012). All genotypes identified as replicates were subsequently confirmed by manually evaluating the SNP calls.

Error rates were calculated using replicate DNA samples ($n = 69$ in total) from 27 individual gray whales. The plurality principle was used to determine a consensus genotype for each individual whale by using SNP calls across replicate samples (see Doyle *et al.*, 2016). The SNP typing error rate (e) was calculated according to the equation $e = m/[d(s)]$, where m represents the total number of mismatches between each replicate sample and the consensus sequence across multiple samples from the same individual, d represents the total number of loci per replicate sample, and s represents the total number of replicate samples. Both incorrect SNP calls (errors of commission) and instances where no amplification occurred (errors of omission) contributed to m.

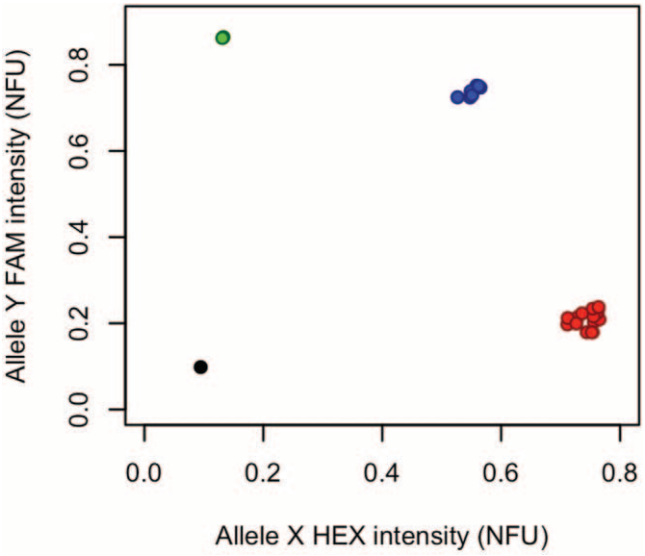

Figure 2. Example of high-quality Fluidigm data from an autosomal whale single-nucleotide polymorphism: clustering results for locus 11737172_20296. GG homozygotes are shown in green, heterozygotes are shown in blue, and TT homozygotes are shown in red. The negative control is shown as the black data point. NFU, normalized fluorescence units.

We used GENALEX software (ver. 6.5; Peakall and Smouse, 2012) to quantify observed (H_O) and expected (H_E) heterozygosity, the mean probability of identity (P_I), and the mean probability of exclusion with neither parent known (P_E). We tested for deviations from Hardy-Weinberg equilibrium (HWE) and for LD after applying a sequential Bonferroni correction to account for multiple tests (Holm, 1979). The inbreeding coefficient f (Weir and Cockerham, 1984) was evaluated in GENODIVE software (ver. 2.0b27; Meirmans and Van Tienderen, 2004) using 10^3 permutations.

Molecular sexing and haplotyping

For validation purposes, all samples were sexed using a traditional PCR/gel method (Bérubé and Palsboll, 1996) as well as by using our novel sexing SNPs. Similarly, mtDNA haplotypes were generated using both traditional dideoxy methods (Alter and Palumbi, 2009) and novel SNP markers. We then compared the concordance among assays to validate our novel markers.

Relatedness and effective size

Relatedness among individuals was first estimated using RELATED software (ver. 1.0; Wang, 2011; Pew *et al.*, 2015), which implements five widely used moment-based related-

ness estimators. To identify the estimator that performed best with our data, we used our empirical allele frequencies to simulate 100 data sets for 4 types of dyads: parent-offspring pairs (expected $r = 0.5$), full siblings ($r = 0.5$), half siblings ($r = 0.25$), and unrelated individuals ($r = 0.0$). Point estimates and 95% confidence intervals (CIs) were estimated on the basis of 100 bootstrap replicates, and the best estimator was identified using Pearson's correlation coefficient. This estimator was used to compare the observed mean pairwise relatedness of each individual whale (r_{pw}) to the mean for the population (r_{pop}). Thus, r_{pw} represents the mean relatedness of a single individual whale to every other whale in the population, whereas r_{pop} represents the mean relatedness of the population as a whole. By comparing r_{pw} to r_{pop}, individual whales were identified that were more or less related to the population than expected by chance alone.

Because several commonly used relatedness estimators can be problematic when used with biallelic loci (Oliehoek *et al.*, 2006), we also calculated a pairwise genotypic similarity index following Blouin *et al.* (1996). The M_{xy} statistic quantifies the mean number of shared alleles (M_{xy}) among pairs of samples (in our case, 630 pairs). For each locus, the number of matching allelic positions (0, 1, or 2) between pairs of individuals was determined using only loci with no missing data among a given pair of whales. For each individual sample ($n = 36$), we calculated mean observed M_{xy} and 95% CI, which was compared with the population mean and 95% CI.

Conventional relatedness and allele-sharing approaches like those described above do not differentiate between relationship categories. For example, both parent-offspring pairs and full-sibling pairs are expected to have $r = 0.5$. CERVUS software (ver. 3.0.7; Marshall *et al.*, 1998; Kalinowski *et al.*, 2007) was used to assign parentage to calves. All adults identified in the field were considered candidate parents. Simulations included 100,000 replicate cycles with the number of candidate males and females set to 200 and the proportion of candidate males and females sampled set to 0.1. The proportion of loci mistyped was set to 0.0002, and the minimum allowable confidence level at which a parent assignment was accepted was 95%.

To provide preliminary estimates of contemporary effective population size (n_e) and effective number of breeders (n_{eb}) of the critically endangered WGW population, we used NeESTIMATOR software (ver. 2.01; Do *et al.*, 2014). The software implements two different methods for estimating n_e from a single sample, based on (1) LD (Waples and Do, 2008) and (2) heterozygosity excess (Zhdanova and Pudovkin, 2008). A molecular coancestry approach (Nomura, 2008)—also implemented in NeESTIMATOR—was used for estimating n_{eb}. Note that these methods assume selectively neutral markers and closed populations, so these n_e and n_{eb} estimates may be biased. Moreover, the influence of selection and migration on such estimates is unknown, as it has not been investigated in a thorough, systematic manner (Waples, 2006).

Results

Genome sequencing, assembly, and annotation

Our WGW sequencing results are compiled in Tables 1 and 2; the EGW genome yielded a poor-quality sequence and was not assembled. We generated >2.5 billion reads (~2 billion high-quality reads after quality control) that collectively span ~200 billion bases and contain nearly all of the core genes common to eukaryotes (Tables 1, 2). The scaffold N50, which represents the value where more than half of the assembly is contained in larger contiguous regions, was ~180,000 bp for the best assembly. We annotated roughly 22,700 genes, a number similar to other cetacean genome studies (Tables S1, S6, available online).

SNP identification and development

We identified 2,057,254 candidate SNPs from the WGWs, of which 1,474,749 passed quality-filtering criteria. Of this high-quality subset, 8413 SNPs were located in exons that were identified in the genome annotation. From these exonic SNPs, we designed and tested 96 SNPs for our genotyping assay. Four were ultimately excluded because they were monomorphic, clustered poorly, or were otherwise of insufficient quality. These novel SNP loci and flanking sequences are described in Table S5, available online. The 92 informative loci include 88 gene-associated nuclear markers, 2 mitochondrial markers, and 2 nuclear sexing markers (Table S2, available online).

SNP genotyping, variability, and error rates

The vast majority of markers amplified in each individual DNA sample. By genotyping 27 of the 36 biopsy samples multiple times, we calculated an overall genotyping error rate (e) of 0.021%. The mean probability of identity (P_I; Waits *et al.*, 2001) was 1.6×10^{-25}, and the mean probability of exclusion (P_E; Jamieson and Taylor, 1997) with neither parent known was >0.999. According to allelematch, the 36 biopsies represented a total of 29 unique multilocus genotypes that correspond to 29 individual gray whales (*i.e.*, we inadvertently sampled 7 whales twice). Observed and expected heterozygosities at autosomal SNPs were 0.32 ± 0.19 (mean ± SD) and 0.31 ± 0.17, respectively, for all WGWs sampled ($n = 28$). All autosomal SNP loci were in HWE following sequential Bonferroni correction (Table S3, available online). The H_O and H_E of male whales ($n = 11$) averaged 0.31 ± 0.02 and 0.29 ± 0.02, respectively, across all autosomal markers, whereas the H_O and H_E of female whales ($n = 17$) averaged 0.33 ± 0.02 and 0.31 ± 0.02, respectively. The mean inbreeding coefficient (f) was -0.05.

Molecular sexing and haplotyping

Samples from the 29 individual gray whales were sexed using both our novel SNP assays and the traditional method

Table 1

Sequencing statistics associated with the western gray whale genome

Sample name	Mean insert size (bp)	Mode insert size (bp)	Total reads	Total bases	Quality reads	Quality bases
Paired-end libraries						
ER-14-0147	471	481	1,331,820,280	134,513,848,280	988,439,854	97,099,230,094
ER-14-0168	497	506	1,254,676,990	126,722,375,990	974,126,824	95,896,562,771
Mate-paired libraries						
ER-14-0147	2223	1463	184,404,728	18,624,877,528	146,095,780	13,350,014,231
ER-14-0168	2363	1426	213,408,466	21,554,255,066	168,844,292	15,387,314,171

with PCR and gel electrophoresis (Table 3). The results of the 2 methods were in complete concordance with one another (see Fig. 3), indicating that our samples were derived from 11 males and 18 females. These same samples were haplotyped using both our mtDNA SNP assays as well as traditional Sanger sequencing. Although our marker set queries only two mtDNA sites, this marker panel could easily be extended to other SNP sites known to be variable in gray whales; we provide here the proof-of-concept data.

Relatedness and effective size

Mean pairwise relatedness (r_{pop}) observed among all 29 individual gray whales (including one EGW individual) was −0.032, and the 95% CI ranged from −0.055 to −0.009. In general, relatedness estimates based on r and on M_{xy} were qualitatively similar, so we focused on M_{xy} for reasons discussed in Oliehoek *et al.* (2006). Our analysis of pairwise relatedness confirmed the allelematch results in that 7 of our biopsies were duplicates. For example, the mean number of shared alleles (M_{xy}) ranged from 0.667 to 1.0 for all 630 pairwise comparisons (Fig. 4), including the 7 duplicate biopsy pairs identified by allelematch, all of which had $M_{xy} = 1.0$. Many dyads were likely first-degree relatives (*e.g.*, full siblings or parent-offspring pairs). The mean number of shared alleles for each of the 29 individual whales ranged from 0.768 to 0.851 (Fig. 5). The population mean $M_{xy(pop)}$ was 0.834 (95% CI: 0.831–0.838; Fig. 5).

The CERVUS analyses were used to investigate suspected relationships among two ostensible cow-calf pairs. CERVUS confirmed one such relationship (ER14-0159/ER14-0173) on the basis of field observations but not the other (ER14-0152/ER14-0172). No sires were identified in our sample, but our relatedness analyses identified two potential full sisters (ER14-0162 and ER14-0173; pairwise $r = 0.483$). These two adult females apparently share the same mother (ER14-0174/ER14-0159).

The n_e estimates of contemporary WGW were similar based on LD (mean $n_e = 14.1$; 95% CI: 12.1–16.7) and heterozygosity excess (mean $n_e = 14.4$; 95% CI: 7.6–254.1). The effective number of breeders, based on individual coancestry, was 1.3 (95% CI: 1.0–1.7).

Discussion

Genome sequencing, assembly, and annotation

The gray whale genome assemblies we describe (Tables 1, 2) consist of ~22,700 genes and contain ~95% of the genes known to be highly conserved among eukaryotes (Parra *et al.*, 2007). These assemblies are relatively complete and reveal that the gray whale genome appears to be fairly typical of cetaceans in terms of genome size and gene complement (Table S1, available online). Foote *et al.* (2015) have argued that the genomes of marine mammals have evolved in a convergent fashion, and future research will determine what propor-

Table 2

Summary statistics generated by ABySS software for the western gray whale genome assemblies

Sample	Contig N50	Scaffolds	Assembly size	Min. length	Max. length	Scaffold N50	*n* : N50	Comp%
ER-14-0147	8336	60,534	3,082,450,012	500	1,943,192	180,882	4539	95
ER-14-0168	8690	57,219	2,849,466,389	500	1,944,941	187,455	4089	96

In both cases, a *k*-mer length of 60 produced the best assemblies shown here. The contigs were created from the paired-end reads, and then the mate-paired reads were used to scaffold the final assembly. The N50, measured in bases, represents a midpoint whereby half of the assembled sequence is contained in contigs or scaffolds larger than the N50. "*n* : N50" refers to the number of scaffolds of length N50 and longer. "Comp%" refers to the percentage of 248 ultraconserved core eukaryotic genes detected in the gray whale assembly (Parra *et al.*, 2007). Ultraconserved genes that were not identified in the gray whale assembly can be found in Table S4, available online.

Table 3

Haplotype and sex data

		mtDNA		Sex chromosomes		
Sample	Population	CR_82	CR_104	ZFY_288	ZFY_342	Sex
ER-14-0147	Western	G : G	G : G	C : C	G : G	Female
ER-14-0148	Western	A : A	G : G	C : C	G : G	Female
ER-14-0149	Western	A : A	G : G	C : C	G : G	Female
ER-14-0150	Western	G : G	A : A	C : T	A : G	Male
ER-14-0153	Western	G : G	G : G	C : C	G : G	Female
ER-14-0155	Western	A : A	G : G	C : C	G : G	Female
ER-14-0156	Western	A : A	G : G	C : T	A : G	Male
ER-14-0160	Western	G : G	A : A	C : T	A : G	Male
ER-14-0161	Western	G : G	A : A	C : C	G : G	Female
ER-14-0162	Western	G : G	G : G	C : C	G : G	Female
ER-14-0163	Western	G : G	G : G	C : C	G : G	Female
ER-14-0164	Western	A : A	G : G	C : T	A : G	Male
ER-14-0165	Western	A : A	G : G	C : T	A : G	Male
ER-14-0167	Western	G : G	G : G	C : T	A : G	Male
ER-14-0168	Western	G : G	G : G	C : T	A : G	Male
ER-14-0169	Western	A : A	G : G	C : T	A : G	Male
ER-14-0170	Western	G : G	A : A	C : T	A : G	Male
ER-14-0171	Western	G : G	A : A	C : C	G : G	Female
ER-14-0172	Western	G : G	G : G	C : C	G : G	Female
ER-14-0173	Western	G : G	G : G	C : C	G : G	Female
ER-14-0174	Western	G : G	G : G	C : C	G : G	Female
ER-14-0175	Western	A : A	G : G	C : T	. . .	Male
Z112743	Western	G : G	G : G	C : T	A : G	Male
Z112744	Western	G : G	G : G	C : C	G : G	Female
Z112745	Western	G : G	G : G	C : C	G : G	Female
Z112746	Western	A : A	G : G	C : C	G : G	Female
Z112747	Western	A : A	G : G	C : C	G : G	Female
Z112748	Western	A : A	G : G	C : C	G : G	Female
GFD02	Eastern	G : G	A : A	C : C	G : G	Female

Shown are genotypes for two mitochondrial (CR_82 and CR_104) and two sexing (ZFY_288 and ZFY_342) markers. A missing genotype is represented by an ellipsis.

tion of the gray whale genes we annotated (Table S1) are orthologues of the 16,878 genes shared by the killer whale, manatee, walrus, and bottlenose dolphin (Foote *et al.*, 2015) and what proportion are paralogues resulting from gene duplication. We expect that many of these species have faced similar selection pressures with regard to genes involved in processes such as osmoregulation (*e.g.*, adaptation to a saline environment), thermoregulation (*e.g.*, adipose deposition), and oxygen binding.

SNP identification and development

From the genomic sequence data, we identified hundreds of thousands of SNPs that could potentially be used in population genetic surveys. Of these, we evaluated 96 and found that 92 were polymorphic, had low error rates, and could be amplified in a single assay. This panel of markers should be sufficient for investigations of genetic parentage, relatedness, individuality (*i.e.*, DNA fingerprinting), demographic turnover, and population structure. However, the much larger set of SNPs we identified could inform future genome scans based on restriction-site-associated DNA sequencing (Miller *et al.*, 2007) or other queries of anonymous SNPs that might also be informative for studies of natural selection and/or demographic history. We note that our markers are useful in the critically endangered WGWs, so we expect them to be variable in the more plentiful EGWs. However, robust allele frequency estimates will be needed to assess their utility in EGWs (and to search for potential ascertainment biases).

SNP genotyping, variability, and error rates

The oligonucleotides we developed and the SNPs they query were assessed with the Fluidigm platform because it requires very little DNA. We note, however, that our markers could instead be assayed with alternative genotyping technologies. Because these markers are polymorphic and have low error rates (~0.02%), we expect laboratory-to-laboratory variability to be low, as 99.98% of our replicate data were identical across independent genotyping runs. For example,

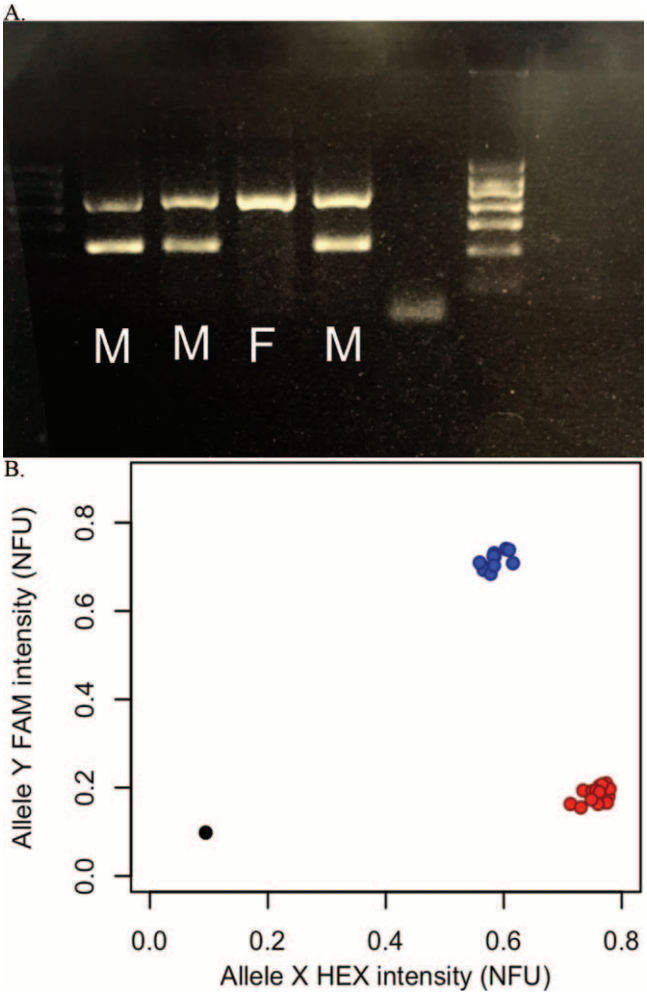

Figure 3. Perfect concordance between (A) the traditional polymerase chain reaction/gel method and (B) our novel single-nucleotide polymorphism sexing assays. (A) demonstrates that the traditional method produces a single product in females (*Zfx*) and two products in males (*Zfx* and *Sry*); also shown are a no-template control and a size standard. (B) demonstrates that males (blue) and females (red) can be distinguished from one another based on HEX and FAM intensity measured in normalized fluorescence units (NFU).

a whale from the western Pacific that is genotyped with these SNPs could be identified as one also sampled in the eastern Pacific provided the genotypes are stored in a common database that could easily be queried by independent research groups (*e.g.*, in a public database on the cloud).

The power available for individual identification and parentage is captured by P_I and P_E, respectively. In theory (based on allele frequencies in our small sample of WGWs), mean $P_I = 1.6 \times 10^{-25}$. In practice, our limited sampling revealed multiple biopsies from the same donor whales (see below). Similarly, a calf's unknown parentage could be determined among hundreds of candidate parents with virtual certainty if all were genotyped with this SNP panel ($P_E >$ 0.999). For applications that require more power, our genome data include a large pool of additional SNPs that could serve as supplemental markers.

Relatedness and effective size

The WGW is critically endangered, and although our sample consisted of only 28 WGW individuals, this is ~20% of the estimated population (Cooke *et al.*, 2013). Our relatedness analysis indicated that a number of our biopsies came from the same whales; seven pairs of samples were found to have identical SNP genotypes across all loci. Given the paucity of WGWs, it is not entirely surprising that over multiple field seasons we (inadvertently) sampled seven individuals twice. Furthermore, a number of individual pairs were apparently derived from close relatives (Figs. 4, 5) that may represent parent-offspring pairs, full siblings, half siblings, and other close relatives. We identified two distinct cow/calf pairs and one ostensible full-sibling pair. Finally, the mean inbreeding coefficient is generally consistent with random mating within the WGW population. Overall, these results illustrate the power of genetic analyses for corroborating or overturning relationships suspected on the basis of fieldwork.

All of our population inferences are necessarily preliminary due to small sample sizes, but we include them here because of the keen interest in the conservation of the WGW population. Whether the population near Sakhalin Island is composed of WGWs, EGWs, or a mixed aggregation of the two stocks is under study by the International Whaling Commission (IWC, 2015). The putative EGW we sampled was no more or less related to the WGW population than expected by chance alone (Fig. 5). If the EGW was derived from an independent gene pool, it should have been more distantly related to the WGW population.

Populations with small effective sizes diverge rapidly due to drift and inbreeding (Wang and Caballero, 1999). Our small estimates of gray whale n_e ($n_e \approx 14$ by both LD and heterozygosity excess) are consistent with each other, with the idea that the extant WGW population is very small, and with published data indicating that the WGW population is genetically differentiated from the EGW population (*e.g.*, LeDuc *et al.*, 2002; Alter *et al.*, 2012; Meschersky *et al.*, 2015). Such genetic differentiation may be due to population structure associated with divergent selection, genetic drift, and/or a lack of migration (gene flow) among gray whale populations. Additional sampling across the range of the gray whale will be required to differentiate among these possibilities, but the genome sequence and the genotyping platform we describe here should enable those efforts.

Conclusions

Here, we describe the gray whale genome and the development of a gray whale genotyping assay that queries 92 autosomal nuclear SNPs (88 gene-associated autosomal mark-

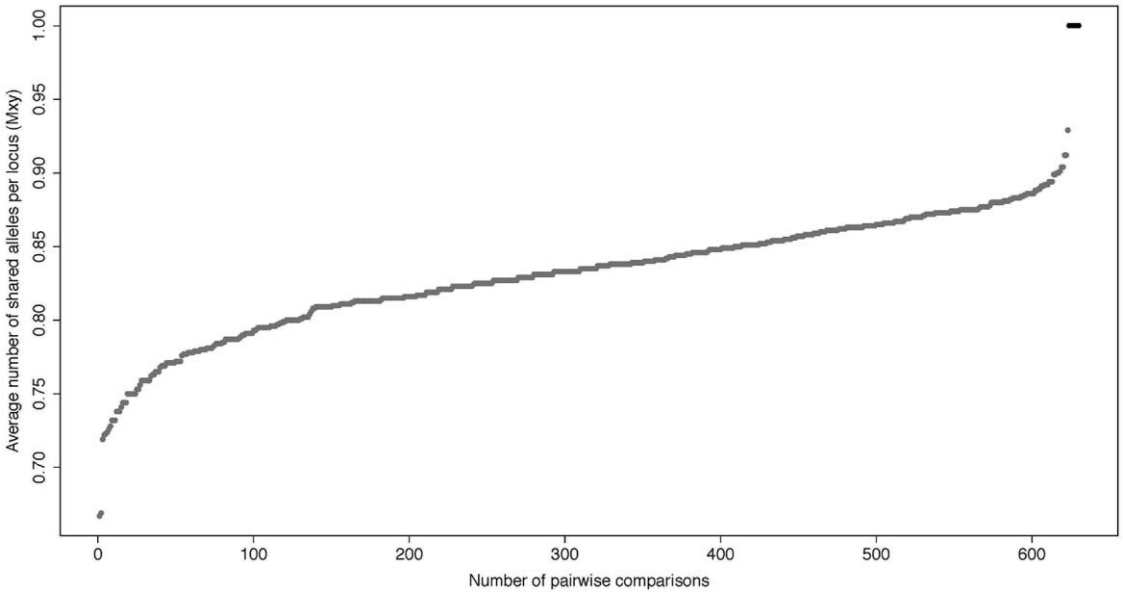

Figure 4. Distribution of average number of shared alleles (M_{xy}) among each possible pair ($n = 630$ pairwise comparisons) of gray whale biopsies ($n = 36$). Seven pairs of biopsies were inadvertently collected from the same individual whales, indicated by black dots clustered at the right tail of the distribution (*i.e.*, $M_{xy} = 1.0$).

ers, 2 mitochondrial markers, and 2 sex-chromosome markers). We validated these markers by repeated genotyping of 36 gray whale samples and determined that the error rates were low and the markers were polymorphic despite small effective population sizes. The single whale we sampled from the eastern population could not be genetically distinguished from the 28 gray whales we sampled near Sakhalin Island, but our markers provide a powerful platform for distinguishing among individuals and kin (*e.g.*, identifying close relatives). Ultimately, these markers should prove a useful resource for biologists and for the broader conservation community given the difficulty and expense associated with sampling and iden-

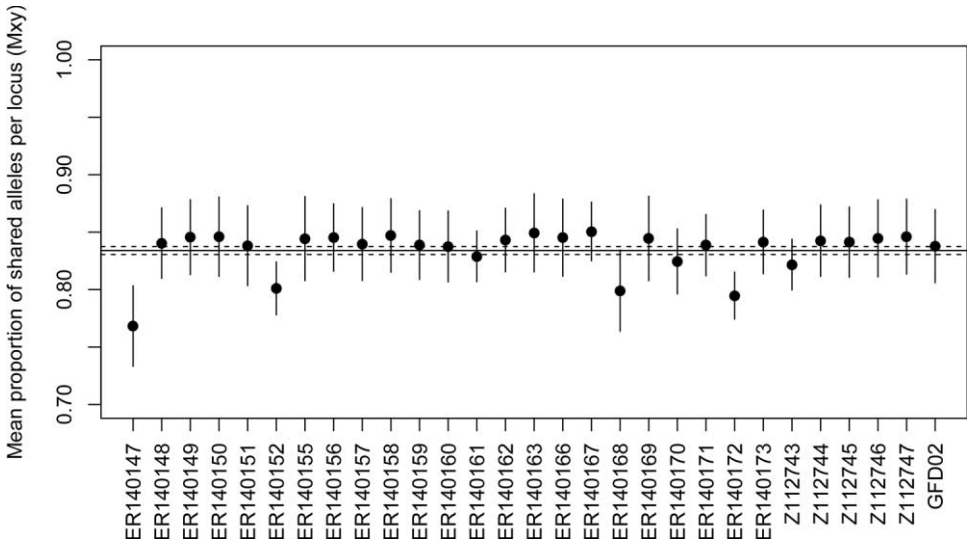

Figure 5. Distribution of individual relatedness values (M_{xy}) and their associated 95% confidence intervals (CIs). The mean pairwise relatedness among all 29 individuals in the population (*i.e.*, 406 pairwise comparisons where mean $M_{xy} = 0.834$) is shown as a solid black line, and the 95% CI (0.831–0.838) is shown as dashed lines. For each individual, M_{xy} is indicated as a dot and the 95% CI is shown as a vertical bar. Note that GFD02, the lone eastern gray whale (EGW), is no more or less related to the population than expected on the basis of chance alone. This plot is based on Blouin *et al.*'s (1996) M_{xy} estimator, but Queller and Goodnight's (1989) estimator produced qualitatively similar results with regard to the lone EGW.

tifying baleen whales. Furthermore, the genome sequence will serve as a resource for basic studies across a diversity of disciplines.

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Data Accessibility

We have deposited the primary data underlying these analyses into the National Center for Biotechnology Information's Short Read Archive (study accession SRP105779; BioProject PRJNA384396), in the Dryad Digital Repository (DeWoody *et al.*, 2017), and in the associated online supplementary material (Tables S1–S6).

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Lack of nuclear differentiation suggests reproductive connectivity between the 'southern feeding group' and the larger population of eastern North Pacific gray whales, despite previous detection of mitochondrial differences

ANNA M. D'INTINO[1], JAMES D. DARLING[2], JORGE URBÁN R.[3] AND TIMOTHY R. FRASIER[1]

Contact e-mail: timothy.frasier@smu.ca

ABSTRACT

During winter, eastern North Pacific gray whales migrate south to calving grounds in the lagoons of Baja California, and in spring they migrate north to their summer feeding grounds in the Chukchi and Beaufort Seas. Although the majority of the population makes this migration, a small subset of the population known as the 'southern feeding group' ends their northward migration early, spending summers feeding in waters ranging from northern California to southern Alaska. Previous analyses based on photo-ID and mtDNA data indicate that this seasonal substructuring results from maternally-directed site fidelity to different feeding grounds, and that this site fidelity and feeding ground preference is passed from mothers to their offspring. It is currently assumed, but not known, that the individuals of the southern feeding group mate with the rest of the population, and therefore that the eastern North Pacific gray whale represents one interbreeding population. Testing this assumption and understanding how these whales are related to the rest of the population, is key to making appropriate management decisions, which are particularly relevant given the recent increase in potential removals, or threats in the area such as the proposed resumption of aboriginal whaling, and increased oil pipeline development and subsequent vessel traffic. This paper analyses 15 nuclear microsatellite loci in 59 individuals from the southern feeding group and 40 individuals from the calving lagoons (representative of the larger population) to test the hypothesis that the eastern North Pacific gray whale represents one interbreeding population. No indication of population substructuring was found based on these nuclear loci, suggesting that all sampled whales do indeed represent one interbreeding population. Combined, these data from mitochondrial and nuclear markers therefore suggest one interbreeding population that is seasonally subdivided based on maternally-directed site fidelity to different feeding areas.

KEYWORDS: EASTERN NORTH PACIFIC; GRAY WHALE; REPRODUCTION; WHALING–ABORIGINAL; FEEDING GROUNDS; GENETICS; SITE FIDELITY; SEGREGATION

INTRODUCTION

The eastern North Pacific gray whale (*Eschrichtius robustus*) was extensively hunted from the mid-1800s through the early 1900s, reducing the population to just a fraction of its estimated pre-exploitation population size (Butterworth *et al.*, 2002; Henderson, 1984; Reilly, 1992). However, since gaining international protection, the population has steadily increased to roughly 20,000 individuals (Laake *et al.*, 2012; Rugh *et al.*, 2005; Sheldon and Laake, 2002). This recovery resulted in the removal of this population from the US Endangered Species List in 1994, and some data suggest it has recovered to its pre-exploitation population size (Alter *et al.*, 2007; Moore *et al.*, 2001; Rugh *et al.*, 2005; Wade, 2002). Despite this recovery, the population is still faced with numerous threats throughout its range, particularly in the area encompassing the Pacific northwest of the USA and the Pacific southwest of Canada (roughly Northern California through southeast Alaska). Here, there are several proposed activities where informed management will be critical. These include the proposed resumption of gray whale hunts by some aboriginal groups, the development of new oil pipelines off the British Columbia coast and the subsequent increase in tanker traffic for shipping oil to Asia.

One of the primary topics of relevance to management is population structure: how individuals are divided in space and/or time such that some groups may be differentially affected by direct hunting or by non-intentional threats. If such structuring exists, then the different groups often require separate management/conservation consideration because the detrimental effects will not be spread evenly throughout the population, but instead will disproportionally affect the different groups (e.g. Hoelzel, 1998; Taylor, 2005; Wang, 2009). Such localised impacts on structured populations, if not considered, can nullify otherwise well-planned management/conservation initiatives. Indeed, there are several case studies where the effectiveness of conservation actions has been compromised because population structure was not taken into consideration (e.g. Daugherty *et al.*, 1990; Frankham *et al.*, 2002).

Previous studies have detected seasonal population substructuring in the eastern North Pacific gray whale in relation to summer feeding ground use (Frasier *et al.*, 2011). As with many other baleen whales, gray whales show a seasonal migration from low-latitude calving grounds in the winter to high-latitude feeding grounds in the summer. The winter calving grounds for this population are located in the lagoons of Baja California (Findley and Vidal, 2002; Swartz, 1986; Swartz *et al.*, 2006), whereas during the summer the majority of the population feeds in the Bering and Chukchi Seas (Moore and Ljungblad, 1984). However, there is a small

[1]*Saint Mary's University, Department of Biology, 923 Robie Street, Halifax, Nova Scotia, B3H 3C3, Canada.*
[2]*Pacific Wildlife Foundation, Vancouver, British Columbia, V3H 1V6, Canada.*
[3]*Departamento de Biologia Marina, Universidad Autonoma Baja California Sur, La Paz, BCS 23081, Mexico.*

subset of the population—estimated at roughly 200 individuals (Calambokidis *et al.*, 2002) that spends the summer in lower-latitude feeding areas ranging from northern California to southeastern Alaska (Calambokidis *et al.*, 2002; Darling, 1984; Hatler and Darling, 1974; Pike, 1962; Swartz *et al.*, 2006). This group is often referred to as the 'southern feeding group', but is also referred to as the 'Pacific coastal feeding group' by the Scientific Committee of the International Whaling Commission (IWC, 2011; 2013a). Data from photo-ID and mitochondrial DNA (mtDNA) show that this seasonal population substructuring results from maternally-directed site fidelity to different feeding areas, and that this differential use of feeding areas is passed from mothers to offspring (Calambokidis *et al.*, 2002; Calambokidis *et al.*, 2010; Darling, 1984; Frasier *et al.*, 2011). This type of seasonal substructuring is common in baleen whales (e.g. Baker *et al.,* 1990; Malik *et al.,* 1999).

Despite this substructuring during the summer, it has always been assumed, but not known, that individuals from all feeding areas utilise the same mating area(s), and therefore represent one interbreeding population. Unfortunately, there is a lack of clarity regarding where fertilisation likely occurs, and hence where the mating grounds are. Sexual behaviour is frequently observed on the winter calving grounds (e.g. Swartz, 1986), and indeed these are often referred to as 'breeding grounds' (e.g. Alter *et al.*, 2009; Goerlitz *et al.*, 2003; Jones, 1990). However, the limited physiological data available actually suggest that fertilisation most often occurs during the southward migration, prior to arrival at the lagoons (Rice and Wolman, 1971). Thus, there is potential for differential feeding area use to also result in substructuring with respect to reproductive patterns.

There is also evidence that individuals show differential use of the calving grounds, with some females showing fidelity to particular lagoons (Jones, 1990; Goerlitz *et al*., 2003; Alter *et al*., 2009). Combined, there are enough questions regarding the timing and location of mating, as well as potential for differential habitat use of potential 'breeding' grounds, to warrant a full evaluation of the hypothesis of one interbreeding population. This paper uses data from nuclear microsatellite loci to compare genetic data from individuals of the southern feeding group to samples obtained from one of the calving lagoons (Laguna San Ignacio) used here as representatives of the larger population to test the hypothesis that individuals of the southern feeding group interbreed with individuals from the larger population. These data, in combination with previous information regarding structuring of mitochondrial haplotypes, can identify the degree of substructuring of the southern feeding group.

METHODS

Sample collection

Samples used for these analyses were collected over many years as part of other long-term research programmes on eastern North Pacific gray whales: off Vancouver Island, Canada by one of the authors (JDD); and off San Ignacio Bay, Mexico by another (JUR). Specifically, 86 samples from Vancouver Island (representing the southern feeding group, collected from 1996–2010) and 51 samples from San Ignacio Bay (representing the larger population, collected from 1996–1997) were analysed. All samples were collected using a crossbow and a modified bolt, as is common for collecting small skin samples from free-ranging large whales (Lambertsen, 1987; Palsbøll *et al.*, 1991). This method of sample collection has been extensively scrutinised, has proven to be safe, and does not have any short- or long-term impacts on the whales, other than an immediate startle response (Best *et al.*, 2005; Brown *et al.*, 1991). All sample collection procedures were conducted under permits obtained from the relevant governmental agencies. The timing of sample collection overlaps between the two sample sets, as is appropriate for comparison. The longer time for sample collection off Vancouver Island should not bias the results because the long life span and generation time of gray whales suggest that substantial genetic change within this putative population would take longer than the time interval sampled here. Thus, both sample sets should represent comparable genetic pools for analysis.

Genetic analyses

DNA was extracted from ~40mg of tissue from all samples using standard phenol:chloroform procedures as commonly used for whale skin (e.g. Wang *et al.*, 2008). The quantity of DNA obtained from each sample was estimated based on spectrophotometry using a NanoDrop 2000 (Thermo Scientific Inc.). The quality of DNA obtained (i.e. the amount of DNA degradation) was assessed based on electrophoresis through 2.0% agarose gels stained with SYBR Green I (Invitrogen). Sex was determined for each sample based on PCR amplification of a region on the X and Y chromosomes using the primers described in Gilson *et al.* (1998).

To identify useful microsatellite markers for this study, 23 loci were screened for amplification and variability in gray whales (Table 1). These loci were chosen because previous experience showed that they amplify well, and are highly variable, across a wide range of whale species. Specifically, loci were initially tested based on the amplification of two gray whale samples (one from the southern feeding group and one from the larger population) using annealing temperatures of 50, 55 and 60°C. The reactions contained 10ng of template DNA, 1X PCR Buffer (20 mM Tris pH 8.4, 50 mM KCl), 1.5 mM $MgCl_2$, 0.05 U/µl *Taq* DNA polymerase (Invitrogen), 0.2 mM each dNTP (Invitrogen), 0.3 µM each primer, and 0.1 mg/ml of bovine serum albumin (BSA) (Invitrogen). The cycling conditions were as follows: an initial denaturing step of 94°C for 5 minutes; 30 cycles of 94°C for 30 seconds, annealing temperature for 1 minute, and 72°C for 1 minute; followed by a final extension step of 60°C for 45 minutes. All PCR was conducted on Veriti® 96-well thermal cyclers (Applied Biosystems). PCR products were then size-separated and visualised via electrophoresis through 1.5% agarose gels stained with ethidium bromide. Loci that showed a clean PCR product (without amplification of multiple regions) were selected for further development.

For primer pairs that amplified well, the forward primer was re-ordered with one of four fluorescent tags (6FAM-Blue, VIC-Green, PET-Red, or NED-Yellow). Each locus was then screened for variation by amplifying 10 samples using the optimal conditions that had previously been

Table 1

Name, and reference for each of the 23 microsatellite loci tested for amplification and variability in gray whales.

Locus	Reference
EV1*Pm*	Valsecchi and Amos (1996)
EV5*Pm*	Valsecchi and Amos (1996)
EV14*Pm*	Valsecchi and Amos (1996)
EV37*Mn*	Valsecchi and Amos (1996)
EV94*Mn*	Valsecchi and Amos (1996)
EV104*Mn*	Valsecchi and Amos (1996)
FCB1	Buchanan *et al*. (1996)
FCB4	Buchanan *et al*. (1996)
FCB5	Buchanan *et al*. (1996)
FCB14	Buchanan *et al*. (1996)
FCB17	Buchanan *et al*. (1996)
GATA028	Palsbøll *et al.* (1997)
GATA098	Palsbøll *et al.* (1997)
GATA417	Palsbøll *et al.* (1997)
GT023	Bérubé *et al*. (2000)
IGF1	Barendse *et al.* (1994)
RW31	Waldick *et al*. (1999)
RW34	Waldick *et al*. (1999)
RW48	Waldick *et al*. (1999)
SW10	Richard *et al*. (1996)
SW13	Richard *et al*. (1996)
SW19	Richard *et al*. (1996)
TexVet5	Rooney *et al*. (1999)

determined. PCR amplification was carried out using the same conditions as described for testing annealing temperatures. PCR products were de-salted via ethanol precipitation (Irwin *et al.*, 2003), and size-separated and visualised on an ABI 3500xl capillary-based genetic analyser (Applied Biosystems).

Based on these amplification data (i.e. peak height and allele ranges) multiplex reactions where multiple loci are amplified simultaneously in the same PCR were developed through testing the amplification of different combinations of loci. These tests resulted in combinations of loci that minimised the number of reactions that were needed to amplify the variable loci. These protocols were then used to genotype all individuals. Alleles were scored using the GeneMarker software (SoftGenetics). Each 96-well plate of samples contained 2 individuals as 'standards', meaning that these same two individuals were present on all plates, to ensure consistency in genotyping across plates. All samples were scored by two individuals in a double-blind fashion to identify any potential scoring errors (Morin *et al.*, 2010).

Statistical analyses

Once genotypes for each sample had been obtained, the program CERVUS (Marshall *et al.*, 1998) was used to identify any duplicate genotypes (i.e. individuals that had unknowingly been sampled more than once). Based on these data, duplicate individuals were removed. CERVUS was also used to obtain estimates of allele frequencies and to estimate the frequency of null alleles for each locus. Loci were tested for deviations from linkage and Hardy-Weinberg Equilibrium (HWE) using exact tests as implemented in the program GENEPOP (Rousset, 2008).

Population structure was assessed using 'classical' approaches based on estimating differentiation of allele frequencies between pre-defined groups of individuals and Bayesian techniques. Classical methods have the benefit of being far more powerful than available Bayesian methods but have the detriment of requiring pre-defined groups of individuals, which may or may not represent the real biological patterns (e.g. Waples and Gaggiotti, 2006). On the other hand, Bayesian methods allow for simultaneous assessment of the number of groups represented by the sampled individuals and the assignment of individuals to those groups (and therefore do not requiring pre-defined groupings) but suffer from lower power.

The classical assessment of population differentiation was conducted using the program GENEPOP. Here, individuals were categorised as representing either the southern feeding group or the larger population, based on sampling location. Specifically, samples collected off Vancouver Island were classified as the southern feeding group, while samples collected on the calving grounds off Baja California were classified as representing the larger population. Based on this division, estimates of F_{ST} were obtained and exact tests of population differentiation were conducted.

To assess the power to detect population structure using the methods implemented in GENEPOP (exact tests), the simulation program POWSIM (Ryman and Palm, 2006) was used. Specifically, conditions were simulated that would result in differing levels of differentiation (F_{ST} = 0.001, 0.0025, 0.005, 0.01, 0.025, and 0.05), given the characteristics of the loci. There are two biologically realistic scenarios that can result in the same F_{ST} value. First, two populations that are not completely isolated will eventually reach an equilibrium F_{ST} value dependent upon the migration rate between populations (N_m). Second, if two populations have recently become reproductively isolated, they will drift apart, with F_{ST} values increasing with increasing time since divergence. POWSIM obtains desired F_{ST} values under the latter scenario by generating a single simulated population and then splitting it into equally sized populations with complete isolation once the split occurs. In this way, different F_{ST} values are obtained based on the number of generations that have passed since the split. Thus, users obtain estimates of the power to detect different degrees of differentiation by selecting combinations of N_e and t that result in the desired F_{ST} value, where $F_{ST} = 1 - (1 - 1/2N_e)^t$ (e.g. Nei, 1987, p.359). Due to uncertainty regarding N_e for the two putative gray whale populations, power to detect the different F_{ST} values (0.001, 0.0025, 0.005 0.01, 0.02, 0.025, and 0.05) was estimated using N_e values spanning three orders of magnitude (500, 5,000, and 50,000) and using t values for each that would result in the appropriate F_{ST} value. Simulations for each scenario (N_e and F_{ST} value) were conducted 100 times and the proportion of iterations where significant differentiation was detected (using a critical α value of 0.05) was recorded.

Population structure was also assessed without making *a priori* assumptions about the nature of population structure (e.g. how many groups there are, and which individuals represent each group). These analyses were conducted in two different ways: using the programs STRUCTURE (Hubisz *et al.*, 2009; Pritchard *et al.*, 2000), and STRUCTURAMA (Huelsenbeck and Andolfatto, 2007). For the analyses in STRUCTURE, the number of groups, and the membership of individuals within those groups, were estimated based a run length of 1,000,000 Markov Chain Monte Carlo

(MCMC) steps, with 50,000 steps as the burn-in period. The program was run assuming that allele frequencies were correlated between groups, and allowing for admixture (i.e. allowing for individuals to have ancestry in more than one group). The program was run 16 times, testing for 1–4 populations (K = 1–4), with four iterations of each K. The average likelihood over the four iterations for each K was taken as the likelihood for that K.

The program STRUCTURAMA works in a similar manner as STRUCTURE but differs in how the user specifies the number of populations to be tested. With STRUCTURE, the user must explicitly specify the number of populations considered and then run the program independently for each hypothesised number, and subsequently compare the probabilities associated with each. With STRUCTURAMA the number of populations considered can be a random variable within the model (Pella and Masuda, 2006) and therefore the posterior probabilities associated with a range of values for the number of putative populations can be obtained within a single run, without requiring *a priori* specification by the user (Huelsenbeck and Andolfatto, 2007). STRUCTURAMA was run allowing the number of populations to be a random variable with a Dirichlet process prior. The alpha value (which determines the shape of Dirichlet prior, where smaller values result in individuals being distributed across fewer populations and larger values result in individuals being dispersed across more populations) was also treated as a random variable, following a gamma distribution. A shape parameter of 1.0001 and a scale parameter of 0.0001 were initially used, which result in a relatively flat distribution. However, to test the robustness of the subsequent posterior probabilities to the choice of shape and scale values, STRUCTURAMA was also run with the shape and scale values both set to 1, which results in an L-shaped distribution. Each scenario was run three times, to ensure consistency between runs under the same conditions. All analyses were run for 1,000,000 MCMC steps, with 10,000 steps used as the burn-in.

Finally, it has been argued that estimating migration rates between putative populations is more biologically meaningful than simply rejecting panmixia when trying to identify biologically independent 'units' for conservation (e.g. Palsbøll *et al.*, 2006). Estimating migration rates from genetic data is challenging, however, particularly when migration rates are high. This is because demographic independence can occur at migration rates that are high enough to genetically homogenise allele frequencies (e.g. Waples and Gaggiotti, 2006). Regardless, great progress has recently been made in the development of analytical techniques designed to address this issue and better infer biological processes from genetic data. For management, the parameter of interest is estimated contemporary migration rates. BayesAss has become the software commonly used for this purpose (Wilson and Rannala, 2003). However, the approach implemented therein is known to perform poorly when genetic differentiation is low (Faubet *et al.*, 2007). Our results suggest extremely low differentiation between the putative groups and perhaps none (see Results), therefore BayesAss was not appropriate for estimating migration rates for our data. Instead, the programs IMa and MIGRATE were used to jointly estimate migration rates in both directions, as well as effective population sizes of each putative population (Beerli, 2006; Beerli and Felsenstein, 1999; 2001; Hey and Nielsen, 2004).

RESULTS

The average yield of DNA from the extraction process was 2.80 nanograms (ng) of DNA per milligram (mg) of tissue for the samples from Vancouver Island, and 0.42 ng/mg for the samples from San Ignacio Bay. This lower yield from the San Ignacio Bay samples likely results from the fact that these samples were stored in ethanol rather than DMSO, and DNA degradation is known to occur at a higher rate in ethanol than DMSO (e.g. Michaud and Foran, 2011).

The tests of microsatellite amplification and variability resulted in the identification of 15 loci that amplify well in gray whales, and are also variable. Multiplex reaction development resulted in all 15 loci being amplified in 5 reactions (Table 2), which were subsequently used for genotyping all samples.

No genotypes differed between the duplicate scoring personnel, indicating that allele calls were consistent across scorers. Genotypes were considered to be 'full' if individuals were missing data from 3 or fewer loci (i.e. they had data for at least 12 of the 15 loci). Full microsatellite profiles were not obtained for 14 samples, resulting in 123 genotyped samples that were used for subsequent analyses. Analysis of the genotypes identified 24 duplicate sampling events (23 off Vancouver Island, 1 from Laguna San Ignacio). All re-sampling events were from the same location (i.e. there were no cases where one individual was sampled in one location and re-sampled at the other). These duplicates were removed from the data set, resulting in genotype data for 99 individuals (59 from off Vancouver Island, 40 from Laguna San Ignacio). The genotypes did not show any significant deviations from Hardy-Weinberg Equilibrium expectations when analysed independently for each putative population, or when the data were combined into one 'population' (Table 3). Out of the 105 pairwise comparisons for assessing linkage between loci (considering all individuals together), six (5.7%) had p-values <0.05. However, none of these were significant after Bonferroni correction (Hochberg, 1988).

Table 2

Amplification information. Included is the locus name, fluorescent label, and reaction number for all loci. The annealing temperature for all reactions is 55°C.

Locus	Label	Reaction
EV14*Pm*	6FAM	1
EV37*Mn*	VIC	1
FCB14	VIC	1
GATA028	NED	1
FCB5	NED	1
GT023	VIC	2
FCB4	PET	2
EV1*Pm*	NED	2
TexVet5	NED	2
FCB17	6FAM	3
GATA417	PET	3
SW10	NED	3
SW13	6FAM	4
EV94*Mn*	6FAM	5
RW31	VIC	5

Table 3

Characteristics of each locus in each putative population for: (a) the southern feeding group; and (b) the larger population. Included is the locus name, the number of alleles, observed heterozygosity (H_O), expected heterozygosity (H_E, Nei, 1987), the polymorphic information content (*PIC*, Botstein *et al*., 1980), and the p-value for deviation from HWE. No p-values were statistically significant after Bonferroni correction (correction conducted independently for each putative population).

Locus	Alleles	H_O	HE	PIC	P-Value
(a) Southern feeding group					
EV14*Pm*	10	0.828	0.852	0.826	0.688
EV37*Mn*	17	0.845	0.886	0.867	0.204
FCB14	7	0.741	0.808	0.773	0.273
FCB5	4	0.500	0.438	0.402	0.765
GATA028	5	0.780	0.753	0.704	0.437
GT023	6	0.741	0.741	0.688	0.642
EV1*Pm*	3	0.603	0.508	0.385	0.184
TexVet5	5	0.741	0.730	0.678	0.678
FCB4	3	0.143	0.250	0.221	0.008
FCB17	13	0.930	0.907	0.890	0.984
SW10	7	0.776	0.776	0.733	0.832
GATA417	7	0.707	0.723	0.676	0.161
SW13	8	0.706	0.630	0.552	0.062
EV94*Mn*	9	0.831	0.816	0.783	0.458
RW31	9	0.828	0.822	0.790	0.216
(b) Larger population					
EV14*Pm*	10	0.769	0.840	0.809	0.132
EV37*Mn*	15	0.914	0.873	0.848	0.644
FCB14	7	0.759	0.836	0.798	0.033
FCB5	4	0.500	0.489	0.451	0.745
GATA028	5	0.769	0.764	0.715	0.185
GT023	7	0.650	0.685	0.627	0.276
EV1*Pm*	2	0.564	0.498	0.371	0.517
TexVet5	5	0.725	0.683	0.621	0.857
FCB4	2	0.105	0.191	0.171	0.036
FCB17	14	0.972	0.903	0.881	0.996
SW10	7	0.750	0.805	0.766	0.295
GATA417	6	0.700	0.717	0.676	0.182
SW13	5	0.629	0.611	0.530	0.738
EV94*Mn*	9	0.806	0.810	0.770	0.757
RW31	9	0.825	0.815	0.777	0.301

No loci had estimates of null allele frequencies greater than 0.05.

Sex could be determined for 86 of the 99 individuals, with 38 males and 48 females. The DNA was too degraded from the remaining 13 individuals to obtain reliable sex information. Within each region, the sex ratios were 33 females: 24 males and 15 females: 14 males for Vancouver Island and Laguna San Ignacio, respectively.

The 'classic' tests (based on hypothesis testing of pre-defined groupings) did not show any significant signs of genetic differentiation between the genotypes of the southern feeding group and the larger population. Specifically, the F_{ST} estimate was –0.0010, with a *P*-value estimate of 0.489. Simulation analysis showed that the power to detect structure, if it exists, was quite high. Specifically, given the sample sizes and the characteristics of the loci, we would expect to detect population structure over 70% of the time with an F_{ST} value as low as 0.005 (Fig. 1). The STRUCTURE analyses also did not detect any significant genetic differentiation within the data set, with one population (K = 1) having the highest probability (Table 4). Similar results were also obtained with STRUCTURAMA, with the scenario of the data representing one single population having a higher probability than scenarios with any other putative number of populations (Table 5).

Table 4

Results from STRUCTURE analysis. Shown is the estimated natural logarithm (*ln*) of the probability of the data with the number of populations (K) ranging from one to four, and performing four iterations of each K. The bold value indicates the average K with the highest probability.

	K			
Iteration	1	2	3	4
1	–4,219.9	–4,243.6	–4,273.9	–4,276.9
2	–4,220.9	–4,243.6	–4,268.5	–4,272.6
3	–4,220.3	–4,238.9	–4,266.2	–4,257.1
4	–4,220.6	–4,228.6	–4,248.7	–4,263.9
Average	–4,220.4	–4,238.7	–4,264.3	–4,267.6

Table 5

Results from STRUCTURAMA analysis. Shown are the estimated posterior probabilities of the data representing 1–3 populations. The top panel shows these probabilities calculated with the alpha value for the Dirichlet process being a random variable following a gamma distribution with a shape parameter of 1.0001, and a scale parameter of 0.0001. The second panel shows these probabilities calculated when the shape and scale value parameters were both set to 1.

	Number of populations		
Iteration	1	2	3
gamma(1.0001,0.0001)			
1	0.96	0.04	0
2	0.96	0.04	0
3	0.96	0.04	0
gamma(1,1)			
1	0.97	0.03	0
2	0.97	0.03	0
3	0.97	0.03	0

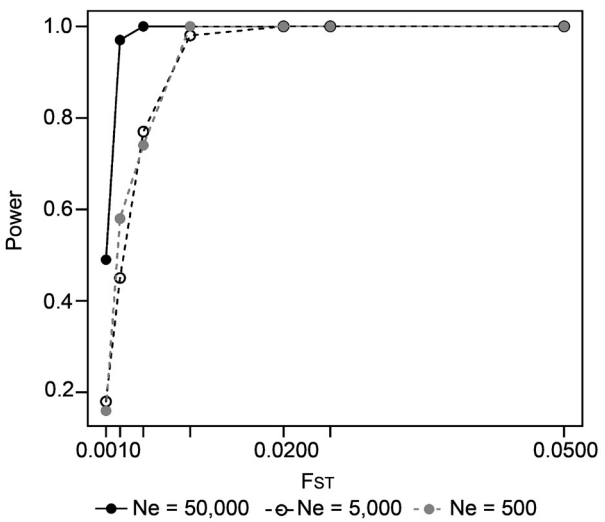

Fig. 1. Results from the POWSIM analyses. Shown is the power of the data (the proportion of simulations where population structure was detected (using a critical α value of 0.05)) under the different scenarios. The F_{ST} values tested were 0.05, 0.025, 0.02, 0.01, 0.005, 0.0025, and 0.001. These F_{ST} values were generated under three scenarios, N_e = 500, 5,000, and 50,000, with the time since divergence (t) varying to result in the desired F_{ST} values.

Despite testing a wide range of options with both IMa and MIGRATE, we were unable to get either program to converge on consistent estimates of migration rates. Our interpretation is that this inability is due to the lack of genetic differentiation of nuclear markers between the putative

groups. This interpretation, as opposed to a lack of information in the data, seems appropriate particularly because we have previously obtained consistent estimates from these same programs and the same individuals but based on mitochondrial data, which showed significant structuring and limited migration consistent with maternally-directed site fidelity (Frasier *et al.*, 2011).

DISCUSSION

The differential recovery of DNA from tissue stored in different solutions merits consideration for future sample storage. Several studies have compared the ability of different solutions (primarily ethanol and DMSO) to preserve DNA over long periods of time (e.g. Michaud and Foran, 2011; Seutin *et al.*, 1991). All such studies indicate that DMSO solutions preserve DNA at a higher quality, and over a longer period of time. However, many researchers and museum staff still use ethanol for the long-term preservation of tissue. The differential yields of DNA obtained here add to the growing amount of data suggesting that DMSO is the desirable storage solution for long-term storage of tissue that may be used as a source of DNA.

The results of all analyses of population structure lead to the same conclusion: a lack of differentiation of nuclear genotypes. The 'classical' tests did not detect significant differences in allele frequencies between whales of the southern feeding group and those sampled in Laguna San Ignacio, and both Bayesian approaches indicated that the probability that all samples originated from one single population was substantially higher than any other alternatives. These data suggest that the whales of the southern feeding group do indeed freely interbreed with whales that utilise other summer feeding grounds. Thus, from these data, it appears that the eastern North Pacific gray whale represents one interbreeding population.

One caveat of our study is that samples representing the larger population were all collected from whales in one of the lagoons Laguna San Ignacio (but spanning several years). Gray whales are not evenly distributed throughout the three known lagoons in winter. Instead, photo-ID data suggest that females show some site fidelity to different lagoons (e.g. Jones, 1990) and genetic data also suggest some structuring (Goerlitz *et al.*, 2003; Alter *et al*., 2009). However, the patterns and degree of structuring between lagoons remains unclear. For example, Alter *et al*. (2009) did not find significant structuring of mitochondrial haplotypes between the lagoons, but found slight but statistically significant differentiation of microsatellite alleles between Laguna San Ignacio and Bahia Magdalena. The authors attribute this pattern to either a high contemporary migration rate, or perhaps to stronger patterns of structuring being erased by whaling and only beginning to accumulate and leave a detectible genetic signature today.

Our justification for using samples from Laguna San Ignacio as representative of the larger population, are three-fold. First, based on numbers of single individuals and mother-calf pairs, Laguna San Ignacio represents the second most populated lagoon, with numbers of whales that are vastly larger than the estimated size of the southern feeding group (Jones and Swartz, 1984; Urban R *et al.*, 2003). Thus, Laguna San Ignacio is clearly used by a larger subset of the population than the southern feeding group. Second, although there are data suggesting that some females show fidelity to specific lagoons, there is also an abundance of data showing that some individuals move freely between lagoons, and that average residence times within the lagoon (for non-mother-calf pairs) are less than a week (Jones and Swartz, 1984; Urbán R *et al*., 2003), suggesting that at least single whales move readily between lagoons. Moreover, some mothers are known to utilise different lagoons in different years (Swartz, 1986). Lastly, even if mothers do show fidelity to specific lagoons, this should not result in corresponding structuring of nuclear gene flow because fertilisation is thought to take place during the southward migration, prior to arrival at the lagoons (Rice and Wolman, 1971). Thus, although it would be ideal to have representative samples from all known lagoons, the available data provide no reason to doubt that the samples from Laguna San Ignacio are representative of the larger population.

These data based on nuclear markers add to previous photo-ID and mtDNA data to provide a more complete picture of the relationship between seasonal habitat use patterns and gene flow throughout the population. The photo-ID and mtDNA data indicate that, during the summer, whales of the southern feeding group represent a seasonal subpopulation, where this differential habitat use is driven by maternally-directed site fidelity to this feeding area that is then passed on to their offspring (Frasier *et al*., 2011). However, the nuclear DNA data suggest that these whales breed with whales that show fidelity to other feeding grounds, and therefore are part of one interbreeding population. Thus, the combined picture is one of seasonal subdivision on summer feeding grounds, but with no such substructuring during the mating season, where all individuals in the eastern North Pacific represent one gene pool.

This result and interpretation is consistent with other data relating to known migration patterns and the timing of fertilisation. Briefly, it is thought that conceptions may occur in December, during the southern migration (Rice and Wolman, 1971). Whales that use the northern feeding grounds migrate through the areas occupied by the southern feeding group suggesting that whales from both known feeding grounds may migrate together the remainder of the way to the winter calving grounds (Darling, 1984). The peak time of migrants passing through the southern feeding area is mid-December to mid-January (Darling, 1984). Thus, the timing of fertilisation coincides with when whales from different feeding grounds become intermingled during their southern migration. This pattern indicates the strong potential for interbreeding regardless of any substructuring that may exist during the summer, or on the winter calving grounds.

Despite the presence of nuclear gene flow between whales from the southern feeding group and the rest of the population, this group still represents a separate management unit that warrants separate consideration with respect to the impacts of proposed threats, such as the resumption of traditional whaling and the impacts of oil distribution. This is the approach being used by the IWC Scientific Committee in examining the potential impacts of hunting (e.g. see IWC,

2013b). The presence of long-term site fidelity to this area that is passed on from mothers to offspring, indicates that these whales represent a seasonal subpopulation. Thus, detrimental impacts (e.g. 'takes') to these whales will not have a 'random' impact on the population at large, but will instead primarily impact these matrilines specifically. The resulting effect on this local subpopulation could be far greater than would be expected under the assumption of a single, unstructured population. Potential impacts could include the loss of knowledge of these feeding areas from this population, and localised extirpation. For example, if the whales that currently show this site fidelity are removed, then this information will be lost, and thus these whales will not likely be replaced by others from the larger population, resulting in localised extirpation. Indeed, the recognition of such seasonal subpopulations as separate management units is recommended, and common, for baleen whales (e.g. Dizon *et al.*, 1997).

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SC/A17/GW/06

Gray whale abundance estimates from shore-based counts off California in 2014/15 and 2015/2016.

John W. Durban, David W. Weller, Wayne L. Perryman

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Gray whale abundance estimates from shore-based counts off California in 2014/15 and 2015/2016.

JOHN W. DURBAN, DAVID W. WELLER, WAYNE L. PERRYMAN

Marine Mammal and Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 8901 La Jolla Shores Dr., La Jolla, CA 92037,USA.

Contact email: john.durban@noaa.gov

METHODS AND COUNT DATA

This paper presents updated counts and abundance estimates for gray whales (*Eschrichtius robustus*) migrating southbound off the central California coast between December and February 2014/15 and 2015/16. Counting and analytical methods followed those described by Durban *et al*. (2015) for four previous abundance estimates between 2006/7 and 2011/12. Counts were made from a shore-based watch station at Granite Canyon, California, by teams of observer pairs rotating from a larger pool. A total of 16 observers were used over the two years, 10 in 2014/15 and 12 in 2015/16; six observers counted in both years. Only five of these 16 observers were not involved in the previous independent counting experiments when the detection models were parameterized; in these cases, observer effects were predicted (with uncertainty) from the hierarchical model for observer effects (Durban *et al*. 2015).

Data were the total counts of whales from each 1.5-hour watch period that had acceptable weather conditions (see Durban *et al*. 2015). These comprised 179 watch periods in 2014/15 and 151 in 2015/16, totaling 269 and 226 hours of watch effort over 39 and 37 days, respectively (Table 1). The result was 2978 and 2666 whales counted in each of these years, the former representing the highest count since our new watch protocol was started in 2006/2007 (Durban et al. 2015).

Table 1: The number of whales recorded during the southbound gray whale surveys in 2014/15 and 2015/16. Data are the total counts of whales, hours and distinct days for watches during acceptable observation conditions.

Migration	Dates	Hours	Days	Whales
2014/2015	30-Dec-14 to 13-Feb-15	269	39	2978
2015/2016	30-Dec-15 to 12-Feb-16	227	37	2666

ABUNDANCE ESTIMATES AND DISCUSSION

Bayesian Markov Chain Monte Carlo (MCMC) sampling was used to simultaneously rescale counts for detectability and also smooth to abundance changes over the course of each migration (Durban *et al*. 2015). These abundance changes were described using Bayesian model selection between a parametric model for a Normally distributed migration trend that borrowed strength across years and a semi-parametric model that estimated the time trends independently for each year; the resultant migration curve was a weighted compromise between models, allowing for key departures from the common trend. The total number of whales passing during each migration was then estimated by summing the expected value (along with associated uncertainty, see error bars in Fig 1) from the model-averaged number of whales passing each day from time 0 (01 December) to 90 days, and these estimates were then rescaled to account for the differential passage rate at night (see Durban et al. 2015).

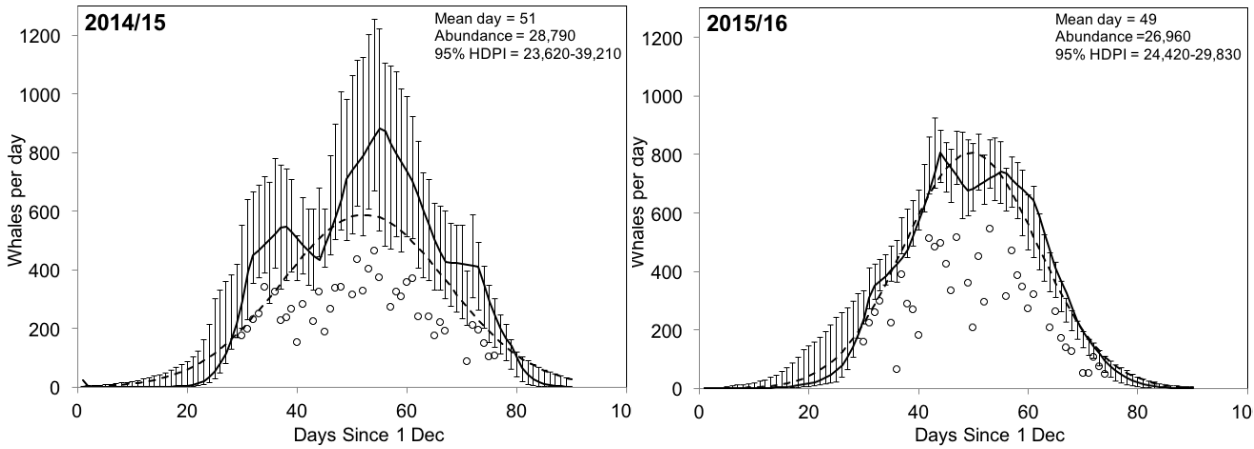

Figure 1. Observed whale passage rates expressed as total counts per day / proportion of day observed (circles) and fitted migrations models (lines) for two gray whale migration counts in 2014/15 and 2015/16. The broken line represents the median estimates from a hierarchical Normal model for migration and the solid line represents a semi-parametric model of penalized splines (see Durban et al. 2015). The abundance estimate for each day (95% highest posterior density interval shown by vertical lines) is a model averaged compromise between the migration models, and these were summed to estimate the overall abundance for the migrations.

To sample the full extent of the uncertainty associated with model parameters, inference was based on each 10th iteration of the MCMC sampler to generate a sample of 30,000 iterations following a burn-in of 10,000. There was consistency between the model predictions and observed counts for both years, with Bayesian P-values of 0.49 and 0.54, respectively; values close to 0.5 would indicate that the data were consistent with replications under the model such that the distribution of the predicted count would symmetrically overlap the observed count (Gelman *et al*. 1996). However, daily and total abundance in 2014/15 were subject to considerable uncertainty, as shown by the large error bars associated with each of the daily estimates (Figure 1) and the large coefficient of variation (CV = posterior standard deviation / posterior median; $CV^{2015} = 0.13$). This is likely explained in part by the results of model fitting, as significant departures from the Normal migration model (probability of Normal model <0.25) were estimated in 18/90 days in 2014/2015 compared to only 9/90 days in 2015/16. These

departures, and the uncertainty associated with estimating an independent migration curve, constrained estimation of a precise migration curve. In contrast the $CV^{2016} = 0.05$ was consistent with previous estimates using this counting approach and model (CV = 0.04-0.06 for four previous estimates since 2006/2007), and this estimate was therefore more useful for interpreting in the context of the abundance time series. Differences in the CVs from the two years demonstrated the value of completing two counts and abundance estimates in back-to-back years, which provided a measure of redundancy.

The 2015/16 estimate of 26,960 (95% highest posterior density interval = 24,420-29,830) represented a 22% (5970 whales) increase in the five years since the 2010/11 estimate of 20,990. This is consistent with high estimates of calf production (Perryman *et al*. SC/67a), with a total of >6000 calves estimated during this period, including four of the highest years of calf production (>1000 calves per year) since our calf counts began in 1994. This increase in gray whale abundance also supports inference that gray whales have been experiencing a period of favorable feeding conditions in the Arctic due to a combination of expanding ice-free habitat (Moore 2016), increased primary production (Arrigo and Dijken 2015) and increased flow of nutrient-rich waters through the Bering Strait (Woodgate et al. 2012).

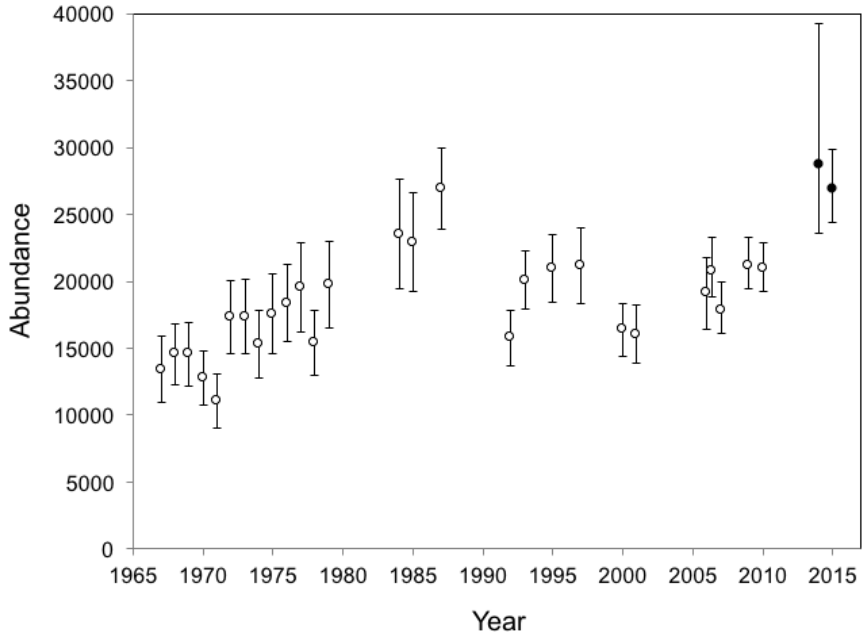

Figure 2: Gray whale abundance estimates for southbound migrations with an end year between 1967 and 2011 (open circles, with 95% confidence intervals; from Laake *et al.,* 2012 and Durban et al. 2015) together with the two recent migrations reported here for 2015 and 2016.

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Assessment of population substructure in relation to summer feeding ground use in the eastern North Pacific gray whale

Timothy R. Frasier[1,3,*], Sharlene M. Koroscil[1], Bradley N. White[1], James D. Darling[2]

[1]Natural Resources DNA Profiling and Forensic Centre, Department of Biology, Trent University, Peterborough, Ontario, K9J 7B8, Canada

[2]Pacific Wildlife Foundation, Vancouver, British Columbia, V3H 1V6, Canada

[3]*Present address:* Department of Biology, Saint Mary's University, Halifax, Nova Scotia, B3H 3C3, Canada

ABSTRACT: The eastern North Pacific gray whale *Eschrichtius robustus* was removed from the US Endangered Species List in 1994, and since then aboriginal groups in Washington (USA) and British Columbia (Canada) have discussed the resumption of traditional whaling. In particular, the Makah are pursuing legal permission to resume their hunt. Although the majority of whales in this population migrate to summer feeding grounds in the Bering, Chukchi, and Beaufort Seas, a small number of individuals (~200) spend the summers feeding in the waters ranging from northern California to southeast Alaska. The relationship of these 'southern feeding group' whales to the rest of the population is unknown. This information is key to making appropriate management decisions, because these whales inhabit the waters directly adjacent to the aboriginal communities interested in resuming whaling. We compared mitochondrial sequence data from 40 southern feeding group individuals to sequences from 105 individuals representing the larger population. We found significant differences in haplotype frequencies between the 2 groups, with an estimated long-term rate of exchange between the groups being <<1%. Moreover, estimates of Θ ($N_e\mu$ for mtDNA data, i.e. the probability of a mutation occurring within the population in each generation) were significantly different between the 2 groups, indicating that the maternal lineages of the southern feeding group represent a distinct seasonal subpopulation. Combined, these data show that the southern feeding group of gray whales qualifies as a separate management unit, which should be considered when making conservation decisions.

KEY WORDS: Gray whale · *Eschrichtius robustus* · Whaling · Population structure · mtDNA · Management unit

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INTRODUCTION

The eastern North Pacific gray whale *Eschrichtius robustus* represents one of the few populations that have been removed from the US Endangered Species List, with the classification changing from 'endangered' to 'recovered' in 1994. Commercial whaling targeting gray whales in the eastern Pacific began in ~1845 (Henderson 1984) and reduced the population from an estimated 12 000–15 000 ind. to as low as 1500–1900 ind. by 1900 (Henderson 1984, Reilly 1992, Butterworth et al. 2002). International protection began in 1937, when the United States and Norway ended their gray whale hunts, but it was not until 1951 that all modern whaling countries agreed to stop hunting gray whales (Reeves 1984). Systematic surveys from 1967 to 1998 showed that the population increased at an annual rate of ~2.6%, reaching as many as 30 000 ind. (Shelden & Laake 2002, Rugh et al. 2005). Current estimates hover around 20 000 ind., and

*Email: timothy.frasier@smu.ca

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there are even some suggestions that the population has reached carrying capacity (Moore et al. 2001, Wade 2002, Rugh et al. 2005, but see Alter et al. 2007 for an alternative perspective).

During the late fall and early winter, whales migrate to the lagoons of Baja California and the Gulf of California, which represent the winter calving grounds for this population (Swartz 1986, Findley & Vidal 2002, Swartz et al. 2006). During the spring, the majority of whales migrate to their northern feeding grounds in the Bering, Chukchi, and Beaufort Seas (Moore & Ljungblad 1984). However, a small subset of the population (~200 ind.) remains in more southerly feeding grounds ranging from northern California to southeast Alaska (Pike 1962, Hatler & Darling 1974, Darling 1984, Darling et al. 1998, Calambokidis et al. 2002, Swartz et al. 2006). These 2 subsets of the population will be referred to as the southern feeding group and the larger population, respectively.

Subdivision with respect to summer feeding ground use is common in baleen whales, and results from maternally directed site fidelity to different feeding grounds. For example, in humpback whales *Megaptera novaeangliae* and North Atlantic right whales *Eubalaena glacialis*, calves nurse for ~11 mo (and occasionally longer) and learn migration routes and the location of summer feeding grounds through cultural transmission from their mother (e.g. Baker et al. 1990, Malik et al. 1999). Thus, if there is differential use of feeding grounds by mothers, these preferences will be passed on to their offspring and result in substructuring with respect to summer feeding ground use. Gray whale calves nurse for a much shorter period of time (~6 mo; Swartz 1986). Although their length of lactation is still long enough to learn migratory routes and the location of summer feeding grounds, it is not yet clear whether gray whales show this maternally directed site fidelity. Because mitochondrial DNA (mtDNA) is maternally inherited, patterns of mtDNA diversity should reflect any maternally based patterns of movement and distribution. Therefore, analysis of mtDNA is ideal for testing hypotheses of maternally based site fidelity and subsequent population structure in baleen whales.

The relationship between the southern feeding group and the larger population is unknown. It is currently assumed that both of these groups use the same breeding ground, and therefore represent the same breeding population (e.g. Swartz et al. 2006). Given the known patterns in other baleen whale species, it seems likely that the southern feeding group and the larger population, and perhaps even smaller, as yet undefined subdivisions, result from maternally directed site fidelity to different feeding grounds by gray whale mothers. Photo-identification data are consistent with this hypothesis, showing that the majority of whales sighted in the southern feeding areas are resighted there in subsequent years, and therefore show the expected site fidelity (Darling 1984, Calambokidis et al. 2002, 2010). For example, Calambokidis et al. (2002) found that between 70 and 100% of the whales photo-identified off British Columbia had been sighted there in previous years. Moreover, the majority (63%) of calves first sighted in the southern feeding area with their mothers are resighted there in subsequent years, suggesting that this differential use of feeding grounds is indeed the result of maternally directed site fidelity (Calambokidis et al. 2010). This resighting rate is high, given the numerous factors that can reduce the resighting rates of calves, including: (1) mortality of individuals between their calf and subsequent year (as this age class has the highest mortality rate in many mammalian populations; Caughley 1966); and (2) changes in physical features that prevent re-identification (Calambokidis et al. 2010). However, preliminary genetic analyses of population structure based on mtDNA were inconclusive (Steeves et al. 2001).

Understanding the relationship between the southern feeding group and the rest of the population is of increasing importance due to the intention of some aboriginal communities to resume hunting gray whales. Several aboriginal groups traditionally hunted gray whales, but voluntarily stopped hunting as whale numbers decreased and/or were required to stop when the population received international protection (O'Leary 1984, Russell 2004). The exception was off Chukotka, Russia, where whaling was allowed to continue. In 1998, the Makah (in Washington, USA) resumed whaling and caught/killed a whale in 1999, but have been prevented from continuing since 2000 by litigation. Specifically, the Makah were given the right to hunt gray whales at traditional sites under the Treaty of Neah Bay in 1855. However, a final court ruling in 2004 determined that in order to resume their hunt, they must follow the necessary procedures for obtaining a waiver under the Marine Mammal Protection Act (MMPA). The Makah have applied for this waiver, and this request is still being processed. The outcome of the Makah application will have large implications for the resumption of whaling by other aboriginal communities in the area as well (Russell 2004).

The relationship of these 'southern feeding group' whales to the rest of the population is unknown. This information is key to making appropriate management decisions, because these whales inhabit the waters directly adjacent to the aboriginal communities interested in resuming whaling. The negative consequences of ignoring potential population structure when making management decisions, such as the extinction of unrecognized populations and/or species,

are well known (e.g. Daugherty et al. 1990, Taylor 1997, Frankham et al. 2002). For the current gray whale situation, an understanding of population substructure in relation to known summer feeding ground use is required to infer how the whales in each feeding area, and the population as a whole, will respond to the removal of individuals through the proposed hunts. Therefore, if informed management decisions are to be made regarding resuming this hunt, it is first necessary to understand the relationship of this southern feeding group to the rest of the larger population. Here, we conducted analyses of the mitochondrial DNA of gray whales representing the southern feeding group, as well as the larger population, in order to better understand their relationship, and therefore inform management decisions.

MATERIALS AND METHODS

Sample collection. Skin samples were collected from whales representing the southern feeding group in Clayoquot Sound, British Columbia, from 1995 to 2006. Individuals of this group appear to move freely between specific feeding sites throughout this southern feeding range from northern California to southeast Alaska in summer (Calambokidis et al. 2002, 2010). Clayoquot Sound on central Vancouver Island is one such site (Darling 1984, Darling et al. 1998). Biopsy samples were collected using a crossbow and modified bolt (e.g. Lambertsen 1987, Palsbøll et al. 1991) or a pneumatic rifle biopsy system (Barrett-Lennard et al. 1996). The samples were collected in association with ongoing photo-identification research (e.g. Darling 1984), and the photo-identification data were used to ensure that individual whales were only represented once within the genetic data set. Moreover, the entire population migrates near this area on its northern and southern migrations. Therefore, samples were only used from whales sampled between 1 July and 15 November, i.e. the time period after which all northward migrants have passed and before which the first migrants start heading south (Darling 1984), to ensure that the sampled individuals actually represented the southern feeding group, as opposed to migratory animals. Tissue samples were stored in a 20% dimethyl sulfoxide (DMSO) solution (Seutin et al. 1991).

Genetic analysis. Approximately 40 mg from each sample was used for subsequent DNA extraction procedures. The skin was frozen in liquid nitrogen, ground to a fine powder, and transferred to a tube with 500 µl of lysis buffer (4 M urea, 0.2 M NaCl, 0.5% *n*-lauroylsarcosine, 10 mM 1,2-cyclohexanediaminetetraacetic acid, 100 mM Tris-HCl, pH 8.0). Samples were rotated in the lysis buffer at room temperature for ≥5 d, after which time they were subjected to 3 aliquots of Proteinase K, each at a concentration of 0.5 U mg^{-1} tissue. The addition of Proteinase K was as follows: after adding the first aliquot, samples were rotated at room temperature overnight; after adding the second aliquot, the samples were placed in a 65°C waterbath for 1 h, then transferred to a 37°C incubator for 1 h; after adding the third aliquot, the samples were rotated at room temperature overnight. Approximately 250 µl of the tissue/lysis buffer solution was subsequently extracted using Qiagen DNeasy Tissue Extraction Kits. DNA quantity was estimated using PicoGreen (Singer et al. 1997). Extracted samples included those previously analyzed by Steeves et al. (2001), which were re-extracted and analyzed here, along with the newly collected samples.

A 345 bp portion of the mitochondrial DNA control region was amplified using the primers t-PRO and Primer-2 from Yoshida et al. (2001). PCR cycling conditions consisted of: (1) an initial denaturation step of 5 min at 94°C; (2) 30 cycles of 94°C for 30 s, 57°C for 1 min, and 72°C for 1 min; and (3) a final extension step of 60°C for 45 min. Reactions were carried out in 20 µl volumes containing 1× PCR Buffer (20 mM Tris-HCl pH 8.0, 50 mM KCl), 0.05 U $µl^{-1}$ *Taq* polymerase (Invitrogen), 1.5 mM $MgCl_2$, 0.2 mM each dNTP (Invitrogen), and 10 ng of DNA. After amplification, primers and unincorporated dNTPs were degraded using EXOSAP-IT (Dugan et al. 2002), and products were sequenced using the DYEnamic dye terminator kit (GE Healthcare). Products were size-separated and visualized on a MegaBACE 1000 (GE Healthcare). Sequences were edited using MEGA 4 (Kumar et al. 2008). Gender was determined for all individuals using the method described by Shaw et al. (2003).

Data analysis. To compare the data from southern feeding group whales to those of the larger population, we compared our mitochondrial sequence data to those reported by LeDuc et al. (2002). Their study reported mitochondrial sequences from 120 ind. representing eastern Pacific gray whales. The majority (>90%) of the samples were from stranded individuals found throughout their range, from southern California to the Chukotka Peninsula in Russia. The remaining samples were collected from subsistence takes, as biopsies of live whales, and from fisheries bycatch. Fifteen of the samples in LeDuc et al. (2002) were from southern feeding group whales. These were removed from the analyses, leaving 105 samples from the LeDuc et al. (2002) data set to compare with our data set of 40 ind. Because the vast majority of samples from the study by LeDuc et al. (2002) were from dead individuals (either stranded, as bycatch, or hunted), the chance of duplicate samples from the same individual being represented in their data is negligible. Given the num-

ber and geographic range of the sampled whales in the study by LeDuc et al. (2002), our rationale for choosing these for comparison was that these sequences would be a good representation of the larger population of eastern gray whales.

Sequences were aligned with CLUSTALX (Thompson et al. 1994). Alignments were conducted under a range of gap opening and extension penalties and compared by eye to establish the optimal alignment. The sequences were very similar, and all alignments were the same under the tested conditions. Haplotype and nucleotide diversity (π) (Nei 1987) were estimated using Arlequin ver. 3.5.1.2 (Excoffier et al. 2005). Variations between mtDNA sequences were recorded, and identical sequences were grouped into haplotypes. Final haplotype assignments were confirmed with FaBox ver. 1.35 (Villesen 2007). Population differentiation of the mtDNA sequences between the southern feeding group and the larger population was estimated using the analysis of molecular variance approach described by Excoffier et al. (1992) as implemented in the program Arlequin. The significance of the resulting estimates of F_{ST} and Φ_{ST} was tested using 1000 permutations. Relationships among haplotypes were visualized via a median-joining network using the program Network 4.5.1.6 (Fluxus Technology).

To gain insight into the nature of the observed population substructure, we estimated effective population sizes, migration rates, time since divergence, and growth rates for the 2 sample sets using the Isolation with Migration program (IM; Nielsen & Wakely 2001, Hey & Nielsen 2004, Hey et al. 2004). However, repeated trials with various parameter options suggested that there was not enough information in our data set to obtain accurate estimates for all of these values (data not shown). Instead, we focused on estimating just the effective population sizes and migration rates using the program MIGRATE (Beerli & Felsenstein 2001, Beerli 2006). The Bayesian inference approach was implemented, using a transition/transversion ratio of 11.22 and an α estimate of 0.09 for the gamma distribution of mutation rate heterogeneity among sites (both estimated using TREE-PUZZLE, Schmidt et al. 2002). We used the Metropolis-Hastings method of generating posterior distributions. The program was run with uniform prior distributions and 1 long chain. To ensure consistency between runs, MIGRATE was run 5 times with a burn-in of 100 000 steps, and a run length of 10 000 000 steps with data recorded every 500 steps. The likelihood ratio test option of MIGRATE was also used to test the hypothesis that the 2 sample sets have different effective population sizes. For the likelihood ratio test, 10 short chains and 1 long chain were run, with a burn-in of 50 000 steps. For the short and long chains, the run length was 10 000 000 steps with data recorded every 500 steps. Specifically, the hypothesis tested was $\Theta_{southern} = \Theta_{larger}$. Theta ($\Theta$) is a parameter that describes the genetic diversity within a population. The genetic variation existing within a single population is ultimately the result of mutations. The rate at which mutations are observed is a combination of the mutation rate (μ), which is how often mutations occur, and the effective population size (N_e), which represents how many 'opportunities' there are for mutations to occur in each generation. The product of these values represents the probability of a mutation occurring within the population in each generation, and this value is called Θ ($\Theta = N_e\mu$ for mitochondrial sequence data). With genetic data, we tend not to know the values of N_e and μ, but the data available are often the frequency of different DNA sequences and the number of mutations separating them. Thus, it is possible to estimate Θ from the data, and use that to make inferences of N_e and μ. Therefore, in this case we can assume that μ is the same for the southern feeding group and the larger population, and therefore comparisons of Θ estimates between the 2 groups directly correspond to comparisons of N_e.

RESULTS

DNA was extracted and mtDNA control regions sequenced from 40 gray whales representing the southern feeding group. Gender was determined for 37 of the 40 sampled whales, and resulted in 15 males and 22 females. This represents a slight female bias, which is contrary to previous studies, which obtained a slight male bias (Steeves et al. 2001). The sequencing protocol resulted in 336 bp of comparable sequence among individuals. Twenty-seven polymorphic sites were identified, which resulted in 18 haplotypes in the southern feeding group whales (Fig. 1). The sequences published in the study by LeDuc et al. (2002) (522 bp) were longer than those obtained here, and therefore all 336 bp from the southern feeding group sequences could be compared to those from the larger population. None of the variable sites or haplotypes identified in the southern feeding group were new; all were also represented by the sequences described by LeDuc et al. (2002) (Fig. 1). However, trimming the sequences of LeDuc et al. (2002) to the comparable 336 bp between the data sets did remove some variable sites that differentiated some of their haplotypes. Specifically, their haplotypes 'G' and 'O' were collapsed into 1 sequence (called 'G' in Fig. 1), haplotypes 'L', 'U,' and 'AD' were collapsed into sequence 'L,' and haplotypes 'AC' and 'AG' were collapsed into haplotype 'AC' (Fig. 1).

Although no haplotypes were found only in the southern feeding group samples, the distribution of

Haplotype	19	53	73	74	75	83	87	89	90	91	109	115	117	123	149	250	251	256	269	273	274	275	284	292	295	296	305	316	324	NFG	SFG	TOT
A	A	T	C	T	T	T	T	C	T	C	G	T	T	T	G	T	A	T	T	G	T	C	C	C	T	T	T	A	A	12	1	13
B	.	C	T	.	C	.	.	T	.	T	A	.	.	C	.	C	G	.	C	.	.	.	.	T	C	.	.	.	G	11	4	15
C	.	.	.	.	.	.	.	.	.	T	.	C	.	.	.	.	G	C	C	.	.	T	.	.	.	.	.	.	.	9	1	10
D	.	.	.	.	.	.	.	.	.	T	.	.	.	.	.	.	G	C	C	.	.	T	.	.	.	.	.	.	.	10	1	11
E	.	.	.	.	C	.	.	.	.	T	.	.	.	.	.	.	G	C	.	.	.	.	.	.	.	.	.	.	.	2	0	2
G	.	.	.	.	.	.	.	.	.	T	.	.	.	.	.	.	.	C	.	A	.	.	.	.	.	.	.	G	.	8	6	14
H	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	G	C	C	.	.	T	.	T	.	.	.	.	.	0	1	1
K	.	.	.	.	.	.	.	C	T	.	C	.	.	.	.	.	G	C	C	.	.	T	.	.	.	.	.	.	.	4	1	5
L	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	A	.	.	.	.	.	.	.	G	.	7	2	9
M	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	C	.	A	.	.	.	.	.	.	.	G	.	3	7	10
N	.	.	.	.	.	.	C	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	.	.	.	.	G	.	4	4	8
P	G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	3	0	3
Q	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	1	0	1
R	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	G	C	C	.	.	.	.	T	.	.	.	.	.	3	1	4
S	.	.	.	.	.	C	.	.	.	T	.	.	C	.	.	.	G	C	C	.	.	T	.	T	.	.	.	.	.	1	0	1
T	.	.	.	C	.	.	.	.	.	T	.	.	.	.	.	.	.	.	.	.	.	.	T	.	C	.	.	.	.	6	3	9
V	.	.	.	.	.	.	.	.	.	T	.	.	.	.	.	.	.	C	.	.	C	.	.	.	.	.	.	.	.	2	0	2
W	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	G	.	1	1	2
X	.	.	.	.	.	C	.	.	.	T	.	.	.	.	.	.	G	C	C	.	.	T	.	T	.	.	.	.	.	1	0	1
Y	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	4	1	5
Z	.	.	.	.	.	.	.	.	.	T	.	C	.	.	.	.	G	.	C	.	.	T	.	.	.	.	.	.	.	2	1	3
AA	.	.	.	C	.	.	C	.	.	T	.	.	.	.	A	.	.	.	.	.	C	.	.	.	.	.	.	G	.	1	3	4
AB	.	.	.	.	.	.	.	.	.	T	.	.	.	.	.	C	G	.	C	.	.	T	.	.	.	.	.	.	.	2	0	2
AC	.	.	.	.	.	.	.	.	.	T	.	.	.	.	.	C	G	.	C	.	.	.	.	.	.	C	C	.	.	3	2	5
AE	.	.	.	C	.	.	C	.	.	.	.	.	.	.	A	.	.	.	.	.	C	.	.	.	.	.	.	G	.	1	0	1
AF	.	.	.	.	.	.	C	.	.	.	.	C	.	.	A	.	.	.	.	.	.	.	.	.	.	.	.	G	.	1	0	1
AH	.	.	.	.	C	.	.	.	.	T	.	.	.	.	.	.	G	C	C	.	.	T	.	.	.	.	.	.	.	1	0	1
AI	G	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	C	.	.	.	T	T	.	.	.	.	.	.	1	0	1
AJ	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	G	C	.	.	.	.	.	.	.	.	.	.	.	1	0	1
																											Total			105	40	145

Fig. 1. *Eschrichtius robustus.* Variable sites characterizing haplotypes from both sample sets of gray whales. NFG, SFG, and TOT (top right) indicate the number of individuals from the northern feeding group (i.e. the larger population), the southern feeding group, and the total number of individuals with each haplotype, respectively

haplotypes was significantly different between the 2 groups, with values of 0.0125 for F_{ST} (p = 0.0303) and 0.0311 for Φ_{ST} (p = 0.0254). The median-joining network shows that although there is some differentiation between the haplotypes from the 2 feeding groups, for the most part the haplotypes from each are scattered throughout the network (Fig. 2). Haplotype diversity and π were estimated at 0.928 and 0.0199, respectively, for the southern feeding group. These values are very similar to estimates obtained for samples representative of the larger population, which were 0.95 and 0.016, respectively (LeDuc et al. 2002).

The results from the MIGRATE analyses are shown in Table 1. Estimates for each value are very similar across iterations, suggesting that the program was run long enough to reach convergence on the estimates. The estimates of Θ for the southern feeding group and the larger population are clearly different. This observation was confirmed by the likelihood ratio test, which rejected the hypothesis of $\Theta_{southern} = \Theta_{larger}$ ($p < 0.001$). The 95% confidence intervals for the migration rate estimates are extremely large, making them uninformative. This result is not surprising, however, because the approach implemented by MIGRATE is known to recover precise and accurate estimates of Θ even in situations where there is not enough information in the data to recover meaningful migration rate estimates (Beerli 2006).

Because the sample of haplotypes found in the southern feeding group represents a subset of the haplotypes found in the larger population (albeit at different frequencies), we conducted further analyses to ensure that our results were not simply due to the effect of sampling. For this assessment, we generated a new set of 40 sequences (representing a simulated southern feeding group data set) by randomly sampling the sequences of LeDuc et al. (2002), using R (R Development Core Team 2009). Thus, this process generated a simulated data set for the southern feeding group under the hypothesis that it represents a random subset of the larger population. This process

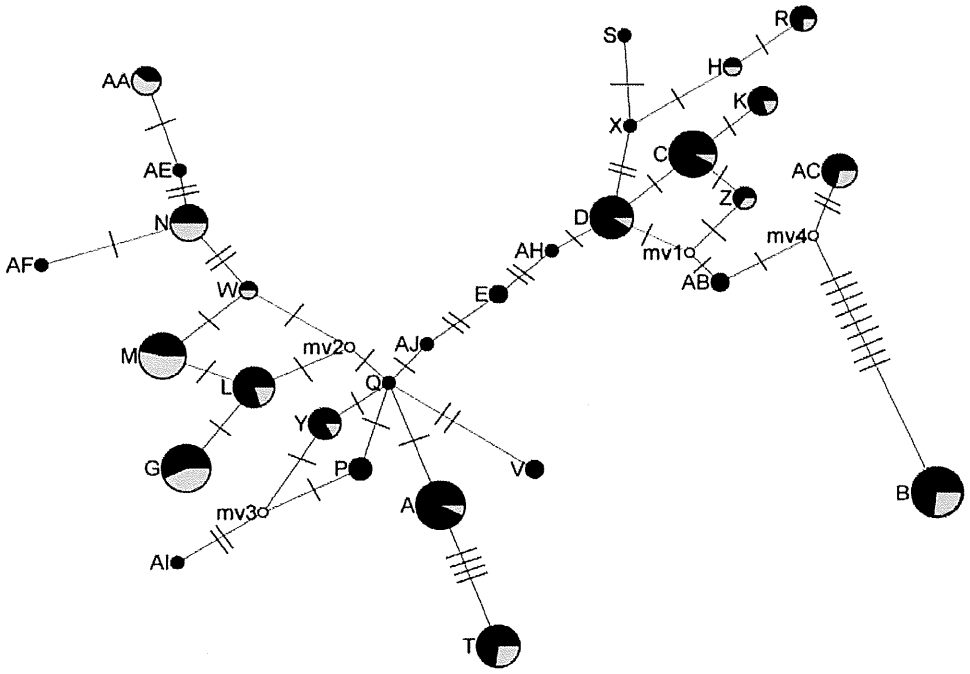

Fig. 2. *Eschrichtius robustus*. Median-joining network for the gray whale sequences. Transitional mutations are indicated with a line, with the number of lines showing the number of transitional mutations. Lengths of the lines connecting nodes are not proportional to the number of mutations. Sizes of the circles are proportional to the haplotype frequencies in the entire data set. Pie charts indicate the proportion of that haplotype found in the larger population (black) and southern feeding group (gray). 'mv' nodes represent inferred nodes that are missing from the data set

was repeated 10 times, generating 10 simulated data sets containing the data from LeDuc et al. (2002), as well as the simulated data for the southern feeding group. Analyses of F_{ST} and Φ_{ST} were conducted for each simulated data set using Arlequin, as were likelihood ratio tests for testing the hypothesis of $\Theta_{southern} = \Theta_{larger}$ using MIGRATE, under the same conditions as were used for the original data.

None of the simulated data sets showed significant signs of structuring based on F_{ST} or Φ_{ST}, and none showed significant differences in estimates of Θ (Table 2). Thus, the significant differentiation found for the real data set, based on all 3 of these analyses, suggests that the observed differentiation is indeed real, and not just an artifact of sampling.

Table 1. *Eschrichtius robustus*. Results from the MIGRATE analysis. Included is the estimated mean for each parameter, as well as the 95% credibility intervals in parentheses (both obtained using the Bayesian approach in MIGRATE). M is the immigration rate m divided by the mutation rate μ. For mitochondrial DNA data, the number of immigrants per generation can be calculated by multiplying M by Θ. Included are the estimates for each of the 5 iterations of the program, as well as the average across all 5 iterations. Southern and larger indicate the southern feeding group of the eastern North Pacific gray whale population, and larger population, respectively

Iteration	Θ_{larger}	$\Theta_{southern}$	$M_{southern-larger}$	$M_{northern-southern}$
1	0.0430 (0.0220–0.0690)	0.0206 (0.00550–0.0380)	522 (205–860)	572 (250–920)
2	0.0462 (0.0235–0.0735)	0.0199 (0.00550–0.0385)	516 (190–865)	565 (245–960)
3	0.0437 (0.0205–0.0730)	0.0208 (0.00650–0.0385)	523 (195–870)	562 (210–920)
4	0.0421 (0.0165–0.0715)	0.0212 (0.00650–0.0425)	515 (190–865)	572 (240–950)
5	0.0430 (0.0200–0.0710)	0.0220 (0.00650–0.0445)	480 (175–810)	526 (195–875)
Avg	0.0436 (0.0205–0.0716)	0.0209 (0.00610–0.0404)	511 (191–854)	559 (228–925)

DISCUSSION

The conservation and/or management of wildlife populations requires knowledge of how individuals are subdivided into separate entities that have relatively independent demographic processes, which are often referred to as 'management units' (MU). Such information is required to identify how each unit, and the popu-

Table 2. *Eschrichtius robustus*. Results from simulation tests under the hypothesis that the southern feeding group represents a random sample of the data set from LeDuc et al. (2002). Included are the F_{ST} and Φ_{ST} estimates, and associated p-values (in parentheses), from Arlequin, as well as p-values from likelihood ratio tests conducted in MIGRATE testing the hypothesis of $\Theta_{southern} = \Theta_{larger}$, where southern is the southern feeding group of the eastern North Pacific gray whale population, and larger is the larger population (not including the southern feeding group)

Iteration	F_{ST}	Φ_{ST}	$\Theta_{southern} = \Theta_{larger}$ p
1	−0.01136 (0.9991)	−0.01489 (1.000)	0.9882
2	−0.00180 (0.5699)	−0.00266 (0.5122)	0.7236
3	0.00019 (0.4018)	−0.00673 (0.7224)	0.1658
4	−0.00980 (0.9863)	−0.01235 (0.9717)	0.9421
5	−0.01047 (1.000)	−0.01156 (0.9609)	0.1167
6	−0.00578 (0.8651)	−0.00873 (0.8358)	0.9632
7	−0.00445 (0.7859)	−0.01000 (0.9042)	0.9805
8	0.00146 (0.3744)	−0.00448 (0.6090)	0.1023
9	−0.00419 (0.7468)	−0.00889 (0.8436)	0.7233
10	−0.00531 (0.82796)	0.00425 (0.2678)	0.2074

lation as a whole, will respond to exploitation and/or unintentional impacts. Moritz (1994) was the first to provide a working definition of MUs in a population genetics context, and defined them as

> ...populations with significant divergence of allele frequencies at nuclear or mitochondrial loci, regardless of the phylogenetic distinctiveness of the alleles. (p. 374)

While this definition has been widely applied in population genetics studies, it has recently been argued that MUs should be defined based on criteria demonstrating demographic isolation rather than simply rejecting the hypothesis of panmixia (Waples & Gaggiotti 2006, Palsbøll et al. 2007, Waples et al. 2008). This idea makes intuitive sense, because the true question for management is whether the units will respond differently to the pressures of concern (e.g. exploitation and/or unintentional mortality). However, there is a disconnect between inferring demographic independence and genetic estimates of differentiation because populations can be demographically independent even when long-term migration rates are high enough to result in relative genetic homogeneity (Waples & Gaggiotti 2006, Waples et al. 2008).

The data presented here show that the southern feeding group of gray whales represents a distinct MU under both of these criteria. The analysis showing statistically significant differentiation of mitochondrial haplotypes demonstrates qualification as an MU under the criteria of Moritz (1994). Moreover, the analysis showing that the effective sizes of both groups are different ($\Theta_{southern} \neq \Theta_{larger}$) shows that the maternal lineages of the southern feeding group represent a distinct seasonal subpopulation. Indeed, if they were not an independent unit but instead just represent different samples from the same mitochondrial 'population,' then estimates of Θ from the 2 data sets should converge on the same value. Thus, the southern feeding group qualifies as a separate MU under the criterion of Palsbøll et al. (2007). Combined, these data show that the southern feeding group requires separate management consideration with regards to resuming whaling.

Hastings (1993) showed that populations behave in a demographically independent manner when migration rates are less than ~10%. We have intentionally not converted Θ estimates to N_e estimates because this requires knowledge of the substitution rate (μ). Estimates of μ for the control region of baleen whale mtDNA vary by over an order of magnitude (e.g. Rooney et al. 2001). Moreover, μ, whatever its true value is, is undoubtedly the same for the southern feeding group and the larger population, and therefore comparing estimates of Θ is an appropriate and less controversial method for comparing N_e. Regardless, if we apply the μ estimate of 1.0×10^{-10} mutations site^{-1} yr^{-1}, estimated by Alter & Palumbi (2009) for North Pacific gray whales, the resulting estimates of migration rates are << 1%. In this case, we are not dealing with migration rates between reproductive populations per se, but rather exchange rates between maternally based feeding groups. As with the haplotype frequency data, this result shows that the southern feeding group represents a distinct seasonal subpopulation.

Estimates of Θ represent long-term averages over the lifetime of the population; therefore, these genetic analyses provide information on an evolutionary time scale, whereas wildlife managers are generally more interested in the current state of a population (e.g. at the ecological time scale; Waples et al. 2008). To address this disconnect, we reiterate that photo-identification data of contemporary individuals also results in the same conclusion that the southern feeding group represents a distinct seasonal subpopulation based on maternally directed site fidelity. Photo-identification data show that the majority of whales sighted in the southern feeding areas are re-sighted there in subsequent years (Darling 1984, Calambokidis et al. 2002), and that the majority of calves first sighted in the southern feeding area with their mothers are re-sighted there as juveniles and adults (Calambokidis et al. 2010). Therefore, the combination of photo-identification and genetic data suggests distinct subdivision of the southern feeding group at both the evolutionary and contemporary (or ecological) time scales.

We reiterate that the southern feeding group likely mates with the rest of the population in the winter breeding grounds, and that the structuring we see is the result of maternally directed site fidelity to different feeding grounds. We used mtDNA (rather than

nuclear markers) to test this hypothesis specifically for this reason, because such a pattern would be reflected in mtDNA and not nuclear DNA. This type of population substructure is common in whales (e.g. Hoelzel 1998), and has proven important for management. The rationale is that, because of this site fidelity, knowledge of specific feeding areas is only present within certain matrilines. Therefore, if whales are extirpated from a specific feeding ground, they will not be 'replaced' (or the area will not be re-populated) by others from the larger population because knowledge of that feeding area has been lost. Indeed, such localized extinctions and lack of subsequent re-population of areas (despite an increasing overall population size) is widely documented in whales (e.g. Northridge 2008). Thus, the combined genetic and photo-identification data showing that the southern feeding group represents a distinct maternally based seasonal subpopulation indicate that these whales require separate management consideration from the larger population.

Previous studies have suggested that the haplotype diversity in the southern feeding group is too high to have resulted from strict maternally directed site fidelity beginning with a few founders after the cessation of commercial whaling within the past century (Ramakrishnan et al. 2001). Under the hypothesis that this group was founded after the cessation of whaling, only a few closely related haplotypes should be represented within the southern feeding group, as opposed to the pattern seen in Fig. 2. In addition, the hypothesis of a founding event within the past century is not consistent with the known sighting information. Indeed, gray whales have been seen in the southern feeding grounds throughout their history, including in times of lowest abundance (Swartz et al. 2006, and references therein). Moreover, if a few individuals recently founded the southern feeding group, then the estimate of $\Theta_{southern}$ should be substantially smaller, as effective population size estimates are heavily influenced by bottlenecks.

Instead, what the sighting and genetic data suggest is that the southern feeding group of gray whales predates whaling. Under this hypothesis, the haplotype diversity is expected to be high, because those lineages that survived whaling would be a random sample from a much larger population. Substantial gaps would also be expected between existing haplotypes resulting from the removal of haplotypes by whaling. This pattern is exactly what is seen in Fig. 2. The similarity of haplotypes, and the degree of haplotype sharing between the southern feeding group and the larger population, both suggest some degree of migration between the 2 groups. However, although reliable estimates of migration rates could not be obtained here, the data clearly show that the rate of migration is low enough for the 2 groups to represent independent demographic entities. The southern feeding group therefore qualifies as a separate MU, and requires separate management consideration.

A larger sample set, and the analysis of more molecular markers (particularly nuclear markers), is obviously desirable for addressing topics such as this one. Moreover, it is possible that further structuring within each of these identified groups exists, but is as yet undetected. However, given the clarity of the results obtained and the implications that they have for the management of these whales, it seemed important to publish these data as soon as possible so that they could be available for informing management decisions. We are currently collecting more samples and collaborating with other scientists to increase the number and geographical representation of our sample set. Protocols for analyzing nuclear loci are also being developed. Combined, these efforts will allow for larger-scale analyses of this issue in the near future.

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Glacial refugia and the phylogeography of Steller's sea lion (*Eumatopias jubatus*) in the North Pacific

A. HARLIN-COGNATO,* J. W. BICKHAM,† T. R. LOUGHLIN‡ & R. L. HONEYCUTT†

*Department of Biology, Texas A&M University, TX, USA
†Department of Wildlife and Fisheries Sciences, Texas A&M University, TX, USA
‡National Marine Mammal Laboratory, National Marine Fisheries Service, Seattle, WA, USA

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population structure;
Steller's sea lion.

Abstract

Mitochondrial DNA sequence data were used to examine the phylogeographic history of Steller's sea lions (*Eumetopias jubatus*) in relation to the presence of Plio-Pleistocene insular refugia. Cytochrome *b* and control region sequences from 336 Steller's sea lions reveal phylogenetic lineages associated with continental refugia south of the ice sheets in North America and Eurasia. Phylogenetic analysis suggests the genetic structure of *E. jubatus* is the result of Pleistocene glacial geology, which caused the elimination and subsequent reappearance of suitable rookery habitat during glacial and interglacial periods. The cyclic nature of geological change produced a series of independent population expansions, contractions and isolations that had analogous results on Steller's sea lions and other marine and terrestrial species. Our data show evidence of four glacial refugia in which populations of Steller's sea lions diverged. These events occurred from approximately 60 000 to 180 000 years BP and thus preceded the last glacial maximum.

Introduction

Several empirical studies have documented the impact of glacial cycles on phylogeographic patterns of terrestrial species of plants and animals with a Beringial distribution (Holder *et al.*, 1999,2000; Abbot *et al.*, 2000; Clarke *et al.*, 2001; Barnes *et al.*, 2002; Flagstad & Roed, 2003). The chronology and geomorphology of glaciation in the North Pacific has been well-documented, and there is a growing body of evidence indicating large ice-free regions in Beringia (BER) and south of the ice sheets in Eurasia (EUR) and North America (NA) that served as refugia during the Wisconsin glaciation 65 000–18 000 years ago (Fig. 1) (Pielou, 1991; Hewitt, 2000). Several species of terrestrial plants and animals confined to these regions reflect patterns of phylogeographic structure that are temporally concordant with these geological events (Holder *et al.*, 1999; Abbot *et al.*, 2000; Barnes *et al.*, 2002; Fedorov & Stenseth, 2002; Fleming & Cook, 2002; Zink *et al.*, 2002; Flagstad & Roed, 2003; Hundertmark *et al.*, 2003). Support for ice-free regions during the last glacial maximum (LGM) also comes from patterns of endemism seen in organisms from coastal islands of British Columbia, Southeastern Alaska and the Gulf of Alaska (Clague, 1989; Heusser, 1989; Cook *et al.*, 2001; Lacourse *et al.*, 2003). For instance, terrestrial species occupying the Alexander Archipelago, Kodiak Islands and the Queen Charlotte Islands (Fig. 1) are considered genetically divergent from mainland relatives as a consequence of insular isolation (Cowan, 1989; Heusser, 1989; Byun *et al.*, 1997; Holder *et al.*, 1999,2000; Clarke *et al.*, 2001; Barnes *et al.*, 2002; Fedorov & Stenseth, 2002; Fleming & Cook, 2002; Brunhoff *et al.*, 2003; Fedorov *et al.*, 2003). As with these terrestrial species, marine mammals and birds, including the sea otter *Enhydra lutris* (Cronin *et al.*, 1996), harbour seal *Phoca vitulina* (Stanley *et al.*, 1996; Gorbics & Bodkin, 2001; Westlake & O'Corry-Crowe, 2002), marbled murrelet *Brachyramphus marmoratus* (Congdon *et al.*, 2000) and rock ptarmigan *Lagopus mutus* (Holder *et al.*, 1999,2000) show similar patterns of divergence. Many of these taxa display female breeding site fidelity, and mitochondrial (mtDNA) gene sequences support genetic

Correspondence: J. W. Bickham, Department of Wildlife and Fisheries Sciences, Texas A &M University, College Station, Texas 77843-2258, USA.
Tel.: +1 979 845 5777; fax: +1 979 845 4096
e-mail: j-bickham@tamu.edu

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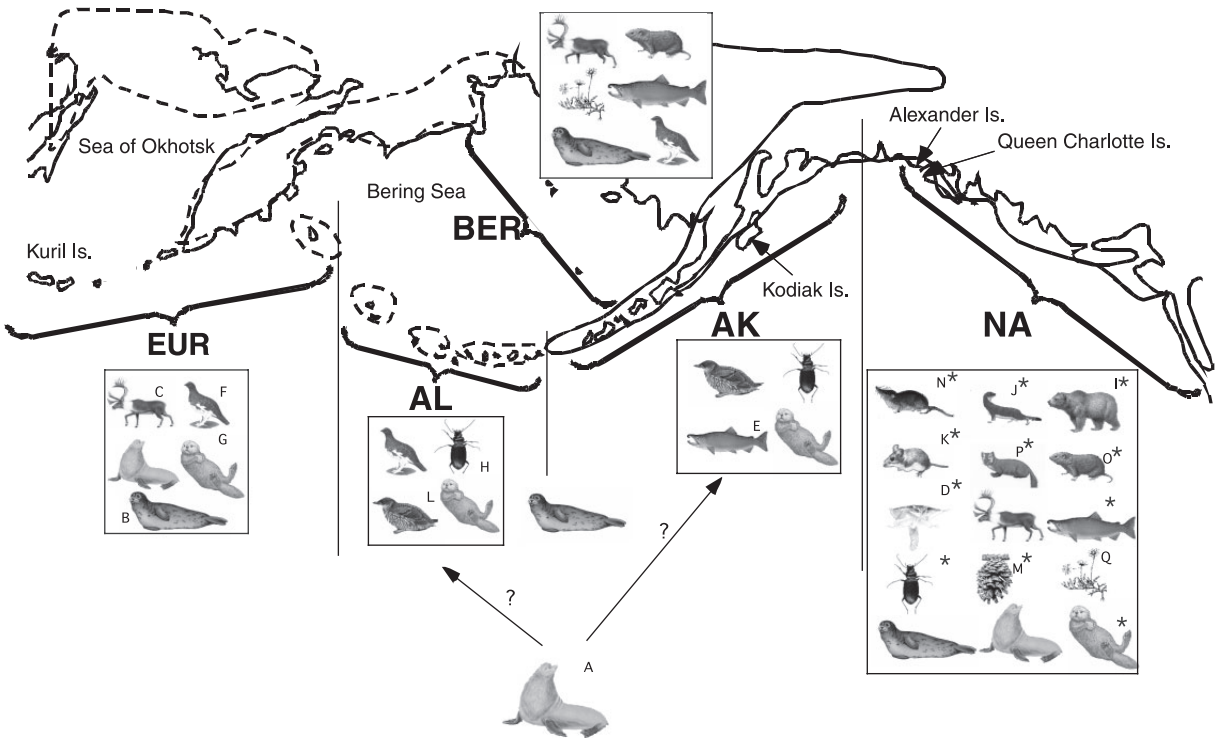

Fig. 1 Association of putative refugia and genetic structure of North Pacific biota. This figure summarizes previous studies of genetic structure of species occupying regions that were subjected to glaciation during the Plio-Pleistocene. Congruence in the distribution of genetic diversity for a wide variety of plants and animals suggests glacial vicariance shaped the history of these species in a similar fashion. Vertical lines roughly correspond to statistically significant breaks in genetic diversity, each associated with a glacial refugium: EUR, Eurasia; AL, Aleutian Islands; AK, Gulf of Alaska and mainland Alaska; NA, Continental North America; BER, Beringia. Asterisks indicate mainland North American taxa which have forms endemic to the Queen Charlotte and Alexander Islands. The solid curve outlines the general limits of the Cordilleran ice sheet during the last glacial maximum (LGM) 18 000–20 000 years ago (Mann & Peteet, 1994). Boundaries of the EUR ice, which remain disputed (Mann & Hamilton, 1995; Rutter, 1995; Grosswald & Hughes, 2002), are represented by hashed curves. Taxa identification: A, *Eumetopias jubatus* (Baker *et al.*, 2005; Bickham *et al.*, 1998); B, *Phoca vitulina* (Westlake & O'Corry-Crowe, 2002); C, *Rangifer tarandus* (Flagstad & Roed, 2003); D, *Glaucomys* sp. (Kavanaugh, 1989; Abbot *et al.*, 2000); E, *Oncorhynchus kisutch* (Smith *et al.*, 2001); F, *Lagopus mutus* (Holder *et al.*, 1999); G, *Enhydra lutris* (Cronin *et al.*, 1996; Gorbics & Bodkin, 2001); H, *Nebria* sp. (Kavanaugh, 1989; Clarke *et al.*, 2001); I, *Ursus americanus* (Byun *et al.*, 1997; Barnes *et al.*, 2002); J, *Mustela erminea* (Fleming & Cook, 2002); K, *Peromyscus* sp. (Cowan, 1989); L, *Brachyramphus marmoratus* (Congdon *et al.*, 2000); M, *Pinus contorta* (Lacourse *et al.*, 2003); N, *Sorex* sp. (Cook *et al.*, 2001); O, *Microtus* sp. (Cook *et al.*, 2001; Brunhoff *et al.*, 2003); P, *Martes* sp. (Cook *et al.*, 2001); Q, *Dryas integrifolia* (Tremblay & Schoen, 1999).

differentiation between rookeries within regions associated with putative insular isolates (Fig. 1). For example, there are genetic breaks in haplotype diversity that define one or more genetic lineages within the Aleutian Islands (AL), the Gulf of Alaska (AK) and coastal continental NA, which contain one or more of the putative insular refugia that remained ice-free at the LGM (Fig. 1).

Steller's sea lion (*Eumetopias jubatus*) is a highly vagile marine mammal with rookeries distributed along rocky continental coasts and near-shore islands from Northern California, through the Gulf of AK, along the AL Archipelago, to the Kamchatka Peninsula, Kuril Islands and the Sea of Okhotsk in Asia (Fig. 2). The species has been studied intensively since the mid-1970s, and as a result, genetic material from more than 2000 individuals has been collected from every rookery within the species' range, and the breeding biology and dispersal behaviour of this species has been well-documented (Raum-Suryan *et al.*, 2002). Previous studies of mtDNA haplotype diversity (Bickham *et al.*, 1996,1998; Baker *et al.*, 2005) defined three genetic stocks of Steller's sea lion – 'eastern' (California to Southeast AK), 'western' (Prince William Sound to the Commander Islands) and 'Asian' (Kamchatka Peninsula, Kuril Islands and Sea of Okhotsk) – with a geographic distribution of genetic diversity generally similar to that of the harbour seal, sea otter, rock ptarmigan, and marbled murrelet (Fig. 1). Combined, the results from mitochondrial (Bickham *et al.*, 1996,1998; Baker *et al.*, 2005) and nuclear loci (Trujillo *et al.*, 2004) support behavioural observations that female Steller's sea lions return to within 500 km of their natal rookeries to reproduce throughout their lifetimes, and that gene flow among regions is predominately mitigated through the long-distance dispersal of males (Raum-Suryan *et al.*, 2002).

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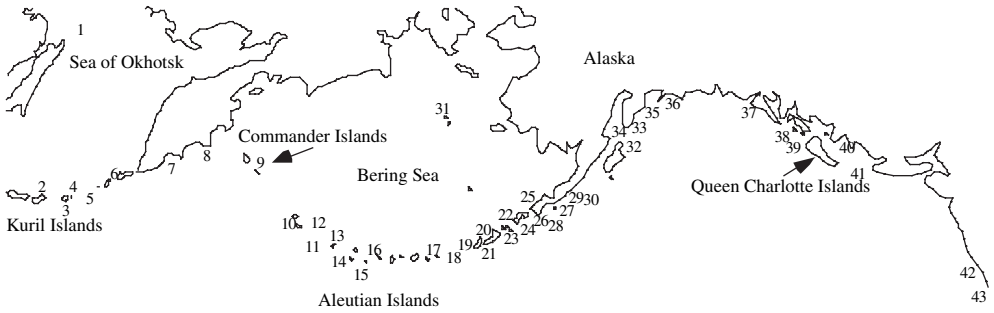

Fig. 2 Map of Steller's sea lion rookeries represented in this study. Sample sizes are in parentheses. 1, Iony Island (27); 2, Chernyya Brat'ya (13); 3, Srednego Island (15); 4, Raikoke Island (14); 5, Lovushki Island (19); 6, Antsiferova Island (13); 7, Zheleznaya Bay (9); 8, Kozlova Cape (11); 9, Medny Island (23); 10, Agatu Island (5); 11, Buldir (4); 12, Attu Island (4); 13, Kiska Island (13); 14, Amchitka Island (2); 15, Ulak Island (6); 16, Gramp Rocks (2); 17, Seguam Island (5); 18, Yunaska Island (3); 19, Adugak Island (4); 20, Bogosloff Island (2); 21, Ogchul Island (2); 22, Akun Island (2); 23, Akutan Island (24); 24, Ugamak Island (13); 25, Amak Island (1); 26, Clubbing Rocks (5); 27, Atkins Island (8); 28, Pinnacle Island (13); 29, Chowiet Island (2); 30 Chirikof Island (2); 31, Walrus Island (2); 32, Marmot Island (6); 33, Chiswell Island (2); 34, Sugarloaf Island (4); 35, Fish Island (9); 36, Seal Rocks (8); 37, White Sisters (6); 38, Hazy Islands (18); 39, Forester Island (5); 40, North Danger Rocks (3); 41, Triangle Island (5); 42, Rogue Reef (1); 43, St. George Reef (1).

The congruent distribution of genetic variation among terrestrial-breeding marine taxa supports the presence of insular refugia during the LGM. However, the extent to which these insular refugia shaped the phylogeographic history of terrestrial-breeding marine taxa remains inconclusive (Holder *et al.*, 1999). To investigate this, we present three testable predictions of the patterns of mtDNA population structure expected from species isolated among insular refugia during the Plio-Pleistocene. First, the effects of glacial vicariance should be detectable in the analyses of maternal lineages, especially in species with female philopatry. Second, geographic regions that demonstrate significant genetic structure are expected to be associated with putative glacial refugia. Third, the rate of coalescence events within maternal lineages is predicted to be synchronized with the chronology of geological events.

To test these hypotheses we studied the mitochondrial DNA control region and complete cytochrome *b* gene from 338 Steller's sea lions, distributed among 43 rookeries. Control region sequences were previously reported in a much larger study of population genetics designed to investigate stock structure of this species (Baker *et al.*, 2005). Based upon haplotype frequencies, they concluded that there are three stocks of Steller's sea lions: an eastern stock includes rookeries from California to southeastern AK, a western stock includes rookeries from Prince William Sound to the Commander Islands, and an Asian stock includes rookeries on the Kamchatka Peninsula, Kuril Islands and Sea of Okhotsk. Their study did not employ a phylogenetic analysis of the sequences or any specific tests to relate population subdivision to geological history. In this study we report new sequence data for the cytochrome *b* gene from a subset of the animals used by Baker *et al.* (2005), and we perform analyses to investigate the relationships among geographic distributions of haplotypes, the phylogenetic history of the haplotypes, and the geological history of the North Pacific region. Our results provide support for the presence of glacial refugia proposed by the congruent distribution of multiple taxa with similar distributions, dispersal capabilities, and dependence on suitable terrestrial breeding habitat. Specifically, we present evidence that geographic variation of the Steller's sea lion is consistent with one or more insular refugia in the Pacific Northwest, Gulf of AK, AL Islands and Russia, and that following glacier recession, rookeries were re-colonized in a linear pattern, resulting in contemporary isolation-by-distance (IBD) between historical refugia. Collectively, this study provides one of the most thorough tests of insular refugia hypotheses, and it illustrates the response of a terrestrially breeding marine mammal to habitat perturbations resulting from glacial cycles.

Materials and methods

Sampling

Tissues were selected from an archive of flipper punches from pups taken at their natal rookeries (Fig. 2) collected from 1994 to 2003. Because Steller's sea lions are not known to twin, it is assumed that all samples are from unrelated individuals. Emphasis was placed on obtaining representation of previously recognized genetic stocks (Bickham *et al.*, 1996) and from regions containing putative insular refugia (Fig. 2), as well as representatives of all 80 control region haplotypes known from pups taken at rookeries at the time we conducted this work. All samples had previously been sequenced for a 238 bp segment of the control region (Bickham *et al.*, 1996,1998; Trujillo *et al.*, 2004; Baker *et al.*, 2005).

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Data collection

Total genomic DNA was isolated using either a standard phenol–chloroform protocol (Maniatis *et al.*, 1982) or a Qiagen DNeasy kit (Qiagen, Valencia, CA, USA). The complete cytochrome *b* (cyt *b*) gene and 238 bp of the 5′ end of the mitochondrial control region (Bickham *et al.*, 1996) were amplified with the polymerase chain reaction (PCR). External primer sets included: (1) cyt *b* – LGL 765F, 5′-GAAAAACCAYCGTTGTWATTCAACT-3′ and LGL 766R, 5′-GTTTAATTACAATYTYAGCTTTGGG-3′; (2) control region – LGL 283F, 5′-TACACTGGTCTT-GTAAACC-3′, LGL 1115R, 5′-ATGACCCTGAAGAA-RGAACCAG-3′. Methods for analysis of the control region were reported previously (Bickham *et al.*, 1996). For cytochrome *b*, approximately 1–2 μL of DNA template were included in 50 μL PCR reactions containing the following: 5 μL each 10X Amplitaq PCR buffer (Perkin Elmer, Boston, MA, USA), 25 mM MgCl, and 10 mM deoxynucleotidetriphosphates (dNTP's, 2.5 mM each), 1 μL each of 10 mg mL^{-1} bovine serum albumin (BSA), 10 μM of each primer, and 5 units (U) of Amplitaq (Perkin Elmer) DNA polymerase. Reactions were performed in an ABI 2700 (Applied Biosystems, Foster City, CA, USA) thermocycler with an initial denaturation at 95 °C for 2 min, followed by 25 cycles of 95 °C (45 s), 50 °C (40 s), 70 °C (2 min 30 s), and a final extension at 72 °C for 10 min.

Amplicons were electrophoresed in 1.5% agarose-TBE (tris, boric acid, EDTA) and visualized under UV light. Prior to sequencing, excess oligonucleotides and dNTP's were removed with a QIAquick PCR purification kit (Qiagen, Valencia). Cleaned PCR products were sequenced with ABI (Applied Biosystems) BigDye sequencing chemistry and an ABI 377 automated sequencer. All amplicons were sequenced in both directions, and two internal primers (560, 5′-GCAACCCTAACACGATTCTT-CG-3′; 610, 5′-CCAGTTTCGTGTAGGAATAATAGG- 3′) designed for Steller's sea lion were used to sequence cytochrome *b* to obtain complete overlap in both directions.

Sequences were aligned with default parameters in Clustal X (Thompson *et al.*, 1994), and published sequences of *E. jubatus* (GenBank accession X82311), *C. ursinus* (AF380888, AF384390 AF380890, AF384389), *P. vitulina* (L39204, AF522864 X82306, AF522865), and *Zalophus californianus* (X82310, L37031), the sister-taxon to Steller's sea lion (Wynen *et al.*, 2001), as guides. The alignment of cyt *b* was unambiguous and contained no insertions or deletions. Subsequent to the Clustal X alignment of the control region, visual alignment in MACCLADE VERSION 4.0 (Maddison & Maddison, 1992) was used to make minor adjustments. Because the mitochondrial genome is inherited as a single genetic locus without recombination, the cytochrome *b* and control region sequences were concatenated to produce a fragment of 1378 base pairs. This alignment is available from authors upon request. All subsequent statistical analyses were performed on this combined data set. The sequences for 28 cytochrome *b* haplotypes were submitted to GenBank under accession numbers DQ144995–DQ145022. All control region sequences were previously submitted to GenBank by Baker *et al.* (2005).

Diversity indices, model of evolution, and rate of substitution

DNASP VERSION 3.99.5 (Rozas & Rozas, 1999) was used to estimate haplotype diversity (Nei, 1987), nucleotide diversity (π) (Nei, 1987), theta, and number of segregating sites. Standard error of these measurements was determined from a null distribution generated from 10 000 random permutations of the data keeping sample size constant. The average number of pair-wise differences was estimated with the program MEGA VERSION 2.1 (Kumar *et al.*, 1993,2001) with gamma-corrected Tamura–Nei (Tamura & Nei, 1993) distances. A 95% confidence interval for the pair-wise distances was calculated from 100 bootstrap replications.

MODELTEST VERSION 3.06 (Posada & Crandall, 1998) was used to test 54 nested hypotheses of nucleotide substitution. The Tamura–Nei model (Tamura & Nei, 1993) with a correction for rate variation among sites (Yang, 1996) and a proportion of invariant sites [$I = 0.9176$; (Waddell *et al.*, 1996)] was selected as the model that best fit the substitution pattern for both genes, and was used in all analyses that employed a model of evolution.

A maximum likelihood analysis of edited *E. jubatus* ($n = 2$, this study) sequences, aligned with GenBank sequences from *C. ursinus* ($n = 3$) and *Z. californianus* ($n = 2$), was performed in PAUP* VERSION 4.0B10 (Swofford, 1999) with model parameters selected via ModelTest Version 3.06 (Posada & Crandall, 1998) and rooted with *P. vitulina* as an outgroup. The resultant phylogeny (not shown) was congruent with a previous analysis (Wynen *et al.*, 2001), with *E. jubatus* and *Z. californianus* as sister taxa and *C. ursinus* at the base of the *E. jubatus* and *Z. californianus* clade. This phylogeny with maximum likelihood optimized branch-lengths was subsequently used in RHINO VERSION 1.2 (Rambaut, 2003) to estimate the divergence time and substitution rate of the *E. jubatus* lineage. Two calibration points, the divergence of *E. jubatus* and *Z. californianus* at 2.0 ybp and *C. ursinus* and the family Otariidae at 6.0 ybp (Repenning, 1976), were used to estimate substitution rates. The rate of evolution obtained with RHINO was compared to that derived with the formula $r = K/2T$ (Li & Graur, 1991), where K is the number of pair-wise differences between Steller's sea lion and *Z. californianus*, and T is the date of divergence in millions of years (ybp). The date of divergence of 2.0 ybp (Repenning, 1976) from the fossil record was used as a calibration point in this analysis.

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Prediction 1: genetic structure of female lineages

Phylogenetic relationships among mtDNA haplotypes within the *E. jubatus* lineage were estimated following the statistical parsimony procedure of Templeton *et al.* (1992) with the program TCS VERSION 1.1.3 (Clement *et al.*, 2000). The haplotype network obtained from TCS was used as the framework for sequential nesting of haplotypes into clades (Templeton, 1998). Reticulations, or equally parsimonious connections within the network, were resolved with two procedures. First, alternative connections between haplotypes were broken following a series of rules based on coalescence theory (Crandall & Templeton, 1993). Second, synapomorphies in the form of nonsynonymous substitutions in the cyt *b* gene, a conservative class of substitution, was used to resolve all cases in which assignment to a nested series was ambiguous ('stranded clades') (Templeton *et al.*, 1987; Templeton & Sing, 1993). The program GEODIS VERSION 2 (Posada *et al.*, 2000) was used to test the null hypothesis of random geographic distribution of genetic variation. This program performs two analyses. The first is an r x c contingency test of geographic locality and frequency of haplotypes. The second is the estimation of haplotype dispersion within and among nested clades (Templeton, 1998). In both cases, the significance of results was derived from comparison to a null distribution generated from 10000 randomizations of the data matrices.

Templeton's nested clade procedure (Templeton *et al.*, 1987,1992; Templeton, 1998) was used to define genetic boundaries of populations by simultaneously incorporating evolutionary history and contemporary geographic distribution and frequency of haplotypes. With this method, it is not required that the number or geographic boundaries of populations be defined *a priori*, but rather genetically distinct populations are defined via statistical tests for association of evolutionary lineages and their geographic distribution. Statistical significance is determined with a permutation procedure that increases the power to detect population structure in species whose genetic variation otherwise does not display a definitive geographic pattern (Templeton, 1998,2004). Because the relative age of clades increases with nesting level, the most contemporary population boundaries were determined from the distribution of 1-step clades that had a significant geographic association in the NCA. The geographic distribution of haplotypes within clades at deeper nested levels (> 1-step) was used to characterize the temporal shift in the geographic distribution of population boundaries over time. A hierarchical AMOVA (Excoffier *et al.*, 1992) was performed with ARLEQUIN VERSION 2.00 (Schneider *et al.*, 1997) to measure the strength of the genetic structure among populations with boundaries defined with NCA, and to quantify the partitioning of variation within rookeries, within populations of rookeries, and among populations. Significance values of ϕ statistics (Weir & Cockerham, 1984) were calculated by comparison to a null distribution derived from 10 000 random permutations of the data.

Prediction 2: association of glacial refugia and population boundaries

The program IBD VERSION 1.5 (Bohonak, 2002) was used to perform a Mantel test that assessed significance of the correlation between geographic and genetic distances. The slope of the regression plus 95% confidence intervals was estimated with reduced major axis regression (RMA), which is considered a more appropriate estimator of slope in IBD analyses than ordinary least squares regression (Hellberg, 1994).

A partial regression was performed with IBD to test for significant association of genetic divergence and putative insular refugia while controlling for the effect of geographic distance. A third variable matrix was created from pair-wise comparisons of rookeries that were or were not potentially separated by inhospitable (ice covered) rookeries at the LGM. For example, a '1' was assigned to individuals from rookeries that were not putatively separated by ice sheets at the LGM, and a '0' was given to comparisons among rookeries that were potentially isolated or extirpated via glacial vicariance. In this manner, we tested for an effect of ice sheets on genetic divergence among rookeries. Furthermore, population boundaries derived from NCA were compared to the geographic location of putative refugia (Fig. 1).

Prediction 3: dates of population divergence and glacier chronology

The stochastic nature of lineage sorting within species makes estimation of intraspecific divergence with a single locus problematic. In an attempt to circumvent this potential problem, times of divergence among populations of Steller's sea lion were calculated with two methods. First, the time to most recent common ancestor (TMRCA) of clades was estimated with the program BEAST VERSION 1.0.3 (Drummond *et al.*, 2002; Drummond & Rambaut, 2003a) that uses a Bayesian approach with a MCMC search strategy to calculate from an aligned sequence matrix, a model of evolution, and a rate of nucleotide substitution, the posterior probability density distribution of divergence dates of clades. One important feature of BEAST is the ability to analyze concatenated DNA sequences from multiple data partitions that have different models of evolution. Therefore, the concatenated cytochrome *b* and control region partitions were assigned independent models of evolution derived from MODELTEST. Three independent MCMC chains were run for 1 000 000 steps each to optimize the scale factors to an acceptance rate probability of 0.25 for each parameter (Drummond *et al.*, 2002). Each initial MCMC chain was run with scale factors adjusted as

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suggested by the operator analysis (Drummond & Rambaut, 2003a) until the scale factors and the length of chains were adequate to produce an effective sample size (ESS) (Drummond *et al.*, 2002) greater than 100 for all estimated parameters. The final BEAST analysis consisted of two independent MCMC chains of 2 500 000 steps each with optimized search settings. TRACER VERSION 1.0.1 (Drummond & Rambaut, 2003b) was used to examine the burn-in period, the degree of mixing, the shape of the probability density distribution, and 95% confidence intervals for estimated divergence dates. A final examination of the two runs combined suggested that the two chains sampled from similar probability density distributions, and that mixing during the search was adequate. The quality of the MCMC search was also supported by high (> 100) ESS values. Second, the TMRCA of clades was estimated by calculating the average number of pair-wise differences between haplotypes within each clade, and multiplying this by the point estimate and 95% confidence intervals of the maximum-likelihood derived mutation rate of the concatenated data partitions (see previous section).

Results

Diversity indices, model of evolution, and rate of substitution

Comparisons of 336 individuals of *E. jubatus* yielded 64 variable sites and 107 haplotypes for the combined data. Haplotypes differed from each other by an average of 2.26 substitutions, and nucleotide diversity was relatively low at 0.18%. Of the 107 haplotypes, 93 were found only in a single individual, and haplotype diversity was 0.89 (±0.01).

The maximum likelihood estimation of the rate of substitution for *E. jubatus* was 1.9% per myr with a 95% confidence interval of 1.5–2.8%. Similarly, the method based on the average number of pair-wise differences produced a substitution rate that ranged between 1.5 and 1.9% per myr with an average of 1.7%, well within the 95% confidence interval of the maximum likelihood estimate.

The maximum likelihood analysis of divergence times proposed a separation of the *E. jubatus* and *Z. californianus* lineages approximately 2.25 myr ago, with a 95% confidence interval of 1.57–3.06. This divergence estimate was cross-validated with independent calibrations, i.e. the 2 myr *E. jubatus*/*Z. californianus* and the 6 myr sea lion/*C. ursinus* fossil dates fell within the 95% confidence intervals of divergence dates derived from the ML analysis of molecular data.

Prediction 1: genetic structure of female lineages

The nested clade procedure produced a network with four nested levels (Fig. 3), each with clades that demonstrated statistically significant geographic patterns (Table 1). For example, Clade 4-2 contained 100% of the haplotypes collected in NA rookeries (British Columbia to California, Fig. 1), and Clade 4-1 showed the opposite pattern containing the majority of haplotypes from EUR (west of the Commander Islands) (Fig. 4). Those rookeries in the central portion of the range, from the Gulf of AK (Fig. 1) through the AL Islands (Fig. 1), most often had haplotypes distributed equally between the two 4-step clades (Fig. 4). There is a similar pattern to the geographic distribution of haplotypes in 1-, 2-, and 3-step clades, but geographic resolution increases as the nested level decreases. For example, 2-step clades show association between EUR and NA, but also clearly demarcate a lineage (clade 2-6) geographically restricted to the AL and AK regions (Fig. 4). Clades at the first nested level defined four lineages, each associated with EUR, NA, AL and AK regions (Fig. 4). Boundaries of contemporary Steller's sea lion populations were defined from the geographic limits of these four regionally associated lineages. Measures of population structure provided additional statistical support for genetic subdivision of *E. jubatus* into these four populations (Table 2).

Prediction 2: association of glacial refugia and population boundaries

The four populations identified with the nested clade procedure roughly corresponded to the location of the NA, EUR, AL and AK refugia (Fig. 4). The partial regression revealed statistical support for the association of genetic distances between rookeries and putative glacial refugia ($r = 0.18$, $P < 0.05$). Additionally, the Mantel and RMA analyses supported a significant positive correlation between genetic and geographic distance between rookeries ($r = 0.36$, $P < 0.001$).

Prediction 3: dates of population divergence and glacier chronology

Estimates of TMRCA derived from Bayesian and maximum likelihood methods varied, so that no two estimates from different methods overlapped in their dates (Table 3). When the results of each method were examined independently, the confidence intervals tended to be large regardless of the method used, such that in most cases estimates of TMRCA among lineages were not significantly different from each other (Fig. 5). Dates derived by the Li & Graur (1991) method produced the smallest confidence intervals with the greatest degree of discrimination of inter-clade divergence (Table 3). These dates were generally 150 000–200 000 years younger than those of the Bayesian method, and the confidence intervals were more consistent (Table 3). Nevertheless, regardless of the method used to derive the dates, analyses supported a divergence of *E. jubatus* populations prior to the Wisconsin glaciation.

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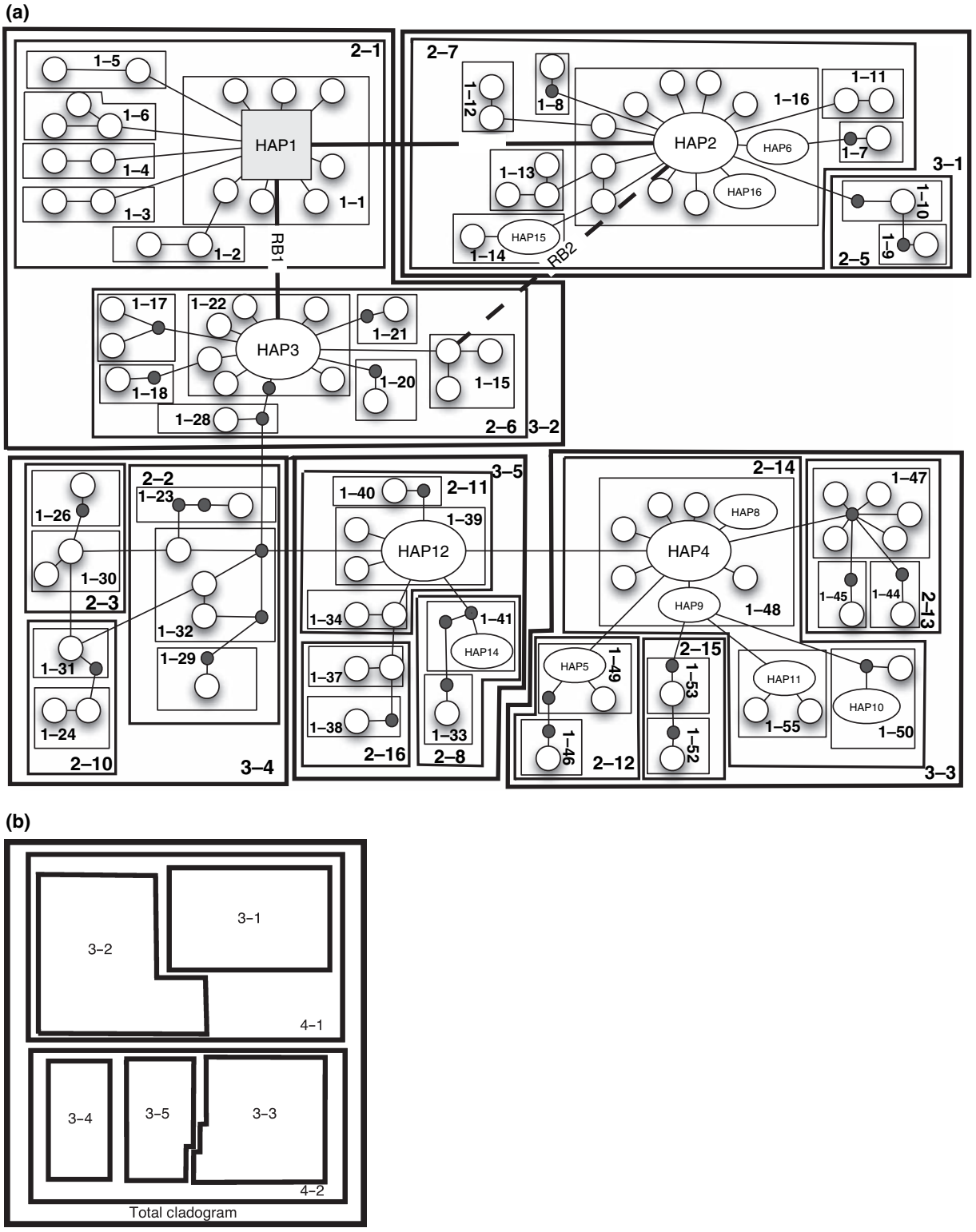

Fig. 3 Nested cladogram. (a) Nested levels 0–3. Haplotype codes are as in Table 1. Ovals designate haplotypes with a frequency > 1 and are roughly proportional to frequency. Solid circles represent inferred intermediate haplotypes. Alpha-numeric designations refer to individual sea lions possessing unique haplotypes. Each line indicates one mutational step. Reticulations are indicated with dashed or heavy solid lines. RB = Reticulation Break. (b) Nested levels 3 and 4.

Table 1 Summary of inferences regarding demographic events deduced from clades with significant nested clade values.

Clade	χ^2	Nested clades	D_c*	D_n*	Chain of inference	Demographic event
1-16	$P = 0.06$	Hap2 (INT)	n.s.	349.3, >, $P = 0.07$	1 yes, 2 no, 11 no, 17 no	Inconclusive
		Hap6 (TIP)	n.s.	n.s.		
		Club8 (TIP)	n.s.	n.s.		
		Lov13 (INT)	n.s.	7762.4, >, $P = 0.019$		
		Hap16 (TIP)	n.s.	n.s.		
		Chis968 (TIP)	n.s.	4471.4, <, $P = 0.10$		
		Club7 (TIP)	n.s.	n.s.		
		N(KP)7 (TIP)	n.s.	7115.7, >, $P = 0.07$		
		Ug469 (TIP)	n.s.	n.s.		
		CM1280 (TIP)	n.s.	n.s.		
		A11 (TIP)	n.s.	7562.7, >, $P = 0.05$		
		Ug486 (TIP)	n.s.	n.s.		
		Chow5 (TIP)	n.s.	n.s.		
		I-T	n.s.	n.s.		
1-48	$P = 0.007$	Hap4 (INT)	649.2, <, $P = 0.002$	n.s	1 yes, 2 yes, 3 yes, 5 no, 6 too few clades for concordance, 7 yes	Restricted gene flow/dispersal or range expansion/colonization, with some long distance dispersal
		CM1256 (TIP)	n.s.	n.s.		
		B453 (TIP)	n.s.	n.s.		
		Og2 (TIP)	n.s.	n.s.		
		Y15 (TIP)	n.s.	4568.4, >, $P = 0.02$		
		Hap8 (TIP)	0.0001, >, $P = 0.08$	n.s.		
		Hap9 (INT)	7255.7, >, $P = 0.03$	n.s.		
1-49	$P = 0.04$	Hap5 (INT)	n.s.	n.s.		No inference possible†
		Lov20 (TIP)	n.s.	n.s.		
		I-T	n.s.	n.s.		
2-1	n.s	1-1 (INT)	n.s.	n.s.	1 yes, 2 yes, 3 yes, 5 no, 6 too few clades, 7 yes	Restricted gene flow/dispersal or range expansion/colonization, with some long distance dispersal
		1-2 (TIP)	28.2, <, $P = 0.07$	8132.1, >, $P = 0.007$		
		1-3 (TIP)	331.6, <, $P = 0.06$	7249.8, <, $P = 0.01$		
		1-4 (TIP)	0.000, <, $P = 0.05$	6315.9. <, $P = 0.01$		
		1-5 (TIP)	n.s	n.s		
		1-6 (TIP)	n.s	n.s		
		I-T	n.s	426.0, >, $P = 0.02$		
2-6	n.s.	1-22 (INT)	63004.9, >, $P = 0.06$	5504.7, >, $P = 0.0084$	1 yes, 2 yes, 3 no, 4 yes, 9 no	Past fragmentation
		1-18 (TIP)	n.s.	n.s.		
		1-28 (TIP)	n.s.	3454.8, <, $P = 0.02$		
		1-17 (TIP)	n.s.	n.s.		
		1-21 (TIP)	n.s.	n.s.		
		1-20 (TIP)	n.s.	n.s.		
		I-T	5982.5, >, $P = 0.09$	383.4, >, $P = 0.07$		
2-13	n.s.	1-47 (INT)	n.s.	6567.7, >, $P = 0.04$	1 yes, 2 no, 11 no, 17 yes, 4 yes, 9 no	Past fragmentation
		1-44 (TIP)	n.s.	n.s.		
		1-45 (TIP)	n.s	n.s		
		I-T	n.s.	1155.6, >, $P = 0.04$		
2-14 (1-48) (1-49)	n.s.	1-48 (INT)	n.s	1916.3, >, $P = 0.001$	1 yes, 2 no, 11 no, 17 yes, 4 no	Restricted gene flow with isolation by distance
		1-50 (TIP)	n.s.	n.s.		
		1-55 (TIP)	n.s.	934.6, <, $P = 0.06$		
		I-T	n.s.	878.0, >, $P = 0.01$		
3-2 (2-6)	$P < 0.0001$	2-1 (INT)	7700.5, <, $P = 0.002$	8205.9, >, $P = 0.0002$	1 yes, 2 no I/T	No inference possible†
		2-6 (INT)	5336.1, <, $P = 0.003$	7953.9, <, $P = 0.001$		
3-3 (2-13) (2-14(1-48)) (1-49)	$P = 0.005$	2-14 (INT)	1673.3, <, $P < 0.001$	3678.4, <, $P = 0.006$	1 yes, 2 no, 11 yes, 12 yes, 13 yes	Range expansion with long distance colonization
		2-15 (TIP)	n.s	2455.5, <, $P = 0.02$		
		2-12 (TIP)	671.4, <, $P < 0.001$	6683.8, >, $P < 0.001$		
		2-13 (TIP)	n.s.	n.s.		
		I-T	n.s.	−2315.4, <, $P < 0.001$		
3-5	n.s.	2-11 (INT)	n.s.	7056.8, >, $P = 0.04$	1 yes, 2 yes, 3 no, 4 yes, 9 no	Past fragmentation
		2-8 (TIP)	n.s.	n.s.		
		2-16 (TIP)	n.s.	n.s.		
		I-T	7196.1, >, $P = 0.10$	966.4, >, $P = 0.07$		
4-1	$P < 0.001$	3-1 (TIP)	5466.1, <, $P = 0.0007$	7366.9, <, $P = 0.0001$	1 yes, 2 yes, 3 no, 4 no	Restricted gene flow with isolation by distance

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Table 1 Continued.

Clade	χ^2	Nested clades	D_c*	D_n*	Chain of inference	Demographic event
(1-16)		3-2 (INT)	8132.9, >, $P < 0.0001$	7817.2, >, $P < 0.0001$		
[3-2(2-6)]		I-T	2666.8, >, $P = 0.0004$	450.3, >, $P < 0.0001$		
4-2	n.s.	3-3 (TIP)	n.s.	n.s.	1 yes, 2 yes,	Restricted gene flow with
[3-3(2-14		3-4 (INT)	235.7, <, $P < 0.0001$	2888.9, <, $P < 0.0001$	3 no, 4 no	isolation by distance
(1-48)]						
[2-12(1-49))		3-5 (INT)	n.s.	6040.6, >, $P = 0.0005$		
(2-13)]						
		I-T	n.s	n.s		
Total	$P < 0.0001$	4-1 (TIP)	7645.5, >, $P = 0.0002$	7015.5, >, $P < 0.00001$	No INT clades	No inference possible†
		4-2 (TIP)	4311.1, <, $P = 0.0004$	6153.8, <, $P < 0.00001$		

TIP, tip clade, INT, interior clade.

Clade numbers within parentheses represent those lower-level clades within the nested series with significant evidence for demographic events. A greater-than or less-than symbol indicates a D_c or D_n value that is significantly larger or smaller than expected if haplotypes were distributed randomly. *P*-values indicate probability that the D_c or D_n estimated from the data were observed by chance. Inferences were drawn from the nested clade analysis key of Templeton (1998). The steps in the chain of inference can be examined by comparison to this key.

*Results are not significant at $P < 0.10$.

†Results of chi-square were significant ($P < 0.05$), but lack of tip clades prevents nested clade inference.

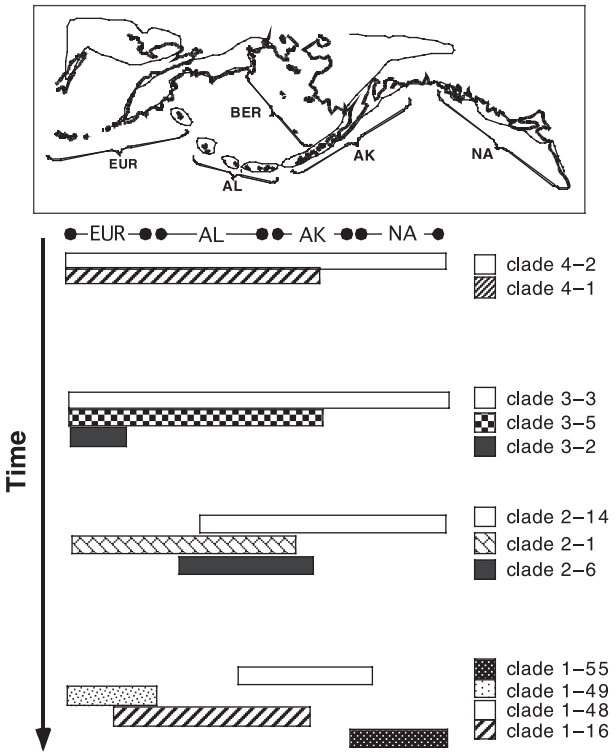

Fig. 4 A summary of *Eumetopias jubatus* phylogeographic history. Shifts in the geographic distribution of lineages over time are synthesized to present a relative chronology of *E. jubatus* phylogeographic history. The horizontal bars represent the geographic distribution of individual clades within the nested series, and therefore roughly correspond to coalescent events. Clades at the 1-step nested level represent the most recent demographic events, and roughly correspond to four glacial isolates.

Table 2 Results of analysis of molecular variance among five Steller's sea lion populations derived from the nested clade procedure.

Variation source	d.f.	SS	Components		Variation (%)	
Among groups	4	70.8	0.28	Va	17.39	Φ ct = 0.17*
Within groups	37	61.5	0.05	Vb	3.24	Φ sc = 0.04*
Within rookeries	287	366.2	1.28	Vc	79.37	Φ st = 0.21*
Total	328	498.5	1.6			

*$P \leq 0.001$.

Because the maximum likelihood divergence estimates had consistently narrower confidence intervals (Table 3), they were used to create a chronology of the history of Steller's sea lion lineages (Fig. 5). In general, the pattern of geographic distribution of maternal lineages suggested that three regional groups formed early in the history of the sea lion (Fig. 4), and that the formation of these groups was loosely associated temporally with glacial cycles (Fig. 5). The broad-scale geographic partitioning of lineages (i.e. 3- and 4-step clades) were coincident with two major ice ages, earlier than the LGM, where sea levels were as much as 140 m below current levels (Fig. 5).

Nested clade inference suggested multiple demographic events in the phylogeographic history of *E. jubatus* (Table 1, Fig. 4). In particular, these results indicated that the rookeries in EUR and NA, at the ends of the species' distribution, experienced multiple periods of geographic isolation and expansion. Nested clade (D_n) and clade (D_c) distances revealed at least three different periods of restricted gene flow between the EUR

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Table 3 Comparison of TMRCA estimates derived with different methods.

A					B	
Clade 4-1	TMRCA (10^6)	Lower	Upper	ESS	Clade 4-1 Rate (sub/site/my)	TMRCA (10^6)
Combined	0.316	0.157	0.51	256.617	0.015	0.23
G4 Run 1	0.298	0.157	0.475	142.035	0.019	0.182
G4 Run 2	0.334	0.181	0.548	114.582	0.028	0.123
Clade 4-2					Clade 4-2	
Combined	0.418	0.231	0.622	480.15	0.015	0.195
G4 Run 1	0.41	0.228	0.606	264.079	0.019	0.154
G4 Run 2	0.426	0.231	0.628	216.071	0.028	0.105
Clade 3-1					Clade 3-1	
Combined	0.302	0.156	0.507	275.547	0.015	0.15
G4 Run 1	0.285	0.139	0.456	168.039	0.019	0.118
G4 Run 2	0.319	0.161	0.53	107.508	0.028	0.08
Clade 3-2					Clade 3-2	
Combined	0.304	0.16	0.488	276.637	0.015	0.154
G4 Run 1	0.287	0.153	0.439	139.704	0.019	0.121
G4 Run 2	0.32	0.18	0.531	136.933	0.028	0.082
Clade 3-3					Clade 3-3	
Combined	0.388	0.199	0.599	383.302	0.015	0.192
G4 Run 1	0.385	0.205	0.578	215.236	0.019	0.151
G4 Run 2	0.39	0.194	0.611	168.066	0.028	0.103
Clade 3-4					Clade 3-4	
Combined	0.228	0.091	0.435	208.879	0.015	0.159
G4 Run 1	0.217	0.085	0.397	100.717	0.019	0.125
G4 Run 2	0.239	0.098	0.455	108.162	0.028	0.085
Clade 2-14					Clade 2-14	
Combined	0.37	0.165	0.572	440.285	0.015	0.133
G4 Run 1	0.367	0.165	0.547	238.398	0.019	0.105
G4 Run 2	0.373	0.166	0.592	201.886	0.028	0.071
Clade 2-13					Clade 2-13	
Combined	0.294	0.101	0.504	429.231	0.015	N/A
G4 Run 1	0.29	0.107	0.502	230.278	0.019	N/A
G4 Run 2	0.297	0.097	0.508	198.953	0.028	N/A
Clade 2-1					Clade 2-1	
Combined	0.274	0.114	0.439	305.444	0.015	0.123
G4 Run 1	0.264	0.123	0.425	164.192	0.019	0.097
G4 Run 2	0.283	0.121	0.469	141.253	0.028	0.066
Clade 2-6					Clade 2-6	
Combined	0.229	0.075	0.424	214.357	0.015	0.141
G4 Run 1	0.219	0.073	0.398	94.71	0.019	0.112
G4 Run 2	0.239	0.082	0.443	119.646	0.028	0.076
Clade 1-48					Clade 1-48	
Combined	0.337	0.115	0.566	332.311	0.015	0.081
G4 Run 1	0.333	0.106	0.547	149.513	0.019	0.064
G4 Run 2	0.341	0.116	0.568	182.798	0.028	0.043

(A) BEAST estimates of time to the most recent common ancestor (TMRCA) for clades identified by nested clade analysis as having experienced a significant demographic event (Fig. 4, Table 1). Results are from independent MCMC chains (G4 Runs 1, 2) and the average over runs (combined) plus 95% confidence intervals derived from the Bayesian probability distributions (BPD). ESS = Effective Sample Size. (B) TMRCA estimated with the method of Li and Graur (1991) based on the average number of pairwise differences among haplotypes. Dates of divergence were calculated for the 95% CI limits of the estimated rate of substitution of the mitochondrial DNA locus.

and other rookeries (Table 1). In other cases, rookeries in CA were isolated from rookeries from AK east to EUR (Fig. 4, Table 1). Therefore, the nested clade inference key supported the interpretation derived independently from observed patterns of lineage distribution, namely that three groups-Eurasian (EUR), NA and a central Alaskan/Aleutian (AK + AL) appeared multiple times during the history of the species (4-, 3- and 2-step clades, Fig. 4), with a recent addition of a fourth group that formed from the division of the central group into AK and AL populations (1-step clades, Fig. 4).

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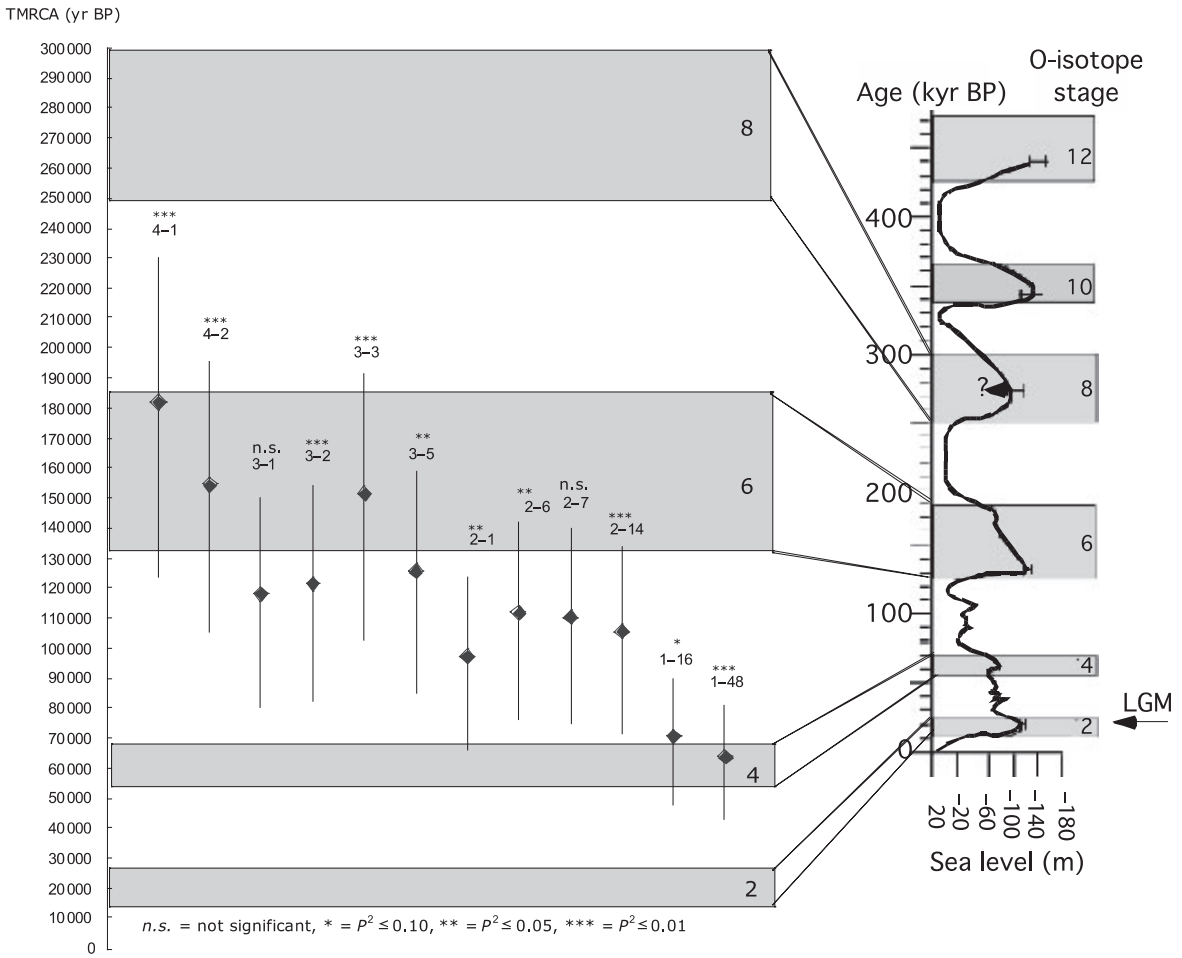

Fig. 5 The chronology of coalescent events derived from the average pair-wise divergence among haplotypes in lineages and the 95% confidence interval of the maximum likelihood estimated rate of substitution. Fluctuations in sea level were derived from Rohling *et al.* (1998) and are presented relative to current sea levels in meters (m). Grey shaded regions represent major periods of glaciation, and lines above and below peaks demarcate the confidence intervals of sea level heights at periods of glacial maxima. LGM is last glacial maximum. TMRCA is time to most recent common ancestor.

Discussion

Predictions 1 and 2: Genetic structure of female lineages and glacial refugia

One attribute of the nested clade approach is its ability to infer historical processes from the phylogenetic association of lineages that otherwise do not display a definitive geographic pattern (Templeton, 1998,2004). In the case of Steller's sea lion, inferences derived from the nested pattern of haplotypes revealed multiple vicariant events, corresponding to either the formation or degeneration of populations associated with glacial refugia (Table 1, Fig. 4). In particular, our results support the association of breaks in the distribution of genetic variation along the coast of NA, including the Gulf of AK and British Columbia, that are congruent with ice-free islands during the LGM, notably Kodiak Island, the Alexander Archipelago and the Queen Charlotte Islands (Fig. 4). In addition, breaks in the distribution of genetic variation suggest that EUR and AL Island rookeries represent remnants of two independent glacial refugia. The exact locations of these refugia are unknown, but they were likely small, ice-free areas in these regions, similar to those off the coast of British Columbia and the Gulf of AK. There are several other lines of evidence supporting an effect of glacial refugia on the structuring of female lineages of Steller's sea lion. First, the derivation of population boundaries was performed with simultaneous incorporation of haplotype frequency and evolutionary history in the nesting procedure. We argue that this is a powerful, objective approach to defining populations without the need for *a priori* assumptions of either the number or geographic boundaries of populations. Furthermore, basic predictions of coalescence theory lead to similar conclusions regarding the genetic

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structure of maternal lineages among geographic localities, i.e. the change in distribution of lineages over time can be interpreted without reference to the nested clade inference key as evidence for the formation of populations at different geographic scales throughout the history of the species (Fig. 4). Yet the most compelling evidence is found in the similar patterns of population structure of Steller's sea lion and other taxa (Fig. 1), including harbour seals and sea otters, that provide additional support for the presence of refugia somewhere within these two regions (Cronin *et al.*, 1993; Bickham *et al.*, 1996; Westlake & O'Corry-Crowe, 2002). In total, we suggest that the geographically extensive sampling of Steller's sea lion rookeries and the congruent patterns of population structure derived from studies of multiple taxa independently validate the presence of multiple insular refugia and their importance in shaping the phylogeographic history of taxa in the North Pacific and Bering Sea.

The divergence between Steller's sea lion populations generally followed a pattern of IBD, with the greatest amount of divergence between rookeries in EUR and NA. This is not unexpected given the relatively early separation of these clades at the 4-step nested level (Fig. 4). However, it is possible that patterns of IBD arise in response to limited dispersal between regions that resulted in the accumulation of genetic divergence over time, and it is not necessary to invoke glacial vicariance as the explanation for patterns of population structure. Nevertheless, the pattern of temporal progresson from 4-step to 1-step clades (Fig. 4) suggests that the boundaries of EUR and NA isolates were somewhat ephemeral, and that AL and AK populations formed and persisted following the expansion and divergence of EUR and NA isolates. The pattern of IBD seems more consistent with a scenario of re-colonization of AL and AK regions from EUR and NA refugia following glacier recession, which is consistent with the presence of multiple insular refugia.

Prediction 3: dates of population divergence and glacier chronology

Estimates of coalescence times suggest a demographic history of *E. jubatus* that predates the Wisconsin glaciation (Fig. 4, Table 3). These results are consistent with several previous studies that attributed population structuring of Arctic species to demographic events older than the LGM. For example, patterns of genetic subdivision of the rock ptarmigan are presumably the result of events occurring prior to the LGM (Holder *et al.*, 2000; Brunhoff *et al.*, 2003). Klicka & Zink (1998) examined the evolution of NA songbirds and proposed that the 35 species of birds in their study underwent speciation prior to the late Pleistocene. Given that *E. jubatus* split from *Z. californianus* approximately 2 000 000 years ago, it is not unreasonable to expect *E. jubatus* populations to currently bear a signature of the effects of glacial cycles that are much older than the Wisconsin glaciation.

The distribution of ice sheets and the duration of the glacial cycles occurring earlier in the Pleistocene are not as well understood as the Winsconsin glaciation. There is strong evidence, however, for changes in sea level associated with glacial cycles dating back to the early Pleistocene (Rohling *et al.*, 1998). Over the last 450 000 years, the sea levels have been as much as 150 m below current levels (Rohling *et al.*, 1998). Many areas of the coastline that are now submerged by seawater were exposed during glacial periods, and served either as corridors for the dispersal of plants and animals (e.g. BER) or as isolated refugia. The fragmentation and expansion of *E. jubatus* coincides with periods of ice sheet advance and retreat, namely the long glacial cycles between 150 000 and 300 000 years ago (Fig. 5, Table 2). This chronology of events is consistent with a scenario of multiple, independent fragmentations by advancing glaciers during interglacial stades, followed by isolation and divergence in several refugia until the ice receded. If it is assumed that contemporary patterns of genetic variation bear the signature of both historic and current processes, one could infer that the effects of insular refugia on population structure represent more recent, fine-scale events in the history of *E. jubatus*, compared to the formation of older and larger glacial refugia associated with the NA mainland. Concordance between the distributions of insular refugia proposed in this study and similar studies of other biota provide additional evidence for the existence of these smaller refugia, despite the inability of phylogenetic methods to detect their formation.

However, it is important to note that confidence intervals associated with estimates of intraspecific divergence times are large, and that there is lack of concordance among estimates derived from different methods. This is not unexpected given the intraspecific lineage sorting process that can be complicated by demographic factors such as population growth, expansion and substructure within regions due to reproductive and dispersal behaviours (Ball *et al.*, 1998; Hoelzer *et al.*, 1998). Nevertheless, results of this study are compelling given the degree of congruence among the structuring of multiple taxa with overlapping distributions, similar dispersal capabilities and ties to terrestrial breeding localities. Even if the dates of divergence of Steller's sea lion are loosely associated with glacier advance, the pattern of population structure supports a region-wide series of phenomena that have shaped the history of multiple taxa before the LGM.

In summary, the pattern of diversification of female lineages of Steller's sea lions appears to correlate with the glacial advances and retreats during the Pleistocene, from approximately 60 000 to 180 000 years BP (Fig. 5). Four populations, ostensibly derived from distinct glacial refugia, are recognized including NA, AK, AL and EUR.

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In a previous study of the population genetics of this species, Baker *et al.* (2005) examined control region sequences from 1568 pups taken from 50 rookeries from throughout the range of the species. That study, which focused primarily on population genetic analyses using haplotype frequencies, resolved three genetically distinct stocks. An eastern stock ranges from northern California to southeastern AK and equates to NA in this study. An Asian stock includes rookeries in the Sea of Okhotsk, Kuril Islands and Kamchatka Peninsula and equates to EUR in this study. And, a western stock ranges from Prince William Sound to the Commander Islands and equates to AK and AL in this study. The addition of the cytochrome *b* dataset and the nested clade analysis performed in this study provide an evolutionary framework that increases our understanding of the dynamic nature of population structure of this endangered species.

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The Gray Whale
Eschrichtius robustus

Edited by

Mary Lou Jones

Steven L. Swartz

Cetacean Research Associates
San Diego, California

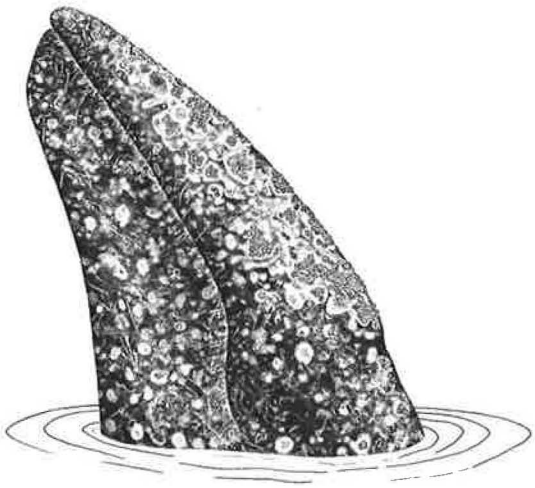
Stephen Leatherwood

Hubbs–Sea World Research Institute
San Diego, California

with illustrations by

Pieter Arend Folkens

Oceanic Society
San Francisco, California



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Nineteenth Century Gray Whaling: Grounds, Catches and Kills, Practices and Depletion of the Whale Population

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Introduction

Catching gray whales was not easy, but because it could be profitable catches in the nineteenth century greatly depleted the number of gray whales. Yankee whalers who dared the dangerous coastal and lagoon waters of Baja California in winter and the treacherous ice-filled seas of the North Pacific and Pacific Arctic in summer to chase the

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wily and destructive devil fish, or gray whale, have much to tell us about their prey. Experiences of the chase, catch reports, and observations that would increase catches reveal much about the populations, behavior, migrations and their timing, the ranges and thus whaling grounds, food, predators, whale size, and other data related to the gray

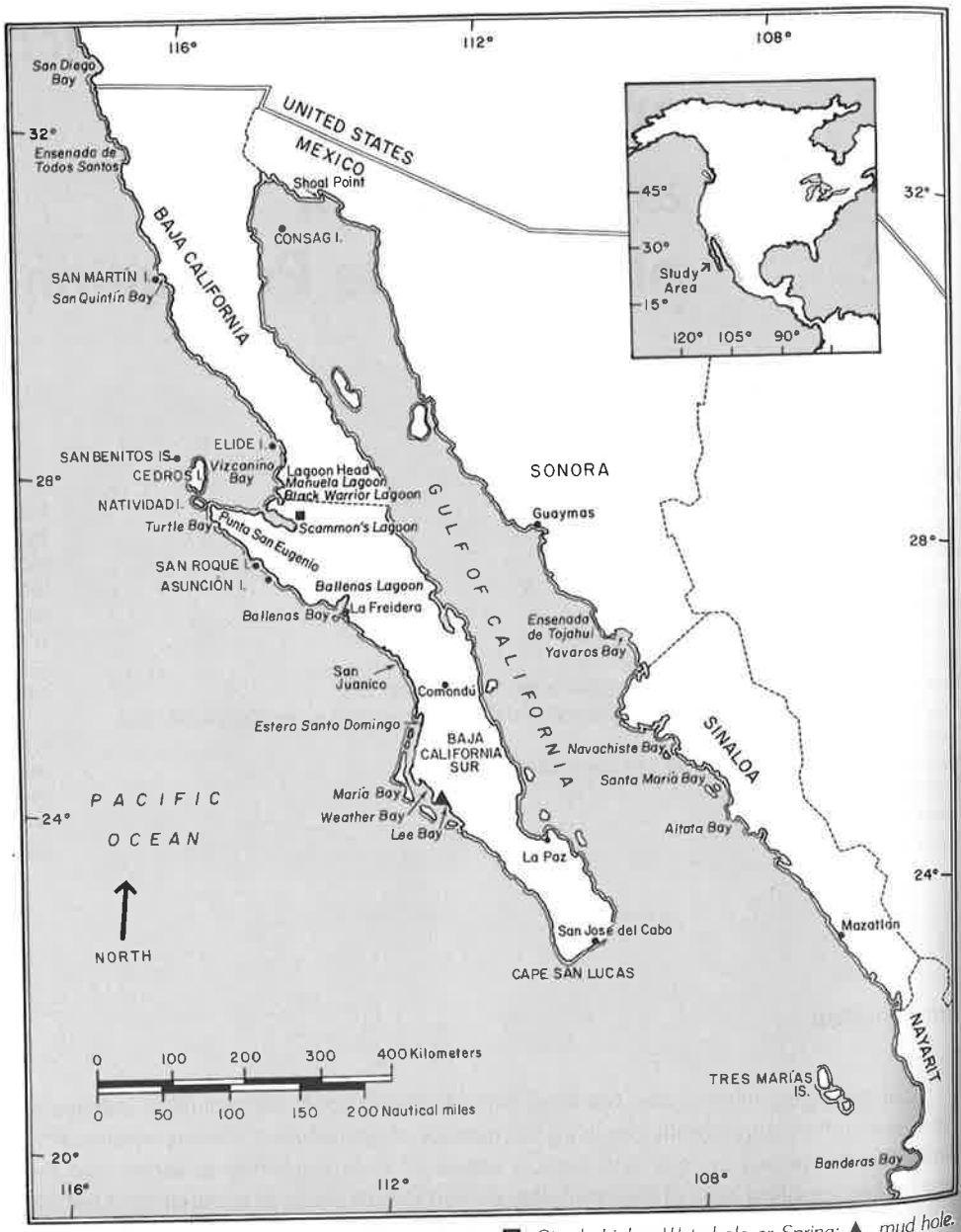

Fig. 1. *Gray whaling grounds of Northwest Mexico.* ■, *Ojo de Liebre Waterhole or Spring:* ▲, *mud hole.*

whales. The history and geography of nineteenth century gray whaling, which shed light on the preceding subjects, are important concerns of this chapter. First, however, we should follow whalemen through history to the gray whaling waters which were confined to the North Pacific.

It was a long sail, historically, from the Atlantic shores from which high-seas whalers had set forth in their vessels since the thirteenth century (Sanderson, 1956, p. 136), to distant Pacific coasts along which Yankee and European whalers of the nineteenth century found an unfamiliar prey awaiting their harpoons and lances, the gray whale. These whalemen found and pursued gray whales in coastal waters of Alta (Upper) California, Baja (Lower) California, Northwest Mexico, and in the Bering, Okhotsk, and Pacific Arctic seas. Once in the Pacific Ocean, whalers searched out that ocean's whaling grounds rapidly.

The first whaler to enter the Pacific was the ship *Amelia* (*Emelia*) of London which rounded Cape Horn in 1789 (Henderson, 1972, p. 16). Whalers then pushed their ships up the west coast of South America, and by 1793 the Englishman Colnett had conducted a survey for whales on the ship *Rattler* as far north as Cape San Lucas (Fig. 1), (Henderson, 1972, p. 15). By 1795, Captain John Locke on the English ship *Resolution* had carried out the first genuine whaling venture in the eastern North Pacific Ocean, during which he reached Baja California. Locke sailed around the Cape of Good Hope with supplies for Australia; he probably sailed next to India and/or China, and thence across the broad North Pacific without a landing until he reached Baja California in October–November 1795 (Cumpston, 1964, p. 29; Henderson, 1972, pp. 17–21). His landfall was near the mouth of the Guadalupe River, and he put ashore just south of there for badly needed "recruits" (supplies) at Ensenada de Todos Santos and later at the end of the peninsula at San José del Cabo. At these places, the Spaniards on the weak mission frontier met his needs and learned that he had 500 barrels of whale oil on board, undoubtedly the sperm whale oil which whalers of those years most desired.

Following Locke's visit, armed English whaleships came to Baja California and Alta California waters, at the end of the eighteenth century and in the early years of the nineteenth century, to prey on sperm whales and the small and isolated Spanish-governed communities alike (Henderson, 1972, p. 21). These whalers followed closely in the wake of English and Yankee vessels that had been guided to the sea otter and fur trade of the Northwest Coast of America by the discoveries of Captain James Cook in 1778 (Henderson, 1972, p. 16). Yankee whalers soon followed the English, and after 1815 American whaleships in the Pacific Ocean outnumbered those of other nations. It was from the coast of Baja California that the first two whaleships arrived in the Hawaiian Islands in 1819—the American ships *Balaena* (New Bedford, Captain Gardner) and *Equator* (Nantucket, Captain Folger) (Stackpole, 1964, pp. 267–268). From that island mecca of Pacific whalers, ships subsequently cruised northward in summer to Japanese seas, the northwest coast of America, and the northeast coast of Asia (both known as the Northwest Coast to whalers), to the Bering and Okhotsk seas, and finally in 1848 to the Pacific Arctic Ocean. The coasts of the Californias became important sperm whale grounds where American, English, and European whalers made abundant catches (Henderson, 1972, pp. 21–22).

North Pacific Whaling

When whalemen began to depart the Hawaiian or Sandwich Islands in spring to cruise for sperm, right, and bowhead whales, they also left ice and cold at summer's end to return to the Hawaiian Islands in autumn. Thence in winter the whalemen could steer for a variety of warmer grounds: New Zealand or even Chilean waters, the line or equator, and the Marianas; most important for this history was the Coast of California ground which to the whalers meant the ground on the west coast of Baja California. Among the various winter cruises, the sail to California was considered a short and easy one during which southern westerlies blew ships to the coast and trade winds carried them back to the Islands. The crossing in each direction took only about 3 weeks.[1] Another recommendation for the cruise to California was that ships could lie at anchor all season in a bay or lagoon or make short runs up and down the coast instead of ranging where wind and wave could be damaging and costly.

A whaling pattern evolved in the North Pacific which involved visits to the Hawaiian Islands in spring and autumn and whaling in northern parts of the Pacific in summer and in warmer parts of that ocean in winter.[2–4] Hundreds of vessels called each spring and fall at the Hawaiian Islands for recruits and to get rid of some whaling hands and sign on others, many of whom were Kanakas. To the Yankee, a Kanaka was any Pacific islander, but most were from Polynesian islands and of those most were from the Hawaiian Islands.[1] Because the northern season when right and bowhead whales were captured was the most productive season for most whalers, the number of "seasons out" from home meant the number of summer seasons spent in the Pacific. Winter whaling on the coast of California or elsewhere was known as "between the seasons" whaling (Henderson, 1972, pp. 85–86). In addition to the cruise patterns which sent most gray whalers from the Hawaiian Islands to Baja California and back to the Islands in the spring, some whalers from New England or San Francisco sailed out of that port directly down the coast to the gray whaling grounds. Some left San Francisco in the spring and summer in search of sperm whales or elephant seals before going after the grays. Other whalers out of New England ports and San Francisco remained in peninsular waters or went south from there to search for sperm whales after the winter gray whaling season had ended (Henderson, 1972, pp. 85, 91–94, 188, 268–270).[1]

Gray Whaling Beginnings

During the several decades preceding gray whaling when whalers worked the sperm whale fishery of Baja California, they recognized gray whales as "scrag" whales

[1]See also logbooks in Whaling Archives (see Appendix).
[2]See also reports in *Seaman's Friend and Temperance Advocate*, Honolulu.
[3]See also reports in *Pacific Commercial Advertiser*, Honolulu.
[4]See also reports in *Whalemen's Shipping List and Merchant's Transcript*, New Bedford, Massachusetts.

and even chased them, but so far as the record shows they never caught any. Of course, native peoples of Baja California and the shores of the northern Pacific Ocean, Okhotsk Sea, and Arctic Ocean, as well as Spaniards, Mexicans, and Siberian Russians, also knew and recognized this whale (Henderson, 1972, pp. 35, 59, 71, 73; Mitchell, 1979, pp. 309–311).[5] Eventually two Connecticut captains who came to the Coast of California decided to go after the grays. Magdalena Bay, known to the whalers as Marguerita Bay, an immense complex of bays and lagoons on the southwest coast of Baja California, was a well-known "between the season" protected haven which sperm whalers from the coast knew well, and it was also a calving and mating ground to which gray whales migrated each winter (Fig. 1).

Thus, whalers had long known that gray whales frequented the bay when Captain James Smith of the New London ship *Hibernia* and Captain Josiah Stevens of the Stonington bark *United States* decided to chance pursuit of grays there in the winter of 1845–1846. That winter in Magdalena Bay, in the first gray whaling by western man on record, the whalers of *Hibernia* captured 22 grays and those of *United States* took 10 (Henderson, 1972, p. 82). They found that the gray whales had no bone worth saving. More importantly, they learned, as did all whalers who chased grays, that they were in a dangerous business. The grays killed the second mate and badly injured the first mate of *United States*. Thus was initiated the nineteenth century gray whaling which would eventually disastrously deplete the population of gray whales in the eastern Pacific California herd and make a significant reduction in the Okhotsk Sea or Korean herd of the western Pacific.

Whalers' Names for Grays

Some of the characteristics of the gray whale are revealed by the various names that the nineteenth century gray whalers applied to this whale which was new to the chase. Even before gray whaling began on the Coast of California, whalemen there hunted sperm whales and also recognized this different whale, which they called a scrag whale because they identified it with a whale of that name reportedly taken off New England coasts in the seventeenth and eighteenth centuries (Dudley, 1725, p. 258). However, early in the history of the fishery of this whale the whalers began to call it California gray, gray whale, gray back, and California whale. Devil fish and hard head were names plainly derived from the reaction of the whales to their hunters, who recognized the gray as a dangerous prey knowing that in the lagoons of Baja California the whales commonly crashed into and stove boats with their heads. The names mussel digger, mud digger, or digger referred to the whales' habit of bottom dredging, which had been observed by the whalers especially in the lagoons. Whalers used two names more on the northern summer grounds than on the Coast of California; one was ripsack, which apparently referred to the manner in which blubber came off the whale in cutting-

[5]See also logbooks in Whaling Archives recording cruises to the Okhotsk Sea (see Appendix).

in (flensing), and scamper down, also the name of another whale but unmistakably used to refer to grays, was the other. Curiously, some whalers referred to the whales by one name on the summer grounds and another on the winter grounds—for instance, ripsack in the Arctic or Okhotsk seas and devil fish or gray on the Coast of California (Henderson, 1972, pp. 26–27, 35).[1]

Initial Period of Gray Whaling

The first years of gray whaling, including the winters of 1845–1846 through 1853–1854, have characteristics that distinguish them from later years. At that time, Magdalena Bay was the only significant gray whaling ground being visited and thus supplied nearly the entire catch (Table I). A few vessels did whale along shore on the coast in addition to entering the bay; the first was the ship *Dromo* of New London in 1851–1852.[6a] Moreover, the captains of some vessels which whaled in the Bering Sea and Arctic Ocean made small incidental gray whale catches when their main quarries, bowhead and right whales, were not available to be chased. Thus, the catch per vessel was small as was the total catch in northern waters.[1,2,4,6]

Connecticut vessels, perhaps from venturesomeness born of competition with the New Bedford and other southern Massachusetts ports, sought out the new fishery and dominated it. Perhaps commercial connections and information drew Connecticut ships together in winter at Magdalena Bay. At any rate, in the second winter of whaling at Magdalena Bay, 1846–1847, three New London, two Stonington, and two Mystic whalers met with one New Bedford ship on that ground.[1,2,4] In the early period, half of the perhaps 50–60 cruises to Magdalena Bay were made by vessels from Connecticut ports. Southern Massachusetts ports, including New Bedford, sent their ships to the new ground only 10 or 11 times. Two vessels each came from Sag Harbor, Long Island, and Warren, Rhode Island, and one from Cold Spring Harbor, Long Island. In 1852–1853, one of the first whalers out of San Francisco, the ship *Aquetnet* (Captain Curry) fished at Magdalena Bay. Foreigners also were willing to try their luck in the new fishery, and from Le Havre came five French vessels and from Bremen and Amsterdam one each.[1,2,4,6] Thus, the representation of hailing ports by vessels at the new ground was distinctive; it was not dominated by ships from southern Massachusetts ports, most of the captains and owners of which probably had not yet the need or desire to chance the pursuit of gray whales.

In this earliest period many of the vessels on the coast or that entered Magdalena Bay to escape weather or cooper oil were sperm whalers, while some captains pursued humpback whales in and outside the bay; however, on at least 50–60 cruises, the whalers concentrated on taking gray whales. The daring and crafty crews of a few vessels captured many; for example, the men of the New London ship *Brooklyn* (Captain Jeffrey) took 29

[6]See also "Dennis Wood Abstracts," manuscript records of whaling voyages 1831–1873. New Bedford Free Public Library, New Bedford, Massachusetts.

[6a]Whalemen's Shipping List and Merchant's Transcript; March 30, 1852, p. 18.

whales in 1846–1847.[1,2,4,6] Most, however, took far fewer. Captain Curry of the *Aquetnet* of San Francisco got only four grays in 1852–1853, although he was at Magdalena Bay from late December to mid-February.[1,2,4,6,7] Some crews were "skunked," that is, they left the bay without taking any oil and were undoubtedly glad to quit such a dangerous business. During the earliest gray whaling period, few captains brought their ships and men back for a second season of the new and hazardous whaling. One who did was Captain James Smith of the New London ship *Hibernia* who had originated gray whaling in 1845–1846 with an excellent catch of 22 whales; he returned the following winter to make another catch at least equal to his first.

A Mexican government report from the mid-nineteenth century archives at La Paz tells us that during the first 3 years of gray whaling at Magdalena Bay, 1845–1846 through 1847–1848, 38 whaleships captured 338 whales in Magdalena Bay (Espinosa, 1854, p. 125). If this report is added to other reports of whalers at the bay later, then the total number of cruises to Magdalena Bay in the early period may have been nearly 70, and the total capture may have been nearly 500 whales. However, if estimates are based on whalemen's records in logbooks and newspapers, the estimate for the early period is closer to 50–60 cruises and 400–450 captures. The capture discrepancy could then amount to as many as 100 whales. This is probably explained by the Mexican report having included some vessels whose crews were not gray whaling, and thus vessel and catch totals were increased by including sperm and humpback whalers. If there were 50–60 cruises for grays and 400–450 captures, then the average catch per vessel was 7–9 whales, figures that seem reasonable in a new fishery in which the men of some vessels caught many whales and those of others caught few or none.

Scammon's statement that in the winter of 1848 (1847–1848) 50 whaleships went to Magdalena Bay is an obvious exaggeration (Scammon, 1874, p. 268). Scammon did not arrive in California until 1850 and he did not whale at Magdalena Bay until the winter of 1855–1856, when he began his gray whaling career at the bay on the San Francisco ship *Leonore;* this was 2 years before he first whaled in Scammon's Lagoon on the brig *Boston* (Henderson, 1972, pp. 82, 267–271). In the winter of 1847–1848, records show that only 20 gray whaling vessels were at Magdalena Bay and that their crews captured at most some 140 gray whales, or an average of 7 each.[1,2,4,6]

A pattern that would persist throughout the history of the fishery had been established; some crews, experts at gray whaling, made exceptional catches, many took few whales, and some who had no knowledge of or taste for chasing the tough grays came away from the Coast of California without a drop of oil.

Right in the middle of the earliest gray whaling period there were three seasons, 1848–1849, 1849–1850, and 1850–1851, during which pursuit of the gray backs stopped. Scammon attributed the abandonment of gray whaling to the disasterous destruction of boats, loss of life, and frequent injuries sustained by those who pursued the grays or devil fish and to the concentrated whaling and associated noise and try-pot fires, which drove the whales outside Magdalena Bay (Scammon, 1874, pp. 268–269). Moreover, the low price of the dark-colored gray whale oil and the fact that the whale's bone

[7]See also reports in *San Francisco Alta California*, San Francisco, California.

(baleen) was next to worthless contributed to the temporary abandonment of the fishery (Henderson, 1972, p. 84).[1,2,4,6] However, the proximity of the California ground to the Hawaiian Islands and San Francisco and probably also overfishing of sperm whales on the Coast of California soon brought revival of the gray whale fishery at Magdalena Bay in the winter of 1851–1852. During that season and the two seasons following it, between 4 and 12 vessels visited Magdalena Bay each winter, and the catch of 1852–1853 was between 65 and 75 whales.[1,2,4,6]

The number of whales which were mortally wounded but escaped the whalers in the early period was probably about 1 for every 10 captured. Although the bomb-lance was not much used in the early period and more whales therefore probably escaped after being attacked, fewer of those which escaped would have been mortally wounded than when the bomb-lance came into wide use in the fishery. Thus, unrecovered dead whales probably averaged about the same relative to those caught both before and after the use of the bomb-lance, which mortally wounded more whales but which also brought death before the wounded animal could swim beyond the inside waters in which its carcass could be recovered. Thus, in the early period of gray whaling at Magdalena Bay, whalemen probably captured 400–450 grays and killed about 450 to 500.

The few cruises alongshore in the early period probably garnered whalemen only about 25 grays, and the number of grays captured on the northern summer grounds probably amounted to only about 52 whales. By the late 1840s whalers in the northern Bering Sea and Arctic Ocean, as well as in the Okhotsk Sea, had observed and commented upon gray whales in their logbooks. They often referred to them as scrag whales, but they chased and captured few as these early whalers were still impressed with the abundance of right and bowhead whales in the northern waters. The loss of grays in the northern waters was high as the wounded whales could escape in fog and under ice to die unretrieved; thus the size of the kill was nearly one-half again that of the catch (see Table I, footnote *g*). As shore whaling had only just begun in this period (at Monterey in 1854), probably only some 10 gray whales were captured there in the initial year of whaling. Whalers made some 75–85 cruises for grays in the early period, and one shore station had been opened along their migration route. The total catch on all grounds in the early period was only some 487–537 grays, and the total kill was between 555 and 610 (Table I). These figures are lower than the estimates I made for this period in 1972 because I have since reviewed more and better records. Nevertheless, my estimate of the total catch and kill of gray whales in the nineteenth century remains about the same because of increases corresponding to other times and places.

Bonanza Period of Gray Whaling

By far the most important gray whaling period was that which lasted the 11 winters from 1854–1855 through 1864–1865. In that period whalers made about two-thirds of all the captures and kills of grays in the California herd that took place prior to the near

abandonment of gray whaling from ships in the mid-1870s. Whaling increased at the old ground of Magdalena Bay; in the winter of 1856–1857, whalers captured 250 grays there and for six seasons (1855–1856 through 1860–1861, gray whaling remained intensive at the bay (Henderson, 1972, p. 151).

At Magdalena Bay, whalers frequented the northern bay of the complex known as Main or Weather Bay as in past seasons, but they also learned of new highly productive parts of the complex. Many vessels anchored in Lee (Almejas) Bay, south of Weather Bay, where they chased the whales especially at the "Mud Hole" at the northeast corner of Lee Bay and along the eastern shore of this bay. More daring captains with large ships, but especially those with small brigs and schooners, had their boat crews tow and kedge their vessels northward into the tortuous, shallow channels of Estero Santo Domingo, north of Weather Bay and behind the long barrier bar, where at low tide vessels rested on their beam ends (Fig. 1). In the bonanza period, 1854–1855 through 1864–1865, whalers on some 125 cruises to Magdalena Bay captured about 1400 grays but killed about 1540 (Table I).

As important as the increase in whaling at Magdalena Bay were the discoveries of new grounds. At the Mexican *Laguna Ojo de Liebre* in 1857–1858, Captain Charles Melville Scammon with the San Francisco brig *Boston* and her schooner–tender *Marin* opened a short-lived bonanza of gray whaling at this calving and mating ground of the gray whale (Henderson, 1872, pp. 113–116, 261). The lagoon became known among whalers as Scammon's Lagoon. During the bonanza period at this lagoon, whalers on 36 cruises took some 553 devil fish and caused the death of about 608 (Table I). Just north of Scammon's Lagoon lie Black Warrior (*Guerrero Negro*) Lagoon and Manuela lagoons. They lie behind the same barrier bar as does Scammon's Lagoon, but are separated from it and one another by transverse bars. Both are mostly tidal flats and have little channel area for gray whale occupance. Few captains poked their vessels' bows into these lagoons, especially after the Honolulu bark *Black Warrior* had entered the lagoon that acquired her name and with her tender, the schooner *J. D. Carr,* had cruised in the lagoon for 2 weeks without success in December 1858 and then was lost just outside while being towed out by the boats of several vessels when swept against the shore by a current (Henderson, 1972, pp. 29–30, 119–121; Scammon, 1874, p. 123). Laguna Manuela, north of Black Warrior Lagoon, has other names, but probably acquired that name from the San Francisco whaling brig *Manuella* which was wrecked in 1871, apparently along its outer coast (Henderson, 1972, p. 48). Whaling vessels did not enter that lagoon. What few gray whales were caught in the two lagoons were taken by boats from whaleships lying outside along the coast.

The same sagacious whaler who first entered the lagoon now bearing his name, Captain Scammon, was also first into another calving and mating area, Ballenas or San Ignacio Lagoon. The husband of Scammon's wife's sister, Captain Jared F. Poole, had seen the lagoon in 1857 and in 1858 he tried to find a channel into it. In the winter of 1859–1860, Scammon took a small fleet of San Francisco vessels into the lagoon (Henderson, 1972, pp. 122–123). That year his schooner–tender *Kate* led his bark *Ocean Bird* and two other barks, Poole's *Sarah Warren* and Captain Easton's *Carib* with two other tenders, between pounding breakers and across the shallow bar into Ballenas Lagoon (Fig. 1). This

was a feat with which Scammon had become familiar at Scammon's Lagoon. Boats of two New Bedford ships joined whaling at the lagoon that winter, but only *Henry Kneeland* went in; *John Howland* remained outside. In subsequent winters many of the grays captured at Ballenas Lagoon were taken in shallow waters behind bars lying southeast of the lagoon mouth (Henderson, 1972, p. 154). Moreover, whalers who chased grays inside Ballenas Lagoon and its southeastern lagoons (*esteros*) also attacked the whales in Ballenas Bay outside the lagoon (Henderson, 1972, pp. 154–155). Thus, it is sometimes difficult to determine if a particular ship captured a whale inside or outside the lagoon itself; only if one has logbook records at hand, rather than newspaper accounts, can he determine how many whales were taken inside or outside the lagoon. The best estimate I can make is that during the bonanza period whalers on some 20 cruises captured about 350 whales, but killed some 385 at the main lagoon and in the smaller lagoons (*esteros*) to the southeast of Ballenas Lagoon (Table I).

Other new whaling grounds and practices were quickly discovered and exploited. At San Diego Bay, San Quintín Bay, and at Turtle Bay (Saint Bartholomew's Bay), ships anchored out of the weather and sent their boats into the kelp beds outside where they lay in wait for grays traveling their migration routes to and from northern waters (Henderson, 1972, pp. 28–29). At San Quintín and Turtle bays, whaleships sometimes waited outside the harbors; at San Quintín, in the lee of tiny San Martín Island (Henderson, 1972, p. 29). At María Bay, south of Cape San Lázaro on the sand bar coast outside northern Magdalena Bay, many whalers also awaited migrating whales. Alongshore whaling, in which vessels waited along the migration route, sometimes anchored and sending their boats off for whales, became a common practice especially when lagoon whale populations began to decline. Thus, whalers along the coast north of several lagoons had a chance to waylay whales en route to several calving grounds.

The stretch of coast where alongshore whaling was most concentrated was between the south shore of Vizcaíno Bay, around Natividad Island and Cape San Eugenio, and on south to San Roque and Asunción islands (Fig. 1). The lee sides of islands and headlands here afforded protection for the waiting ships. From the ships, boats set out down the migration route propelled by sails and steady northern winds to capture grays by the method that Scammon called "sailing them down" (Scammon, 1874, p. 27). Boats with captured whales could row (pull) the whales back to the ships or the ships could sail south after their boats. A practice employed by some captains was that of buoying their anchors so that they could slip anchor quickly to sail after boats fast to rapidly swimming wounded whales.[1] Off the San Benitos Islands and Cedros Island, off San Juanico, the last point between Ballenas and Magdalena bays, and off Cape San Lucas, whalers also practiced alongshore whaling (Fig. 1). In Ballenas Bay, whalemen also took advantage of whaling along the migration route by pursuing whales entering and leaving Ballenas Lagoon. During the peak period of gray whaling, whalers on some 80 alongshore cruises captured some 900 whales, but killed about 990 (Table I).

Some masters took their vessels to places in the Gulf of California, but especially to grounds along the mainland coast of the southern Gulf and south from there (Henderson, 1972, pp. 30–31, 96–97, 165–166). Most important of these grounds was Banderas Bay, which was the southern limit of gray whaling at about 20°N latitude. Others

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Table 1
Catch and Kill of Gray Whales in the California Herd, 1845–1846 through 1873–1874[a]

Whaling grounds	1845–1846 through 1853–1854: Cruises	1845–1846 through 1853–1854: captured[b]	1854–1855 through 1864–1865: Cruises	1854–1855 through 1864–1865: captured[b]	1865–1866 through 1873–1874: Cruises	1865–1866 through 1873–1874: captured[b]	Totals: Cruises	Totals: 1845–1846 through 1873–1874: captured[b]
Magdalena Bay	50–60	400–450[c] (440–495)[d]	125	1400 (1540)	25	150 (165)	200– 210	1950–2000 (2145–2200)
Scammon's lagoon			36	553 (608)	5	38 (42)	41	591 (650)
Ballenas Lagoon (San Ignacio Lagoon) and adjacent waters			20	350 (385)	7	50 (55)	27	400 (440)
Baja California lagoons and bays: Totals	50–60	400–450 (440–495)	181	2303 (2533)	37	238 (262)	268– 278	2941–2991 (3235–3290)
Alongshore whaling on the coasts of the Californias	5	25 (28)	80	900 (990)	45	400 (440)	130	1325 (1458)
Shore Whaling Stations and Camps		10 (12)[e]	—	1190 (1428)	—	960 (1152)	—	2160 (2592)
Gulf of California and mainland Mexico	?	? 52	15	150 (165) 175	10	50 (55) 175	25	200 (220) 402
Northern Summer[f] Grounds	20	(75)[g]	80	(232)	40	(232)	140	(539)
Totals	75–85	487–537 (555–610)	356	4718 (5348)	132	1823 (2141)	563– 573	7028–7078 (8044–8099)

[a]Information from reports in *Seaman's Friend and Temperance Advocate*, Honolulu; *Pacific Commercial Advertiser*, Honolulu; *San Francisco Alta California*; *San Francisco Bulletin*; *San Francisco Chronicle*; "Dennis Wood Abstracts," manuscript records of whaling voyages 1831–1873, New Bedford Free Public Library; and *Whalemen's Shipping List and Merchants Transcript*, New Bedford, Massachusetts. Sources: Summer catch and kill data based on information collected by Dr. John R. Bockstoce, Old Dartmouth Historical Society, New Bedford, Massachusetts, when making his studies of bowhead whaling in the Western Arctic and Bering Sea. Henderson, 1972, 258. Logbooks in Whaling Archives listed in Appendix. Scammon, 1874, pp. 250–251, 270. Starks, 1922, pp. 17–18, 20, 29. Townsend, 1935, pp. 19–20.

[b]Numbers in parentheses are the whales killed (not all were retrieved or captured).

[c]Average yield per whale 35 barrels.

[d]Includes whales captured plus 1 lost mortally wounded for every 10 captured. Ratios the same throughout Table I except for shore and northern gray whaling.

[e]Includes whales captured plus 1 lost mortally wounded for every 5 captured.

[f]Includes summers following winters designated at head of column.

[g]Catch and kill information based on data collected by Dr. John R. Bockstoce. See footnote *a*.

included inlets and alongshore waters at Yavaros and Tojahui in southern Sonora, and Navachiste, Santa María, and Altata on the coast of Sinaloa (Fig. 1). A few captains also chased grays at the Tres Marías Islands where the primary quarry was the humpback whale. Scammon once made a notation that grays also went to the head of the Gulf. He wrote "Around Consag Island and off Shoal Point near the head of the Gulf of California large numbers of California Gray whales have been seen in March (Henderson, 1972, pp. 31–32). In the bonanza period whalers in perhaps 15 cruises captured about 150 gray whales, but killed some 165 in the Gulf and along the Mexican mainland coast (Table I).

During this peak period of gray whaling, 1854–1855 through 1864–1865, shore whaling, using shore-based whaleboats and try-works on the beach, was initiated and expanded at a series of places on the Alta California shore and in Baja California. This low-cost kind of whaling without ships was never important in Mexican waters where the gray whalers on ships made almost all of their catch, and some of the shore stations there were not started until the final, declining period of gray whaling. However, in the peak period at Magdalena Bay, local Mexicans, as well as Americans and English whalers (probably deserters) who lived northeast of the bay at Comondú, came to the shores in winter to practice "carcassing." This operation involved the retrieval of "stinkers" or dead whales and also carcasses which still had tongues and organs in them, to try-out the blubber and meat in order to sell oil to ships in the bay (Henderson, 1972, p. 127). These shore whalers also caught a few live whales. Moreover, in 1860–1861 at least there was a shore station on the southeast side of Ballenas Lagoon, at a place that was designated as Carcass Town on Scammon's map of the lagoon and is still called *La Freidera* (Try-pot or Tryworks) by local Mexicans (Henderson, 1972, p. 100). Those vessels anchored for the season at San Diego and San Quintín bays, which sent their boats outside to whale, became in essence floating shore stations. Shore whalers at all stations probably captured some 1190 grays, but caused the death of 1428 during the peak period of gray whaling (Table I). Not many of these whales were captured or killed in Baja California waters.

Beginning in the 1840s, as whalers in summer cruised farther and farther northward up the coast of Asia to enter the Arctic Ocean in 1848, gray whales on their northern summer grounds were attacked when right and bowhead whales were nowhere to be found; the whalers had really come north for those two whales. By the peak period of gray whaling, whalers in many vessels pursued grays in the north, but with rare exceptions they captured few on any one northern cruise. In 1858, when ice conditions were bad in the Bering Straits, whalers caught gray whales early in the season, as they often did, before they could sail on north in search of bowheads.[8] In that summer Captain Fisher of the Edgartown bark *Rose Pool* reported on the catches of 30 vessels in the Bering and Arctic seas as of July 18. Of the 30, 5 had gray whale catches amounting to a total of 13; none had captured more than 4. However, that year another report tells us that the New Bedford bark *Emerald* (Captain Peirce) as of August 25 had a catch of 2 bowheads, but 9 devil fish.[9] As mentioned earlier, many were killed but lost in fog and

[8] *Seaman's Friend and Temperance Advocate*, Honolulu; October, 1858, p. 80; November, 1858, p. 86; December, 1858, p. 94.

[9] *Seaman's Friend and Temperance Advocate*, Honolulu; November, 1858, p. 86.

under ice; so that more whales were lost, relative to those caught, than in any other sector of the gray whale fishery. Grounds of the California herd where grays were most pursued and captured included the Koryak Coast and Anadir Sea, waters in and off Plover and Saint Lawrence bays, the coast of Saint Lawrence and King islands, the Bering Straits (especially off East Cape), the Chukchi Sea, and all along the north coast of Alaska eastward nearly to Point Barrow. Even during the later period of steam whaling, none appears to have been sighted in the open northern Arctic Ocean on such bowhead grounds as those around Herald Island.[1–4] In the north, it appears that there was more of a mix of large and small whales, for many of the grays captured in the north yielded less oil than those taken on the Coast of California. In all, whalers on about 80 northern cruises probably captured 175 grays, but killed some 232 during the bonanza period (Table I).

As the waters in which gray whales could be caught became widely known and as techniques and equipment improved, the number of vessels that came to the Coast of California each winter increased. The years of maximum cruises and catches were between 1857–1858 and 1861–1862. After rapid depletion, the grounds sustained significant whaling until the mid-1860s. Some captains sought not only grays but also sperm whales or humpbacks or elephant seals. Some cruises by small vessels out of San Francisco were called "pick-up" cruises, and on such a cruise in 1856–1857 the schooner *Henry* (Captain Reynolds) was out 10 months, excluding only summer, and returned with gray and sperm oil, green turtles, and the dried meat and shells of abalone (Henderson, 1972, pp. 94–95).

Catches were low for crews that knew not the ways of the gray whales and gray whaling but large for the experts. In 1856–1857, the few men on the schooner *Henry* filled their casks in just 4 weeks in Estero Santo Domingo where they obtained 500 barrels of oil from 19 whales. Scammon, on the bark *Ocean Bird* in 1858–1859 at Scammon's Lagoon, captured 47 whales in 3 months of whaling and returned to San Francisco with 1700 barrels of oil. On 9 different days from December 9 through February 27, his boat crews took 2 whales per day, and between January 13 and 17, 1859, they captured 6 whales (Henderson, 1970, pp. 39, 45–48, 52, 58; 1972, p. 91). In a catch which may have been made partially at Scammon's Lagoon but probably mostly in Ballenas Bay and Lagoon, Captain Whelden of the New Bedford ship *John Howland* took 1700 barrels of gray whale oil in the winter of 1860–1861.[10]

There are a number of reasons why gray whaling revived after its initiation and decline at Magdalena Bay in the late 1840s. Some reasons included the discovery of new grounds, and others were the new practices, techniques, and equipment that aided gray whaling. Among the most significant contributions to the improvement of gray whaling was the use of the bomb-lance. This device was a large shoulder-held gun which fired a pointed bomb so that a tough gray could be wounded or killed while a whale boat and crew were already attached to it by harpoon and line (a "fast" boat) although out of the range of danger (Henderson, 1972, p. 98). However, sometimes the bombs were fired while a fast (attached) boat was right next to a whale, in order to take the fight out of the whale before hand-lancing began, and sometimes bombs were fired

[10]*Whaleman's Shipping List and Merchants Transcript;* records of her catches, January–June, 1861.

into whales even before the harpoons had been thrown (darted).[1] Nevertheless, because the bombs were expensive, many gray whales were killed without the use of bomb guns even after the instrument became common.[1] Scammon said that the first winter's whaling at Scammon's Lagoon would have been a failure had it not been for the bomb-lances he had on board (Scammon, 1874, pp. 263–264). To shore whalers who had to catch grays swimming rapidly past the station along the migration routes, bomb-lances were especially useful in waylaying whales that were some distance from the boats.

Greener's guns, which were swivel-mounted in the bows of whaleboats, fired harpoons greater distances than they could be thrown, and these contrivances became especially useful in shore whaling or whaling outside lagoons in the breakers, where the migrating whales or rough water precluded close approach and use of the hand-thrown harpoon (Henderson, 1972, p. 98). Scammon termed this practice "whaling in the breakers" (Scammon, 1874, p. 28). Those whalers who employed the Greener's gun also used bomb lances and other kinds of guns which attached boats to whales or killed whales.

During the bonanza period of gray whaling on the Coast of California, vessels from a wide range of home ports entered the fishery. The Connecticut whalers continued to come, but so now did many from the ports of southern Massachusetts such as New Bedford, Fairhaven, and Nantucket. Others came from the Long Island ports. Moreover, vessels from San Francisco and Honolulu increasingly joined in the gray whaling. Some of these vessels were small brigs and schooners, especially well suited for reaching shallow grounds such as the long lagoon, Estero Santo Domingo, which leads northward from Magdalena Bay. German whalers, some of Hawaiian registry, and French whalers continued in the fishery; one Russian vessel, the brig *Constantine*, came to Scammon's Lagoon in 1859–1860 (Henderson, 1972, p. 261).[1–4] Her master Captain Lindholm, a Swede from Russian Finland, whaled in the Okhotsk Sea with the Russian whalers, and undoubtedly had been induced to come to the Coast of California by gray whalers who sought bowheads and rights in the Okhotsk Sea in summer (Beane, 1905, pp. 208–209).

The total catch and kill of gray whales in the California herd in the bonanza period were probably about 4718 and 5348 respectively (Table 1). For whaling vessels, Magdalena Bay remained the most important ground; the alongshore ground was second in importance, followed by Scammon's Lagoon and Ballenas Lagoon. Grounds of lesser significance for the whaleships in the winter season were those in the Gulf of California and along the mainland shore of Mexico. However, whalers were catching a fair number of grays now on their summer grounds in the Bering Sea, Arctic Ocean, and Okhotsk Sea. Very significantly, shore whalers on the coasts of both Alta and Baja California, but especially in Alta California, probably had caught and killed more grays than whalers in any other single sector of the fishery except at Magdalena Bay.

Because the number of whales in the California herd was not large, gray whaling grounds were rapidly depleted during the 11 seasons in the bonanza period. Whalers essentially abandoned Scammon's Lagoon by the mid-1860s, and by that time Ballenas Lagoon was little more productive than was Scammon's. Magdalena Bay still had more whales left than did its northern counterparts but had declined rapidly as a gray whaling

ground. The Coast of California was entering its final period as a gray whaling ground for sailing ships.

Period of Declining Gray Whaling

The last period of significant whaling from ships on the Coast of California was from the mid-1860s into the early 1870s. It was a period of such declining rewards that at its end masters of whaleships had abandoned most of the gray whaling grounds. During this last period, the formerly important grounds at Magdalena Bay, Scammon's Lagoon, and Ballenas Lagoon were reduced to minor whale grounds. For example, only 5 vessels entered Scammon's Lagoon. However, because so little whaling had occurred there since 1861–1862, Captain James McKenzie made fair catches of 14 whales each season in the winters of 1868–1869 and 1869–1870. He and his crew visited the lagoon alone on the New Bedford barks *Eagle* and *Hercules*, successively (Henderson, 1972, pp. 263, 266). At Magdalena Bay in late January of 1867, J. Ross Browne visited the shores during his explorations for the Lower California Company, and at that time he found only 2 whaleships in the bay. Although the whalers had "scoured" the waters of the bay for 2 months, they had captured only 2 whales, and the whalemen told Browne that it was then an achievement to capture 2 or 3 whales per month (Henderson, 1972, p. 172). Actually some 16 vessels did visit Magdalena Bay in 1866–1867, but most were whaling alongshore outside and had come in for wood and water and to look for grays.[1] The New Bedford ship *Milo* (Captain Hawes) spent only 2 weeks in the bay and saw a few whales, but captured none.[11]

Whalers on vessels engaged in alongshore whaling and shore whalers, however, continued to do relatively well (Henderson, 1972, pp. 174, 178). Both exploited the grays along their migration route and so had the advantage of waylaying whales headed to or from the several calving and mating grounds. At San Quintín, masters of vessels anchored inside the bay made moderate catches as late as the winter of 1866–1867 by whaling outside the bay (Henderson, 1972, p. 39, n. 24). Moreover, shore whalers, with their low investment, could make a living from small annual catches. This opportunity thereby attracted enough men into shore whaling to bring about the establishment of numerous shore stations and the largest catch of any sector of the gray whale fishery. As whaling declined on the west coast of Baja California, a few whalers still sought out grays in the Gulf of California and along the mainland coast of Mexico where they made small catches (Henderson, 1972, pp. 175–176). However, the northern grounds remained important because although few vessels now cruised the Coast of California, a good many went north into the Arctic Ocean and Okhotsk Sea in search of bowhead whales. In the northern Bering Sea and the Arctic Ocean, the California herd probably suffered as great a catch and kill as it did during the peak period of gray whaling (Table I). More whaleships caught grays than they did earlier, but usually only a few grays were taken by

[11]Ship *Milo* 1863–1868; New Bedford Free Public Library.

any one vessel. In 1871, however, Captain Valentine Lewis of the New Bedford bark *Thomas Dickason* captured 1 at Plover Bay and 10 off King Island, which lies in the northeastern Bering Sea.[12]

In the final period of significant gray whaling from sailing ships, whalers on some 25 cruises probably took about 150 whales at Magdalena Bay, but killed 165. At Scammon's Lagoon, some 38 whales were captured and about 42 killed on 5 cruises, whereas at Ballenas Lagoon and in adjacent waters whalers on about 7 cruises probably killed some 55 whales and retrieved perhaps 50. Alongshore whaling from about 45 cruises accounted for the death of approximately 440 grays and the capture of 400 of them. In the Gulf of California and on the coast of mainland Mexico, whalemen probably made only 10 cruises and captured 50 grays from a kill of 55. On the northern summer grounds, whalers took more grays per cruise as bowhead and right whales became more scarce. On some 40 cruises, 175 grays were probably captured out of 232 killed. The most important part of the gray whale fishery had become shore whaling, because of the low costs involved and the opportunity to prey on all of the much reduced California herd as it passed along the coast. Shore whalers, almost all of whom were from stations in Upper California, probably captured 960 grays from among the 1152 they killed (Table I). During the period of declining gray whaling from ships, considerably fewer than one-half as many gray whales were captured or killed as during the preceding bonanza period. Two-thirds of the whales caught and killed fell victim to shore and alongshore whalers. Whaling at the formerly productive lagoons and Magdalena Bay was essentially abandoned by the end of the period.

Throughout the entire period of significant gray whaling from whaleships on the Coast of California (1845–1846 through 1873–1874), whalers had made a total of about 563–573 cruises to California and northern waters on which they captured and killed gray whales. Moreover, shore stations, easily established and moved, had become involved in the gray whale fishery on the California coasts (Chapter 6, this volume). In all, the gray whalers captured approximately 7028–7078 whales of a total kill of about 8044–8090 (Table I).

Whaling and Whale Population

From its inception, nineteenth century gray whaling had a devastating effect on the population of the California herd. The kill was, to a large extent, concentrated on the cows and calves that were easily killed in the crowded lagoons and bays. Calves, however, were not counted in the recorded catch or kill. Because most of the cows carried fetuses, or would have been impregnated had they not died, or had calves which either were killed or died of starvation, the reproductive capacity of the population was greatly reduced through this excessive slaughter of cows and calves relative to the kill within the total population (Henderson, 1972, pp. 132, 149).

[12]Nicholson Whaling Collection, C798, 1866; Providence Public Library.

The number of grays killed during the initial period of 9 winters of concentrated whaling and the summers following those winters averaged only 62–68 whales per year. This was undoubtedly a sustainable kill for the existing population. During the peak period of gray whaling (1854–1855 through 1864–1865), in 11 winters and succeeding summers the number killed averaged 486, which must have far exceeded a sustainable kill. And in the 10-year period of whaling decline (1865–1866 through 1873–1874), although the kills declined each year, the average kill of 214 per year was still well in excess of that sustainable by a rapidly declining population.

The population decrease is clearly demonstrated by the precipitious decline in the ability of the major calving grounds to sustain whaling. At Scammon's Lagoon, after only 4 years of intensive whaling (1858–1859 through 1861–1862), so few whales remained that few whaling vessels continued to visit the lagoon. With a total kill at Scammon's Lagoon of 650 whales, the lagoon was essentially emptied of whales. Captain Nye of the New Bedford bark *Louisa* reported on February 20, 1873 that whales were scarce and that he had taken only 2 whales at the lagoon during the entire season (Henderson, 1972, p. 170).

At Ballenas Lagoon, a total catch of some 400 whales eliminated most of the population on that whaling ground. Scammon and a few other masters had initiated whaling there in 1859–1860. That winter and the next were seasons of big catches. However, only seven seasons later, in 1866–1867, whalers apparently had essentially abandoned Ballenas Lagoon as an exploitable ground.

The huge complex of waters at Magdalena (Marguerita) Bay sustained more whaling and for a longer time than did the two lagoons to the north. However, after a total kill there of a maximum of 2200 whales over a period of some 25 to 30 years, Magdalena Bay was ignored as a gray whaling ground.

Of course, many whales headed for the calving and mating grounds at the lagoons and bays were killed by alongshore whalers on ships and by other whalers from shore stations. These same whalers killed many of the grays as they made their way back to the northern summer grounds. Whether the grays were killed at the lagoons and bays, en route to or from those waters, or on their northern grounds, a total kill of only about 8100 eliminated pursuit of California gray whales as a truly profitable sector of the nineteenth century whaling business.

So few gray whales remained after 1874 that only whalers at a few shore stations or those on ships seeking right or bowhead whales in northern seas continued to kill a small number of graybacks. Nevertheless, those which survived may have numbered as many as 4000–5000 (Storro-Patterson, 1980, p. 9; Ohsumi, 1976), although they were no longer pursued intensively because of the inefficiencies of nineteenth century whalemen in small boats compared to those in modern powered catcher boats. Many nineteenth century whalng grounds appear to have been left behind for other places as soon as whales ceased to be easily found and captured.

Whalers captured or killed most of the whales at the known and originally crowded grounds within a period of two decades. At some individual grounds, such as Scammon's Lagoon, they eliminated most of the whales in only a few years. Thus, the whale kill must have represented most of the population of California gray whales alive at the

time gray whaling began. However, some gray whales survived at the well-known grounds, and a fair number must have spent winters sparsely distributed at various places along their migration route. Considering the kill of some 8100, unreplaced natural mortality, and those perhaps 4000 that may have survived in 1874, the population of the California herd of gray whales probably was not over 15,000 when gray whaling began at Magdalena Bay in 1845–1846 (Henderson, 1972, p. 185; Rice and Wolman, 1971, pp. 118, 130; Storro-Patterson, 1977, p. 46).

Scammon, estimating the number of gray whales killed by 1874 as 10,800, and the number of the California herd between 1853 and 1856 as 30,000–40,000, was undoubtedly high on both estimates (Henderson, 1972, p. 179). His estimate of 8,000–10,000 whales that may have survived in 1874 is also too high (Henderson, 1972, p. 183). Captain Packard (of a San Diego shore station) was probably low in his estimate that the population was only about 1,900 in 1874 (Henderson, 1972, p. 183). The size of catches and kills in the twentieth century, on the other hand, make the extremely low appraisals of population size in the late nineteenth century and early twentieth century obviously wrong (Henderson, 1972, pp. 183, 229).

Gray whales of the California herd did survive the onslaught of the nineteenth century Yankee and other whalers on ships and at shore stations in considerable numbers, as is illustrated by both sightings and catches in the late nineteenth and early twentieth centuries. Whalers on vessels from San Francisco and some other ports continued to exploit the Arctic bowhead fishery in those times, and they also continued to catch a few grays and sight many more (Henderson, 1972, p. 232).[1] As late as 1922, the San Francisco motor ship *Herman* arrived at Nome on July 10 with a catch of four devil fish which had an average yield of 28 barrels, only slightly lower than the average yield of grays on the coast of California during the boom years of gray whaling.[13] Moreover, in the twentieth century, on floating factories, at shore stations where grays have been taken commercially and for scientific study, and from or for aboriginal communities in northeast Siberia and Alaska whalers have probably killed at least 4000 California gray whales (Rice and Wolman, 1971, p. 123; Storro-Patterson, 1977, p. 47; 1980, p. 8).

Nineteenth Century Whaling for Gray Whales in the Okhotsk Sea

Perhaps this is the place to insert that nineteenth century whalers when in northern waters in summer captured many gray whales in the Sea of Okhotsk, that is, grays of the so-called Korean herd.[14] They did not capture grays until the late 1840s. By that time

[13]An "account book of P. James Laflin, shipping agent, San Francisco," in "San Francisco Crew Lists 1906–1928." Original at San Francisco Maritime Museum. Transcript read at Old Dartmouth Historical Society, New Bedford, Massachusetts.

[14]The information upon which the following observations are based is now being utilized by the author in a study of whaling in the Okhotsk Sea, and has been derived from newspaper accounts, books on the Okhotsk Sea, and manuscript whaling records and logbooks.

whalers had pushed their vessels far enough into the Sea to be on the northern and southwestern bowhead grounds of the Upper Sea, that part of the Sea north of 53°N where they found gray whales in abundance. By the early 1850s some captains chased and captured grays and soon some good-sized catches had been made, that is, catches of six or seven grays per vessel.[15] The primary quarry of the whalers in the Okhotsk Sea was the bowhead; so whalers, as in the Bering Sea and Arctic Ocean, took grays only when no bowheads were around. Sometimes this meant a concentrated chase of grays for several weeks. As on other northern grounds, many of the grays captured were smaller than those taken on the Coast of California. Whales of only 10–15 barrels yield, less than half the average yield on the coast of California, were not uncommon in the Okhotsk catches, an indication that many young whales born the previous winter must have been captured. As in the Bering Sea and Arctic Ocean, whalers continued to pursue gray whales in the Okhotsk Sea into the late nineteenth century, that is, at least into the mid-1880s. The total number of grays taken and killed in the Okhotsk Sea by nineteenth century whalers probably approached that of those captured and killed in the Bering Sea and Arctic Ocean; and as the Okhotsk (Korean) herd must have been smaller than the California herd, greater inroads into that population must have been made in summers than were made in the California herd in that season.

Gray Whaling: Problems and Dangers, Practices, Equipment, Resources of the Shores and Bays, Trade, Catches and Yields

Shipwrecks on the Coast of California were surprisingly few considering the currents which swept the coast and the difficulties of working whaleships into, out of, and within the shallow lagoons with only very shallow water over bars across their mouths. Only about 10 vessels were lost during the nineteenth century whaling (Henderson, 1972, pp. 110, 117, 144–145, 170).[1–4,6] Probably the most remembered of the wrecks is that of the Honolulu bark *Black Warrior* (Captain Brown) which, as previously described, was swept against the coast in December 1858 while being towed out of the lagoon that bears her name (*Guerrero Negro* in Spanish) (Henderson, 1972, pp. 109–110, 119–121).

The absence of hard bottoms throughout much of the lagoon area and on the bars saved a good many vessels from disaster, although damage from grounding hulls of heavily laden whalers was not uncommon. Once inside the lagoons and bays, whalers usually anchored their ships for long periods of time and sent their boats on what often turned out to be long chases. To facilitate cutting-in whales far from the ships and save a long boat tow of the whale or his rafted blubber back to the ship, schooner tenders accompanied some larger vessels into the lagoons (Henderson, 1970, p. 14). These schooners could work into the very shallow calving grounds, like those at the Mud Hole in Lee (Almejas) Bay, at Magdalena Bay, and the Nursery in Main Lagoon at the inner reaches of Scammon's Lagoon. It was in such places that cows and calves were concen-

[15] *Seaman's Friend and Temperance Advocate*, Honolulu; December, 1858, p. 84.

trated, whereas bulls when taken were in the outer lagoons, outside in the breakers, and along the migration routes. In the winter of 1861–1862 at Ballenas Lagoon, the 299-ton bark *Delaware* served as a tender to the larger ship (377 tons) *John Howland* so that the ship could remain completely outside the lagoon in Ballenas Bay (Henderson, 1972, p. 158; Starbuck, 1878, pp. 556, 560). Whalers staked out the channels of the lagoons to guide whaleships, tenders, and boats away from grounding and to prevent a 3- or 4-ft falling tide from leaving them high and dry (Henderson, 1970, p. 27). In Estero Santo Domingo, low tide at some places exposed a mile of sandy bottom on either side of the channel (Henderson, 1970, p. 27).

Dangers other than those of managing the ship awaited the gray whalers when they set out in their boats after gray whales in lagoons, bays, or alongshore.[16] Whalers with long experience gave precedence to the grays as the most dangerous of whales. Many men were killed or badly injured in the business of gray whaling. In the bays and lagoons, equipment (whalecraft) and practices were geared to dangers as well as other peculiarities of "lagoon whaling." Of prime importance in all kinds of gray whaling was the use of the bomb lance, which has already been described. To make sure that the wily grays did not escape, often men in four or more boats would attack one whale which meant that if some got fast with their harpoons the whale would have less chance to escape. However, it meant also that lines could become fouled and boats overturned, so special rules of attack were normally observed. One of these was that the men in the first boat to locate and pull toward a whale would set a waif, which was supposed to give that boat and boats cooperating with it by ownership or agreement first chance at the whale.

In order to bring as many boats as possible to bear down upon a whale or several whales, captains often mated their vessels, that is, worked together and shared the catch. Sometimes as many as three vessels in a lagoon were mated. Lagoon whaling could be a crowded affair in which one whale could stave several boats and endanger many men. Unfortunately, so many boats often entered the small areas of calving waters where boats and whales were packed together that great confusion during the chase, disputes over claims to whales, and many accidents occurred. Such waters included the Mud Hole in Almejas Bay and the inner Main Lagoon at Scammon's Lagoon. Also in lagoon calving waters, whalers often had problems with calves fouling their lines and with confusing a rising calf with its mother so that they attacked the calf while the cow escaped. Whalers handled attacks on calves in two ways: some preferred to harpoon the calf first so that the cow would stay close by; others left calves alone out of fear that wounded and dying calves provoked the cows into more destructive behavior.

In the lagoons, boat crews sometimes bombed whales repeatedly so that if they escaped they would die and eventually rise to the surface to be captured. Whalers sometimes marked dead whales with a waif (flag) so that they could be located later, while boat crews went in search of more whales (Henderson, 1970, p. 72). Bombing and harpooning could sometimes be done while the boat was stationed where the whale could not reach it, as in shallow water on a tidal flat next to a channel. Moreover, in the

[16]The following observations about gray whaling have been abstracted from Whaling Archives (see Appendix).

channels currents could be swift and sweep a boat onto its quarry, to the dismay of the crew.

Some other kinds of equipment, in addition to the advantageous bomb lances and Greener's guns, were very useful to gray whalers. Because whalers often had to cut lines to keep their boats from being pulled a long way from their ships and even outside the lagoons or to keep from becoming foul of other boats' lines, a large supply of line was necessary. If ships were anchored in channels where currents were swift, a supply of extra anchors helped hold them in place. Kedges were needed in ships and boats alike to keep from running with the tide, to pull into shallow water, and to warp ships off the mud when grounded (Henderson, 1970, p. 32).[1] Gray whalers carried grapnels to haul sunken whales up from the shallow bottom. Some whalers carried cutting spades in their boats in order to stab into the "small" of the backs of the tough grays just ahead of the flukes, to slow the escape of a whale towing a boat about the lagoon.

Whalers at the lagoons spent much time ashore. They often beached their boats when away from the ships on long searches for whales, at times overnight (Henderson, 1970, p. 14).[1] Sometimes a dead whale beached itself and was then cut-in ashore and the blubber rafted back to the ship (Henderson, 1970, p. 27).[1] To make more room aboard the ships during the busy whaling season, carpenters and coopers sometimes worked ashore; sails, rigging, and casks also were sometimes stored ashore (Henderson, 1970, pp. 21–22, 59).[1] Moreover, whalers often went ashore to cut wood, obtain water, and shoot birds, rabbits, and deer; they also traded with Mexicans who traveled to the shores with cattle, cheese, fruit, game, and other trade items from near or distant ranches and towns (Henderson, 1972, pp. 125; 1975, pp. 51–52). Even some "ladies of the evening" trekked across the desert from La Paz to Magdalena Bay to come aboard ships waiting to whale (Henderson, 1975, p. 53). Some whalers with time on their hands, when whales were scarce both before and after the whaling season, walked inland to visit Mexican and American ranchers who lived near the shores of Magdalena Bay (Henderson, 1975, p. 53).[1] Deserters, who did not find berths on other vessels and thus remain undiscovered, were usually unsuccessful except for those few who found refuge on ranches and in towns near Magdalena Bay. However, most deserters were caught by Mexicans who returned them for a reward, or the desperate men themselves returned from the desolate desert. Some died in their attempted escapes (Henderson, 1970, p. 26; 1972, p. 128; 1975, p. 53).[1]

The waters of the bays and lagoons or those just outside were especially attractive to the whalers in the food supply they afforded. During their stays the whalemen were well provided with green turtles, spiny lobsters, abalone, oysters, and clams. Whalers salted fish and caught live turtles in quantity at the end of the season to provide free food on board after they left the Coast of California (Henderson, 1970, p. 71).[1]

The many inducements to whalers on the Coast of California included the possibility of doing little if any sailing for the season; the provision of cheap food from the shore, especially the favorites of New Englanders (i.e., beef, cheese, and fresh milk); the abundance of free food in the sea; the availability of cheap Mexican laborers aboard ships and ashore as collectors and processors of "stinkers;" the low number of successful desertions; the ready supply of wood and water ashore; and the mild weather.

Even if many catches were low, the cruise to the Coast of California was a cheap and a pleasant way to spend the "between the seasons" winter in anticipation of a good northern summer catch in "the season."

Because the bays and lagoons were quiet places where whalers could repair ships and sails and paint their vessels, rather than remain in such places as Honolulu and San Francisco where expenditures were necessary and desertions easy, many whaleships arrived at the Coast of California grounds early in the winter. But then, so did the whales. Although January and February were the months in which most whales were caught, whalers captured and killed many before and after those months. In the winter of 1858–1859 at Scammon's Lagoon, Captain Scammon on the San Francisco bark *Ocean Bird* was 20 miles into the lagoon in The Narrows when he saw the first whales on November 24.[17] By November 26, he had anchored for the season off Cooper's Lagoon (Nursery Inlet), and from December 11 on he and his crew saw whales regularly from The Narrows to the inner lagoon. His men chased their first whale on December 18 and captured their first on December 22. Nevertheless, on December 20 Scammon and Captain Poole, on the San Francisco bark *Sarah Warren*, had made the kind of agreement that became common among bay and lagoon whalers on the Coast of California; they agreed to let a good number of whales come into the lagoon before beginning to whale. Scammon's men killed their last whale on March 13; of 47 grays captured that season, they took 7 in late December and 6 in early March. As did whalers at other lagoons and bays, Scammon's crew spent the last days or weeks on the ground at such tasks as catching turtles and fish and cutting wood. That season *Ocean Bird* went over the bar and out of Scammon's Lagoon on March 27.

Unfortunately, whalers made essentially no reports on the measurements of grays but were interested only in the oil yield of their catches, either per whale or for the season. However, oil yields reveal relative sizes of whales from one time or place to another. Most gray whales yielded 35 barrels (31.5 gal per barrel). In fact, newspaper reports from whale grounds almost always equated 1 gray whale to 35 barrels of oil. If a ship was reported to have taken 10 grays, her catch would be reported as 350 barrels.[2–4,7] During the entire period of gray whaling up to the early 1870s, Scammon also equated 1 gray to 35 barrels of oil (Henderson, 1972, p. 138). In some reports he reported that the yield averaged between 20 and 40 barrels (Henderson, 1972, p. 138). In the early years of gray whaling whalers caught some whales that were much larger. In 1858–1859 at Scammon's Lagoon on *Ocean Bird*, Scammon caught a whale on December 25 that yielded 55 barrels (Henderson, 1970, p. 37), and he said that very large grays might yield 60–70 barrels (Henderson, 1972, p. 137). The records of huge gray whales, which could have yielded the 101 barrels reported by a New London whaler and the 90 barrels reported taken from 1 whale caught by San Diego shore whalers, appear to be mistakes in catch size or species taken (Henderson, 1972, p. 137). Both could have been right whales. Perhaps there was some decline in the size of whales captured; various reports of the oil taken in 1846–1847 at Magdalena Bay by the New London ship *Hibernia* and the Stonington bark *United States*

[17]This and the following information about Scammon's whaling in 1858–1859 is from Henderson, 1970, pp. 17, 19–20, 21, 28, 31, 33, 35, 67, 68, 71; and from logbooks in Whaling Archives (see Appendix).

in the first year of gray whaling indicate an average yield of 45 to 55 barrels per whale.[2,4,6] Nevertheless, except for that indication, average yields on the Coast of California do not seem to have declined with total catch declines, perhaps because some large bulls were taken outside the bays and lagoon in the late years of gray whaling (Henderson, 1972, pp. 140, 148–149). Catches on the northern grounds in the Bering Sea and Arctic Ocean as well as in the Okhotsk Sea did seem to produce lower yields per whale, however, probably because whalers on those grounds caught more young whales born the previous winter (Henderson, 1972, pp. 137–138).[1]

Revisions of Gray Whaling History and Geography

The historical record supports a number of revisions in conceptions about gray whales and gray whaling which I should like to emphasize before ending this chapter. First, the idea that before gray whaling began there was a large population of grays in the California herd numbering 30, 40, or even 50 thousand is not borne out by the historical record of catches and the number of whales that survived in the twentieth century. The population of the California herd when nineteenth century whaling began was probably around 15,000 and certainly not more than 20,000 (Henderson, 1972, pp. 132, 154, 169–191).

Another misconception is that Scammon's Lagoon contained more gray whales than any other lagoon or bay on the Coast of California. Records of vessels on the grounds and reported catches demonstrate that in Magdalena Bay whalers caught and killed over three times as many whales as they did in Scammon's Lagoon (Table I). Moreover, in 4 years of intensive whaling at Scammon's Lagoon, it was effectively ruined as an important whaling ground, although Magdalena Bay endured at least 12 years of intensive whaling. Of course, the Magdalena Bay complex is much larger than Scammon's Lagoon and contains three distinct parts; these are, from south to north, Lee (Almejas) Bay; Weather, Main, or Magdalena Bay; and Estero Santo Domingo, the long lagoon behind the barrier bar north of Weather Bay. Nevertheless, in comparing the total size of Scammon's Lagoon to that of the Magdalena Bay complex, it would appear that whales were just as concentrated in Magdalena Bay as in Scammon's Lagoon.

Among the persistent errors concerning gray whale migration and range is that which places the most northern bays of winter habitation at San Diego and San Quintín bays. The report that Captain W. W. Clark killed two whales of some kind in the bay in 1842 may be true; on the other hand, it may simply have meant that he had his ship in the bay and captured the whales outside the bay as he did some 15 years later (Henderson, 1972, p. 28). This may be a good place to point out that Captain W. W. Clark was a Yankee who conducted shore whaling outside the bay in boats of the ship *Ocean* which was anchored in the bay (Henderson, 1972, p. 28). This Clark has been confused with another Captain Clark who was a shore whaler in California but who came from the Azores and changed his name from Machado to Clark (Henderson, 1972, p. 210, footnote 357). A few grays may have visited San Diego Bay; but if the account, in a 1908

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history of San Diego County (Smythe, 1908, p. 110), of many calving whales passing in and out of the bay in the early 1840s were correct, it would seem that such a well-known and well-stocked potential whaling ground would have attracted many whalers to those waters after gray whaling was initiated at Magdalena Bay in the winter of 1845–1846. Such was not the case, and it appears unlikely that the harbor traffic, which is credited with driving the grays from the bay, increased that much in the early years of this quiet port between 1840 and 1846 (Henderson, 1972, pp. 28, 82–83, 133–134).

The maritime traffic, both at Scammon's Lagoon, since salt works were re-established there in 1857, and at Magdalena Bay, where fishing, agricultural export, and other marine traffic has been increasing since World War II, has not driven gray whale populations from those places. Thus, how could the few merchant ships visiting San Diego Bay in the early 1840s ruin the bay as a whaling ground for whalers who knew it well and had been taking large numbers of grays at Magdalena Bay between 1845–1846 and 1847–1848? Certainly by the time shore whaling from stations just inside San Diego Bay began in the late 1850s, the whalers were sailing their boats outside the bay to attack whales along the migration route (Henderson, 1972, p. 28); whaling vessels reported sighting shore boats whaling outside the bay.[1]

Like San Diego Bay, the much smaller and shallower San Quintín Bay approximately 190 miles south of San Diego in Baja California was a protected place from which masters of whaleships could send out their boats. Some vessels reported at San Quintín were actually anchored outside, south of the small island of San Martín off Point San Quintín. From vessels anchored inside or outside the bay, whalemen in their boats chased the grays along the migration route outside the bay (Henderson, 1972, pp. 28–29).

An historical myth about the discovery of Scammon's Lagoon has Captain Scammon following grays through the surf to find himself inside a lagoon full of whales (Henderson, 1972, p. 114). In fact, Indians and Spaniards had passed knowledge of the lagoon and its whales down to nineteenth century Mexicans (Henderson, 1972, pp. 53–54; 60–77). Sea otter hunters knew the lagoon prior to Scammon's entry (Henderson, 1972, pp. 102–103), and early sperm whalers on the coast of California, including those of the English ship *Toward Castle* (misidentified by Scammon as *Tower Castle*) which was wrecked in 1836 on the west side of the mouth of the lagoon, surely knew that the lagoon was there.[18] Early hunters of Guadalupe fur seals and elephant seals at Cedros Island and the small island rookeries in Vizcaíno Bay also must have known the lagoon (Henderson, 1972, pp. 102–104). At Elide Island almost on the coast and just north of Scammon's Lagoon, guano collectors had contacts with Mexican traders who must have told them about Scammon's Lagoon at least a year before Scammon went into it (Henderson, 1972, pp. 104–105). A most believable account of whaling on the Coast of California says that Scammon learned of the lagoon from a Mexican at Magdalena Bay, where Scammon whaled in 1855–1856 on the San Francisco ship *Leonore* and in 1856–1857 on the San Francisco brig *Boston* (Henderson, 1972, pp. 113, 115, 268). And in fact,

[18]Scammon's misidentification is in Scammon, 1869, p. 124 (see Henderson, 1972, pp. 109, 202, footnote 153). The correct identity of the vessel as *Toward Castle* is found in *Lloyd's Register*, July 1, 1838–June 30, 1839, T301; *Sandwich Island Gazette*, October 21, 1837, p. 3.

after a disappointing cruise on *Boston* whaling, sealing, and sea elephant hunting off the coasts of the Californias in the summer and autumn of 1857, Scammon decided to attempt to find a way into the gray whale lagoon of which he had heard at Magdalena Bay (Henderson, 1972, p. 115). Scammon had taken his brig from Cedros Island to the peninsular coast north of Vizcaíno Bay and had worked his way southward to Lagoon Head, just north of the three lagoons on Vizcaíno Bay (Henderson, 1972, pp. 115, 268). From the protected anchorage on the lee side of this headland, which other whalers must have visited by 1857, Scammon could easily have seen the mouths of the two northern lagoons (later named Manuela and Black Warrior lagoons). Later on the voyage, Scammon had arranged to have the small schooner-tender *Marin* sent south from San Francisco, and the two vessels met at Catalina Island to sail southward. After they arrived at Lagoon Head, Scammon sent his tender and three whale boats to explore southward along the coast. This expedition partially explored the two lagoons north of *Ojo de Liebre* (Scammon's) Lagoon. Then, after 2 days, news was sent back to Scammon that the tender had entered the large southernmost lagoon. Scammon then followed *Marin* and took his brig *Boston* into the lagoon which was to acquire his name (Henderson, 1972, pp. 115–116, 268).

A clarification of the translation of the Spanish name for Scammon's Lagoon, *Laguna Ojo de Liebre*, is needed at this point. Many authors have translated the name as Eye of the Jack Rabbit Lagoon or Jack Rabbit Eye Lagoon, rather meaningless names. The correct translation is Jack Rabbit Spring Lagoon. At the eastern end of the Lagoon is a freshwater hole or spring called *Ojo de Liebre* which takes its name from the *Llanos de Liebre* (Jack Rabbit Plains) on whose western edge the spring is located. These are old Spanish names, which probably go back to the mission period prior to the nineteenth century. *Ojo*, however, has other meanings than eye, one of the most common of which is spring, its obvious meaning at Scammon's Lagoon. The lagoon was named after the spring because it undoubtedly had more significance to Spaniards on the trail, which passed the spring, than did the lagoon. Thus, they named the Lagoon after the spring which in turn got its name from the plains to the east.

Another myth which has been perpetuated about Captain Scammon and the lagoon is that he kept his "discovery" concealed for several seasons, and that only by smelling the odors emanating from Scammon's trypots did other whalers later discover his secret (Henderson, 1972, p. 118). In fact, Scammon himself made arrangements in his second winter at the lagoon, 1858–1859 on the San Francisco bark *Ocean Bird*, to join his tender *A. M. Simpson* and the San Francisco bark *Sarah Warren*, commanded by the husband of Scammon's wife's sister, Jared F. Poole, at Lagoon Head from which the vessels entered the lagoon together on November 20, 1858 (Henderson, 1970, p. 17). Although Scammon's journal makes it clear that *Sarah Warren* awaited Scammon at Lagoon Head and sailed into the lagoon with him, in his book "The Marine Mammals" Scammon does not acknowledge Poole's company but indicates that Poole was among the captains who "succeeded in finding their way in" after Scammon had entered the lagoon (Henderson, 1970, pp. 17–18; 1972, p. 204, footnote 197; Scammon, 1874, pp. 265–266). Furthermore, captains on whaleships recruiting in the Hawaiian Islands had learned of the lagoon by the second year of whaling there,

through reports from Scammon's mate on *Boston* during the first year's whaling at the lagoon. Thus, by the second year of whaling at the lagoon a fleet of 18 vessels came from the Islands to attempt whaling at Scammon's Lagoon and those lagoons adjacent to it. Most of the masters found entry difficult, and after the loss of *Black Warrior* at Middle Lagoon (now Black Warrior or *Guerrero Negro* Lagoon) they went elsewhere on the coast. In the second winter of whaling at Scammon's Lagoon, however, seven vessels excluding tenders whaled at the lagoon, including the barks *Ocean Bird* and *Sarah Warren* of San Francisco; four from the Islands, and one, flying a New Granada flag of convenience, which was a merchant vessel-become-whaler and probably came south from San Francisco, the bark *Cleopatra* (Henderson, 1970, pp. 44–45, footnote 62; 1972, pp. 119, 161).

Summary

After whalers had worked the sperm whale fishery of the Coast of California and had largely turned their attention northward in the Pacific Ocean, they returned to the Coast of California in many vessels to attack gray whales in winter when they had fled the cold and icy northern grounds. The new ground was easy to reach from the whalers' recruiting ports in the Hawaiian Islands and San Francisco, and it afforded mild weather, little sailing, food supplies, and good catches for those who understood the ways of gray whales and gray whaling. Some whalers avoided this peculiar and dangerous kind of whaling. The gray whale fishery lasted only some three decades, but other nineteenth century whale fisheries were also short lived because whalers attacked whales without thought of conservation, moving on when whales were hard to find but often far from extinct on the grounds. Nevertheless, nineteenth century gray whaling from ships and shore stations on the coasts of the Californias caused a devastating decline in the gray whale population, and probably only the early whalers' inability to pursue a species to its end saved the California grays from near extinction or complete extirpation.

Appendix: Whaling Archives in Which Source Manuscripts, Chiefly Logbooks, Are Located

Bancroft Library
University of California
Berkeley, California

Dukes County Historical Society
Edgartown, Massachusetts

East Hampton Free Library
East Hampton, Long Island, New York

Falmouth Public Library
Falmouth, Massachusetts

Kendall Whaling Museum
Sharon, Massachusetts

The Mariners Museum
Newport News, Virginia

Mystic Seaport, Inc.
G. W. Blunt White Library
Mystic, Connecticut

Nantucket Historical Association
Peter Foulger Museum
Nantucket, Massachusetts

New Bedford Free Public Library
Melville Whaling Room Collection
New Bedford, Massachusetts

New London County Historical Society
New London, Connecticut

Old Dartmouth Historical Society
Whaling Museum
New Bedford, Massachusetts[19]

Peabody Museum of Salem
Salem, Massachusetts

Providence Public Library
Nicholson Whaling Collection
Providence, Rhode Island

San Francisco Maritime Museum
San Francisco, California

Stonington Historical Society
Stonington, Connecticut

Suffolk County Whaling Museum of Sag Harbor, L. I.
Sag Harbor, New York

Whaling Museum Society, Inc.
Cold Spring Harbor, New York

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ception, quite rightly, to the association of the *Apternodus* lower jaw with the upper dentition indicated by the *Xenotherium* skull, although unacquainted with my subsequent description of the skull of *Apternodus*. He might also have strengthened his argument as to the adaptive nature of the skull proportions by reference to *Necrolestes* of the Patagonian Miocene, regarded by Scott as a distant relative of *Chrysochloris* with a marked resemblance to *Notoryctes* in many respects; also to *Proscalops secundus* of the Lower Miocene of South Dakota, a supposed talpid with several points of adaptive resemblance to *Chrysochloris*, etc. Moreover, the a priori probability of *Xenotherium* being an edentate (Zdansky specifies that he uses the term in its larger sense to include Pholidota and Tubulidentata as well as Xenarthra) is much strengthened by the discovery of *Metacheiromys* in the Middle Eocene and *Palaeanodon* in the Lower Eocene of North America, both of them representing a primitive and partly aberrant group of edentates, which I have called Palaeanodonta.[7] It is quite likely that a small surviving relative of these Eocene palaeanodonts might be found in the Lower Oligocene of North America.

After looking over the matter somewhat cursorily, and in consideration of the trend of later evidence cited above, it appears to me that Zdansky and Simpson are almost certainly right in referring *Xenotherium* to the Edentata. I believe that it may be provisionally placed among the Palaeanodonta.

As to the supposed chrysochlorid humerus from the Lower Miocene of South Dakota, which I named *Arctoryctes terrenus*, it continues problematic. It shows the degree of fossorial specialization of the moles, but the fundamental plan of the humerus appears to be distinct, and offers some resemblance to that of Chrysochloridae although decidedly more specialized fossorially. On the basis of this alone one might suppose it to be the humerus of *Apternodus*, but neither this genus nor any allied form is known to occur after the Lower Oligocene. True moles of the peculiar and primitive genus *Proscalops* do occur in the same formation as *Arctoryctes*, and it is possible that this is the humerus of *P. secundus*, which has some curiously chrysochlorid features in the skull. If this be so, *Proscalops*, *P. secundus* at least, can hardly belong to the Talpidae, but must represent a distinct family,—a view for which considerable evidence might be adduced from its skull and teeth, but not enough in my opinion to be at all convincing. *Arctoryctes* is best left for the present as of problematic affinities.—W. D. MATTHEW, *University of California, Berkeley, California.*

NOTES ON THE CALIFORNIA GRAY WHALE

The California gray whale (*Rhachianectes glaucus*) has for some time been reported as on the verge of extinction. The writer was therefore pleased, while in the company of A. Brazier Howell of the United States National Museum during August, 1926, to have an opportunity of photographing and examining a whale of this species, as it was being cut up at the plant of the California Sea Products Company at Trinidad, Humboldt County, California. This animal was captured near shore at Crescent City, California, and was the only whale of this species taken by the company's whaling fleet at this point during six years of operation.

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[7] Matthew, 1918, Bull. Amer. Mus. Nat. Hist., vol. 38, art. 16, pp. 620–657, figs. 39–68.

With these data in mind, it was with no little surprise and pleasure that, on the afternoon of April 17, 1927, the writer saw three California gray whales in San Ignacio Lagoon, on the west coast of central Lower California. At the time he was on board the fishing boat "Nuchum," as a guest of Capt. O. M. Seely, on one of his fishing trips from San Diego down the Mexican coast. Early on the morning of the following day, April 18, the school was found to have been increased to five whales.

At this time the animals were occasionally almost touching the boat; in fact, the huge beasts twice ran into the anchor chain with such violence that we thought the chain had parted. There were two large adult cows, each with a calf, and a large adult bull. It was impossible to estimate the size of the animals with accuracy, but when one of the cows and her calf came up alongside the boat, the writer roughly figured her length to be between 40 and 45 feet, while the calf was between 18 and 22 feet.

During the hour and a half that the writer had the pleasure of watching these whales at close range, some habits were observed that have apparently never before been recorded. The actions of the young whales were extremely interesting. They seemed always to swim at the sides of their mothers, but they would blow just twice to the mother's once, although the mother would rise to the surface at each blow of the young. The actions of the young when sounding were exactly like those of the parent. In the writer's previous experience with whales in deep water, he had observed two types of submersion: one with an easy bend of the body when the animal was descending but a short distance below the surface, and the other with a sharp bend, as though the position of the animal would be vertical as soon as enough distance below the surface had been reached to cover the tail. This position is always assumed when whales leave the surface for a deep sound.

Both of these attitudes were assumed by the whales under observation on April 18, though to the writer's knowledge, from actual measurement, there were but $2\frac{1}{4}$ to 3 fathoms (13 feet 6 inches to 18 feet) of water in the area where the whales were sporting. Unfortunately, the water of the lagoon and along this part of the coast of Lower California at this season was so clouded with minute marine growth that a white object of good dimensions could not be seen three feet below the surface. The whales were therefore not visible beneath the water, although numerous "slicks" indicated the sweeps of their mighty flukes and told the direction in which they were traveling. The writer timed several of the submersions and found the young ones to blow at an interval of 50 seconds as a minimum and $2\frac{1}{2}$ minutes as a maximum. The mother's blowing occurred with every other rise of the young. This short period between breathings would not seem to hold with the adults when they are in deep water, for it is the writer's experience with finback whales that they stay down for periods exceeding twenty minutes.

The attentions of the bull were about equally divided between the two cows and he was three times observed in the act of copulation. The position of the two animals at this time was on their sides, with their bellies together and the flippers on the upper sides exposed; but at no time were the tails or parts of the tails above water. The length of time of cohesion was about 30 seconds. There was no visible struggle by either animal, nor was there any attempt to pursue or escape. The act, so far as it could be observed, consisted in the quiet appearance

above water of the parts of the bodies of the two animals in a parallel position, close together, and then the simultaneous appearance of the side flipper on each, in corresponding position, rolled upward to a vertical position from where the animals were touching. The flippers, when elevated above water, were seen to vibrate as though flipped by the wind. The two animals engaged were within 200 feet of the boat and it was easy to determine that one flipper was left and the other right by their positions.

The presence of small young of equal size with the two cows at the time of mating would suggest that the gray whales have a definite breeding season. With this knowledge, further observations may lead to some conclusion regarding the period of gestation.—LAURENCE M. HUEY, *Natural History Museum, San Diego, California.*

RELATIONSHIP OF PREDATORY MAMMALS AND BIRDS OF PREY TO RODENT LIFE

Much has been written concerning the effect that predatory mammals have on the rise and fall in abundance of various rodent species. Many contend that the persistent warfare on coyotes, bobcats, wolves, weasels, badgers, and other predatory fur-bearing animals is responsible for the excessive abundance, at times, of jack rabbits, field mice, ground squirrels, marmots, and pocket gophers.

While there is no doubt that predatory mammals are a factor in controlling rodents, yet they play but a small part in maintaining the natural balance. Larger factors are involved, and these include seasonal conditions, fecundity of the species, the acts of man in providing abundant food, and the presence of natural and other shelter. On the other hand, rodents the size of ground squirrels, or smaller, are more effectively decreased in numbers by raptorial birds than by predatory mammals. The quantity of rodent remains found in the stomachs and disgorges of individual owls is almost unbelievable.

Over a series of years, the writer has made observations in various sections where certain rodent species were extremely abundant. For several years Grant County, Washington, had been let alone by government hunters, as the residents and landowners believed that coyotes were necessary to keep down jack rabbits; but when rabies appeared there among coyotes and domestic dogs during August, 1921, it was necessary to clean out the coyotes. Hunters were concentrated in this and five adjacent counties, and approximately 1,800 coyotes were taken in the area during the year ending June 30, 1922. At the same time, jack rabbits had increased along with the coyotes in such numbers that organized campaigns were necessary to stop their depredations. During this same period, 61,000 jack rabbits were killed in Grant County and 94,000 in adjacent counties. During the fiscal year following, 2,062 coyotes were taken in the same district. Jack rabbits were practically at an "ebb." Since that time jack rabbits and coyotes have not been troublesome except in a few local spots.

During 1922 and 1923, serious field mouse (*Microtus*) outbreaks occurred in Washington in the Yakima, Wenatchee, and Okanogan valleys. The mice were very numerous in orchards and alfalfa fields. During previous years the growers had introduced house cats in great numbers—it was not unusual to see ten or twelve cats on three or four acres—but in spite of this the mice started damaging trees, so that organized poisoning was necessary. Orchardists distributed 75,986

Gray Whale re-inhabits former species area

V.Yu. Ilyashenko

A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences,
e-mail: valpero53@gmail.com

Historic range of gray whale - *Eschrichtius robustus* Lillijeborg, 1861, is located in the Northern hemisphere. Gilmore (1955) proposed that in the interglacial period, there was a channel of swapping between stocks of gray whales in the North Atlantic and North Pacific. The gray whale is described on subfossil remnants from Sweden. These whales was feeding in the North Atlantic during summertime in the Baltic Sea and off Iceland and wintered off the coast of South-Western Europe or North-West Africa and south of 50 ^{0} NE off the Atlantic coast of North America. The gray whale disappeared in Atlantic as a result of whaling at the beginning of the XVIII century (Mead & Mitchell, 1984; Sokolov, Arseniev, 1994). Gray whales are also distributed in North Pacific coastal waters. During the glacial period when the feeding areas moved South, the whales from West and East coasts could have mixed (Swartz *et al*., 2006). The gray whale stocks were undermined by whaling in the North Pacific in XIX century.

There are two populations of gray whales in the Pacific Ocean which are considered by some researchers as divided into two substocks in each of them.

Some gray whales were reportedly occurring year round at the border of the USA and Canada (Pike, 1954; Wilke, Fiscus, 1961). In the summer here there are about two hundred such individuals known as the Pacific Coast Feeding Aggregation. These whales are not significantly different genetically or demographically from the rest of the Eastern population. It is suggested that panmixia between the main Eastern stock and Southern substock is not presented. Most of the whales of the Southern substock are observed in the feeding on a regular basis, while the other whales do not come every year and only in some areas (Calambokidis *et al*., 2010).

The whales of main Eastern (or Chukotka-California) population feed along the mainland coast of the Eastern Siberian, Chukchi and Bering Seas, and winter mainly along the Baja California, Mexico coast. By examining whaling records Henderson (1984) made a qualitative conclusion that the population did not exceed 15.0 – 20.0 thousand whales before the initiation of commercial exploitation in the middle of the 19-th century. By 1900, the eastern population abundance had declined to 2.8 thousand individuals as a result of large-scale whaling. The population was restored after the ban of whaling in 1938 by the end of 1950-s were 6.0-8.0,

by 1968 had reached 13.5, in 1975 - 17.4, 1980 - 19.8, 1985 - 23.5 1988 - 26.9 thousand individuals. Thereafter, it declined by 1993 to 15.8 and by 1998 again reached the peak of 21.1 thousand individuals. In 2000 the number fell to 16.4 in 2002 - 16.0, and by 2007 had increased again to 19.1 thousand individuals (Laake *et al*., 2009). This indicates that Eastern population abundance reached or even exceeded the initial pre-whaling abundance in 1980-88, 1998 and in 2007. Seemingly, the decennial abundance fluctuations were balanced by carrying capacity around 15.0-22.0 thousand whales. The above is believed to be caused by whale's prey species abundance, temperature regime and other factors (Rugh *et al*., 2005).

Western population contains Okhotsk-Korean and Japanese substocks, which before 1910 jointly numbered about 1.0 -1.5 thousand individuals (Berzin & Vladimirov, 1981). Area of wintering and breeding of the small Japanese substock (knocked by the end of the XIX) were situated in the straits between the islands of Honshu, Kyushu and Shikoku, and summer feeding areas were situated at the North waters of Hokkaido (Andrews, 1914; Mizue, 1951).

The whales of the Okhotsk-Korean substock are fattening primarily in the coastal waters of the Okhotsk Sea, and they were sighted off the coast of Korea and China in winter time. The last whales were hunted at the southern coast of Sakhalin in 1926, at the northern Kuril Islands in 1942 (Mizue, 1951), off the coast of Korea sporadically and not annually the gray whales were hunted until 1966 (Brownell and Chun, 1977). Since that time, most researchers suggested that the western population had gone extinct. Nonetheless until early 1980-s some singles, couples sometimes and three whales once were sighting off the coast of South China Sea, Japanese Sea (near to Vladivostok) and Okhotsk Sea (Kuril Islands, South of Kamchatka) only in 1965, 1968, 1977, 1978 and 1979. In 1970 population estimated as 100-200 individuals (Berzin and Yablokov, 1978). Since the early 1980s the whales has began more common in groups: 1982 - 4 whales, 1983 - 8 (in the South of Kamchatka) and 3 (near Shantar Islands), 1982 - 14 whales and 1985 - group (in the south of Sakhalin Island), 1983 - 20 whales (in the northeast of Sakhalin Island), 1987 - 18 whales (the mainland coast opposite the South of Sakhalin), 1988 - 3 whales (Middle Kuril Islands) (Maminov, Blokhin, 2004; Nambu *et al*., 2010). In the area of the Piltun lagoon (south-west of Sakhalin Island) were observed 34 whales in September and in the sea near to Cape of Kril'on the five whales in January, 1989 (Berzin *et al*., 1990). It was believed that the spatial separation of Bering and Okhotsk Seas and lack of gray whales sightings in the northern part of the Okhotsk Sea and off Western Kamchatka provide enough evidence to consider the Western North Pacific population of gray whales completely independent (Vladimirov, 1994).

In late 1990-s early 2000-s based on systematic data collected by Russia-US Program off NE Sakhalin (Piltun lagoon) population's abundance was re-assessed around 100 whales (Weller *et*

al., 1999). The population was listed as Critically Endangered by the IUCN in 2000. In 2001 additional feeding location located south-east from Piltun nearshore feeding area was discovered and population was estimated to number at least 120 whales (Vladimirov, 2002).After applying the method of photo identification, including the 2002 Russian programs in other areas off Sakhalin and Kamchatka in 2004, the number was evaluated from 130 (Cooke *et al.,* 2008) to 140-150 individuals (Yakovlev and Tyurneva, 2004). From 1995 to 2009 were identified about 180 whales, about 80 of which about were first sighted as calves (Bradford *et al.,* 2010; Tyurneva *et al.,* 2009). Other researchers suggested that animals sighted at feeding grounds do not represent the whole population (Zemsky, Smelova, 2004), it's survival rates overestimated while abundance - underestimated (Vladimirov, 2004; Kanda *et al,* 2010).

In 2005 IWC Scientific Committee noted, that about half of the year Western gray whales spend in waters of East Asia: Japan, Republic of Korea, Korean Democratic People's Republic and Peoples Republic of China and that additional removal of one reproductive female per year is likely to drive population extinct by 2050 (IWC, 2006, pp.10, 67). In 2009 it was noted that from 2005 population slowly increases and numbers about 130 (IWC, 2010, p.1, 17).

The contemporary **migration routes and wintering places** are unknown. Researchers suggest that they may pass from the Okhotsk Sea to the shores of Korea and China, through the Laperouse Strait (Czapski, 1963) and the Tatar Strait (Yablokov and Bogoslovskaya, 1984). Whales found off the coast of Eastern Kamchatka and the Commander Islands, and they can come here from the East coast of Japan along the Kuril Islands and are owned to "Japanese" substock of Western population (Maminov, Blokhin, 2004). It was also supposed that some of the whales may remain in the Sea of Okhotsk for winter in polinyas (Blokhin, 2004; Reeves *et al*., 2008).

Some single gray whales have been noted at the **South-Eastern coast of Kamchatka** in the summer since the early 1980-s. (Blokhin *et al.*, 1985). In following years the number of the gray whale sightings and their numbers have been continually increasing off the central part of Kamchatka. The regular observations were not allowed to suppose whether these are due to the expansion of the Eastern population or as the result of special attention of scientists. It was believed that whales of Eastern population inhabit in the Northern waters off Kamchatka and the Commander Islands, and Western population is in the Southern Kamchatka. Some supposed that the northward extension of the Western North Pacific gray whales population range could have been caused by impacts of oil and gas development at Sakhalin shelf (Vertyankin *et al.,* 2004). **The lacks of isolation between Western and Eastern gray whales** are discussed many times.

Some authors discussed a possibility of western gray whales reaching feeding grounds of Eastern population (Omura, 1974; Vertyankin *et al*., 2004). On the other hand, some authors

suggested considering whales migrating along eastern Japan as transients from Eastern population (Nishiwaki and Kasuya, 1970; Bowen, 1974).

Some authors believed that eastern gray whales migrate northward; leaving Alaska Gulf along south side of Aleutian chain and only around Commander Islands they turn to the North and enter into the Bering Sea (Gilmore, 1955). But this is not confirmed by the direct observations (Berzin, Rovnin, 1966). The researchers are not leave out the scattered migration of Eastern whales in North-West across the Bering Sea and turn around on St. Lawrence Island in the South-West direction along the Koryak coast. A stranded whale was found at the Commander Islands (Medny Island) in 1978, and in 1983 were met 55 gray whales in the northern border of Kamchatka Peninsula (Votrogov, Bogoslovskaya, 1986). They are occurred almost every year at the Bering Island since 1995. Nonetheless, in 2000 a whale, first sighted as a calf off Sakhalin in 1997, was photographed offshore Bering Island. The same whale was later identified off Sakhalin in 2002 (Weller *et al*., 2003). The Institute of Marine Biology of the Far East Branch of Russian Academy of Sciences photocatalog of gray whaled identified off Kamchatka in 2004-2008 holds 78 whales [the catalog is a subject to annual updates]. Roughly half of the animals in this catalog, including females with calves, were at least once sighted off Sakhalin (Tyurneva *et al.,* 2009).

It is believed that the gray whales copulate in the winter areas and for them are characterized with polygamous relationships (Hubbs, 1962). The other researchers believe that the gray whales are likely to gravitate toward a monogamy (Calambokidis *et al.,* 2010). However, there are some records of mating being observed in April and September in Bering and Chukchi Seas (Tomilin, 1957; Clarke *et al.,* 1989). Some behavior with obvious mating features have been recorded in fall off Sakhalin (Vladimirov, 2004) and in the area of two population ranges overlap off Kamchatka (Vertyankin, pers. comm.).

There are some data that the distance from the tip of the rostrum to the base of the pectoral flippers, from the tip of the rostrum to the eye, the maximum width of the pectoral flipper, and the length of the baleen plates were statistically greater in the western gray whales, and that western gray whales had fewer baleen plates and fewer throat grooves (Zimushko, Ivashin, 1980). It was concluded analyzing data of size for more than 30 whales caught in 1925 off the North-East coast of Kamchatka that the young whales have come from the waters of Korea (Risting, 1928). The study the size of whales caught in 1980 in the Bering and Chukchi Seas has led to the same conclusion (Blokhin, 1982). Contrary, D.W. Rice (1998) summarized several studies that found no clear differences in skeletons of gray whales from the Atlantic Ocean and from the western and eastern pacific populations.

Populations of gray whales with respect to markers of mitochondrial and nuclear DNA have revealed that the western and eastern populations have been isolated, and, presumably, over a long time (LeDuc *et al*., 2002; Brownell *et al*., 2009; Burdin *et al*., 2009; Lang *et al*., 2010). Migration of whales of two populations towards to each other or unilateral migration of whales of one population - both hypotheses may be suggested, but none can be ruled out for gray whales migrating and feeding in the Russian seas based on mtDNA haplotypes distribution (Meschersky *et al*., 2011). The study 6 of whales ran aground in Japan showed that there may be gene flow between the two populations, because of the long life and historically large abundance, the western population may still retains considerable amount of genetic diversity after sever, but recent, population reduction (Kanda *et al*., 2010). While previous studies have supported genetic differentiation between eastern and western populations of gray whales, the relatively low level of genetic differences observed at nuclear markers suggests that some dispersal between the two populations could be occurring. The finding of two whales apparently sampled on both sides of the North Pacific, although subject to numerous caveats, provides support for that possibility (Lang, 2010).

The scenario of gray whale recovering its own natural history area has also been proposed (Ilyashenko, 2009), but without sufficient arguments and has been criticized (Brownell *et al*., 2009). In favor of this scenario have been analyses the following information.

As marked above, there is no consensus that the Eastern and Western populations infallibly distinguished on any remarks.

Since the mid XX century individual whales of Western population were observed only in 1965, 1966, 1968, 1977, 1978 and 1979. The groups of whales were seen from the beginning of 1980, when the number of Eastern population exceeded the initial pre-whaling abundance.

It could be assumed that there had been the simultaneous growth of both populations. However, it should be noted that the period of completion of the next growth of the Eastern population in the late 1990-s there was the period of biggest mortality due to the stranded of 274 whales in 1999 and 368 in 2000 at the shores from California to Alaska (Brownell, 2010). The number of the Western population in these years was estimated at about 100 individuals, while in 1999 on Sakhalin were 19 skinny whales in 2000 - 30, 2001 - 21, further decreased the number of observing of whales. This phenomenon is recorded for the Eastern population (Burdin *et al*., 2004). It means that the negative processes were synchronous in the Eastern and Western populations with different phases of population dynamics.

Exactly during the years previous to the peaks of the Eastern population in 1998 and 2007 were recorded, stranded or accidentally bycatched in nets the individual whales in 1996 near to

Hainan Island in Southern China (Zhu, 1998), 1995, 1996, 2005 and 2007. Hokkaido and Honsu. And only one of them were found on the West coast of Japan (Kanda *et al*., 2010).

It is noted that the whales arrive to the coast of Sakhalin Island in late of May, usually from the North, and in November again shift to the North (Blokhin, Burdin, 2001). The similar migration patterns are observed for the Eastern Kamchatka (Vertyankin, pers. Comm.).

It is suggested that the daily consumption of food by the adult gray whale is about 1.0 - 1.2 thousand kilos (Zimusko, Lenskaya, 1970). The whales are spotty distributed in areas of summer feeding, and the changing of the feeding areas takes place not only for the years but also during the season (Bogoslovskaya *et al*., 1981). Photo identification confirmed that a significant number of whales move from one station to another. For example, there were identified 77 of Sakhalin whales in 2009, and taking into account the photo identification data from Kamchatka the total amount are 117 individuals (Vladimirov *et al*., 2010). In recent years, each year photocatalogues replenished with new adult whales, and some of whales do not meet the 5 - 7 years (Tyurneva *et al*., 2009).

There is reason to believe that even the gray whale is considered as homing animal to the places of feeding and breeding, however, at the same the gray whale is a nomadic animal. In the 1980-s the gray whales of Eastern population have rarely came into the East Siberian Sea, and in 1990 they have becoming more common in Wrangel Island, where in some areas were met up to 7 individuals per 10 km (Kochnev, 2001). At the same time the whales have been met in the Eastern parts of the Beaufort Sea. The unique example of long-distance migrations was recorded meetings of a gray whale off the coast of Israel and Spain in May 2010 within the area of extinct Atlantic population (http://www.epochtimes.ru/content/view/37236/5/). The thirteen years old male was tagged in October 2010 with satellite transmitter near to Sakhalin have reached off Oregon US state coast in February 2011.

It is clear that in hundred years after the destructive whaling and as a result the measures of protection, the gray whale began to restore its habitat. The satellite telemetry is a priority and will promote measures for its recovery at the national level in the range states and international cooperation.

Protection measures. The above evidence suggests that the western part of the species range in the Pacific is being re-inhabited not by (or *not only by*) potentially survived whales of the relict Western population, but by Eastern animals re-inhabiting historic parts of the species range. At the same time, some individuals have continued or just started to use the historical winter areas to the South of the Sea of Okhotsk. Taking into account intensive exploitation of the continental shelf: fisheries and mariculture in Japan, Korea and China, oil and gas development in the Okhotsk Sea, it is critical to identify key habitats of the Western North Pacific population

of gray whales. Implementation of the Western Gray Whale Rangewide Conservation Plan recommended by IUCN (Western Gray Range Wide Workshop, September 2008, Tokyo) is needed, including consideration of Canada, USA and Mexico as range states.

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Report of the Scientific Committee

The meeting was held at the Lotte Hotel, Ulsan, Korea, from 30 May-10 June 2005 and was chaired by Doug DeMaster. A list of participants is given as Annex A.

1. INTRODUCTORY ITEMS

1.1 Chair's welcome and opening remarks

DeMaster welcomed the participants to the meeting. He thanked the Government of Korea, the City of Ulsan and the local organising Committee for hosting the meeting and for providing the excellent facilities. He also extended his gratitude to the Korean organisers for all their help and for making all participants very welcome in Ulsan.

1.2 Appointment of rapporteurs

Donovan was appointed rapporteur with assistance from various members of the Committee as appropriate. Chairs of sub-committees and Working Groups appointed rapporteurs for their individual meetings.

1.3 Meeting procedures and time schedule

Grandy summarised the meeting arrangements and information for participants. The Committee agreed to follow the work schedule prepared by the Chair.

1.4 Establishment of sub-committees and Working Groups

Three meetings preceded the start of the Scientific Committee. The AWMP Standing Working Group (SWG) met 28-29 May, in which agenda items covered were incorporated into the AWMP main agenda and report (Annex E). Two-day Workshops on the Use of Market Sampling to Estimate Bycatch of Large Whales (27-28 May) and High Latitude Sea Ice Environments (28-29 May) were also held and the reports of these Workshops are given as SC/57/Rep4 and SC/57/Rep5 respectively.

A number of sub-committees and Working Groups were established. Their reports were either made annexes (see below) or subsumed into this report.

Annex D – Sub-Committee on the Revised Management Procedure (RMP);
Annex E – Standing Working Group on an Aboriginal Whaling Management Procedure (AWMP);
Annex F – Sub-Committee on Bowhead, Right and Gray Whales (BRG);
Annex G – Sub-Committee on In-Depth Assessments (IA);
Annex H – Sub-Committee on Other Southern Hemisphere Whale Stocks (SH);
Annex I – Working Group on Stock Definition (SD);
Annex J – Working Group on Estimation of Bycatch and other Human-induced Mortality (BC);
Annex K – Standing Working Group on Environmental Concerns (E);
Annex L – Standing Sub-Committee on Small Cetaceans (SM);
Annex M – Sub-Committee on Whalewatching (WW);
Annex N – Working Group on DNA (DNA); and
Annex O – Working Group on Scientific Permits (SP).

1.5 Computing arrangements

Allison outlined the computing and printing facilities available for delegate use. Requests for Secretariat computing would be addressed according to priorities set by the Convenors.

2. ADOPTION OF AGENDA

The adopted Agenda is given as Annex B1. Statements on the Agenda are given as Annex S. The Agenda took into account the priority items agreed last year and approved by the Commission (IWC, 2005c, pp.52-4). Annex B2 links the Committee's Agenda with that of the Commission.

3. REVIEW OF AVAILABLE DATA, DOCUMENTS AND REPORTS

3.1 Documents submitted

Donovan reported that the new pre-registration procedure had again been successful. With such a large number of documents, pre-specifying papers had reduced the amount of photocopying and unnecessary paper dramatically.

The list of documents is given as Annex C.

3.2 National progress reports on research

Progress reports presented at the 2001-05 meetings are accessible on the IWC website. Reports from previous years will also become available in this format in future.

The Committee reaffirmed its view of the importance of national progress reports and **recommends** that the Commission continues to urge member nations to submit them following the approved guidelines (IWC, 1998b). Non-member nations wishing to submit progress reports are welcome to do so.

A summary of the information included in the reports presented this year is given as Annex Q; the modified report template, taking account of the updates made in 2004, is available on the IWC website (*www.iwcoffice.org/commission/sci_com/scprogress*). The Committee **agrees** that the bycatch reporting tables for small cetaceans should be brought into line with those for large whales with respect to reporting fishing gear types (see Item 13.4).

3.3 Data collection, storage and manipulation

3.3.1 Catch data and other statistical material

Table 1 lists data received by the Secretariat since the 2004 meeting.

3.3.2 Progress of data coding projects and computing tasks

Allison reported that the first phase of work to encode the revised Soviet individual catch data from the Southern Hemisphere had been completed and the data are in the process of being validated. The validation stage is particularly important for these data, as the source records

Table 1
List of data and programs received by the IWC Secretariat since the 2004 meeting.

Date	From	IWC ref.	Details
Catch data			
5/4/05	Norway: N. Øien	E56	Individual common minke catch records from the Norwegian 2004 commercial catch. Access restricted (specified 14/11/00).
30/5/05	Japan: J. Morishita	D175	Individual catch records from the 2004 Japanese Whale Research Programme under special permit in the North Pacific (JARPN II) and the 2004/05 Japanese whale research programme under special permit in the Antarctic (JARPA).
30/5/05	Russia: R.G. Borodin	D176	Individual catch records from Russian gray and bowhead whale hunt 2004.
6/6/05	St. Vincent and the Grenadines: S. Punnett		Details of the humpback whale taken by St. Vincent and the Grenadines, 2005.
28/9/04	T. Kasuya	CD46	Data in support of Kondo and Kasuya (2002) on revised Japanese coastal catch statistics.
1/2/05	Korea: H. Sohn	E51	Korean data for the North Pacific common minke IA: (i) data for common minke bycatch or stranded 1996-2004; (ii) revised individual catch data 1980-86.
16/3/05	Greenland: L. Witting	E54	Greenland individual common minke and fin catch data, 1988-2004 (2000-04, incomplete) including skin sample data.
30/5/05	J. Brandon	E58	Individual Russian aboriginal gray whale catch records coded from the whale passports 1980-91 (supplied to Brandon by R. Brownell).
Sightings data			
18/3/05	P. Ensor	CD48(E)	2004/05 Southern Ocean Whale and Ecosystem Research Programme (SOWER) cruise data including blue whale data (sightings, effort, weather, ice edge, inter-stratum and way-pt.).
5/4/05	L. Burt	CD50	Database and Estimation of Software System (DESS) version 3.5.
4/1/05	Japan: T. Miyashita	E49	Japanese North Pacific common minke whale sighting data 1994, 1999-2003 for use in the forthcoming North Pacific common minke IA.
1/2/05	Korea: H. Sohn	E51	Korean sightings data 1999-2004 for North Pacific common minke IA.
Other data			
7/1/05	Japan: Y. Fujise	E57	Revised age data for JARPA Antarctic minke earplug samples 1987/88-2000/01, to replaces data sent 11/5/04.
21/1/05, 10/2/05	C.S. Baker	E50, E53	Genetic data for the North Pacific common minke IA. Revised data received 10/2/05.
7/2/05	Iceland: A. Daníelsdóttir	E52	Overview of North Atlantic fin whale genetic samples examined at the Marine Research Institute, Iceland.
30/5/05	D. Palka	CD51-52	Simulation data sets 2004 (SC01-SC16) and 2005 (SC17-SC32).

are handwritten and many are of poor quality. The detailed biological data are not being coded in this first phase of the coding work.

The small technical workshop on the revised Soviet Southern Hemisphere catch data (consisting of Allison, Brownell, Donovan, Mikhalev and Tormosov plus an interpreter, see IWC, 2004b, p.2 and p.55) to consider how best to fill the gaps in the data, is expected to take place in September or October 2005. The Steering Group (Annex P(1)) appointed to assist with this work was retained and augmented with Findlay and Clapham with respect to Southern Hemisphere humpback whales (*Megaptera novaeangliae*) (see Item 10.3.1.2).

Data received from the 2003 season has been entered into the individual catch database and work has begun to enter the Faroese data from 1902 onwards supplied by Dorete Bloch.

Allison reported good progress on the summary catch database (begun last year), which aims to be a complete listing of all 20th century whaling catch data and to supplement the data held in the individual catch database. The summary database is now substantially complete and has been used to extract the revised catch series for use in the in-depth assessment of Southern Hemisphere humpback whales (see Item 10.3.1.2). Review of the database by members of the Scientific Committee would be appreciated; specifically, assistance would be welcomed in identifying any errors or additional sources of catch data.

Allison has worked with Bloch on catch data in the Northeast Atlantic with a view to obtaining a common agreed catch series with the North Atlantic Marine Mammal Commission (NAMMCO) (see also Item 6.2.2).

Information on catches of western North Pacific Bryde's whales (*Balaenoptera edeni*) has been collated using information supplied by Ohsumi since the North Pacific Bryde's whale workshop in March (see Annex D, item 6). In addition the information was being used to identify Bryde's whales in the individual database which were not distinguished from sei whales (*B. borealis*).

Data from the 2003/04 SOWER sightings cruises have been validated and incorporated into the DESS database.

4. CO-OPERATION WITH OTHER ORGANISATIONS

4.1 Convention on the Conservation of Migratory Species (CMS)

4.1.1 Scientific Council

The 2005 meeting of the Scientific Council had not occurred during the IWC intersessional period. Perrin will attend as the IWC observer at the series of meetings in November 2005.

4.1.2 Agreement on Small Cetaceans of the Baltic and North Sea (ASCOBANS)

The report of the IWC observer at the 12th Meeting of the ASCOBANS Advisory Committee (AC) held in Brest, France is given as IWC/57/5F. Preparation for SCANS II was discussed and surveys will be conducted from 27 June-29 July 2005. This will cover the entire North Sea, Celtic Shelf and Gulf of Biscay and is intended to extend to offshore European waters during 2007. New data on population sizes, distribution and structures were reviewed and this included results of sighting schemes, genetic studies and photo-identification.

The IWC POLLUTION 2000+ programme was reviewed, and the AC looks forward to the final report of Phase I in 2006. The AC noted the value of such co-operation between the IWC and ASCOBANS and plans to

contact the IWC to re-establish the IWC-ASCOBANS Working Group on Harbour Porpoises (*Phocoena phocoena*). The AC intends to review its earlier management advice that a bycatch rate of 1.7% is not sustainable, and that 1% should be an alert to consider management measures (and see Item 13.2.3). Drafting of a Recovery Plan for harbour porpoises in the North Sea was continued, focusing on recommending specific management measures in specific areas where high bycatch rates are known to occur.

Implementation of the ASCOBANS Baltic Harbour Porpoise Recovery Plan, The Jastarnia Plan, is progressing and a related Working Group consisting of both environmental and fisheries stakeholders met in Bonn, Germany during March. Two recovery recommendations were extensively discussed; analyses of stock affinities in the transition zone and the development and application of acoustic monitoring techniques. Other relevant items discussed were bycatch reduction, marine protected areas (MPAs) and public awareness. The full report of this meeting is available on the ASCOBANS website (*www.ascobans.org/index0504.html*).

In light of the EU-Council Regulations, it was agreed that managing observer schemes on vessels under 12m should be investigated.

Further topics of interest to the IWC Scientific Committee included:

(1) disturbance to small cetaceans due to seismic surveys;
(2) approaches and progress in reducing/eliminating the adverse effects of military activity; and
(3) comprehensive assessment of bottlenose dolphins (*Tursiops truncatus*) in European waters, including abundance estimates, distribution, ranging patterns, population social structure and gene flow and design of an integrated monitoring protocol to assess conservation status.

The full report of the meeting is available on the ASCOBANS website at *www.ascobans.org/index0502.html*.

The Committee thanked Reijnders for attending the meeting on its behalf and **agrees** that he or Donovan should attend the next AC.

4.1.3 Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS)

The report of the IWC observer at ACCOBAMS meetings is given in IWC/57/5I. At the 2nd meeting of the parties to ACCOBAMS held in Majorca, Spain from 9-12 December, a number of resolutions were adopted concerning:

(1) a major abundance survey in the region;
(2) improved compliance with rules concerning pelagic gillnets;
(3) interaction between cetaceans and fisheries;
(4) guidelines for the use of acoustic deterrent devices;
(5) exchange of tissue samples;
(6) guidelines on tissue banks;
(7) photo-identification studies;
(8) guidelines on research and disturbance;
(9) a Conservation Plan for common dolphins (*Delphinus delphis*);
(10) the impact of anthropogenic noise;
(11) facilitation of research (e.g. by providing permits);
(12) the value of protected areas;
(13) effects of prey depletion; and
(14) release of cetaceans into the wild.

The full report of the meeting is available on the ACCOBAMS website (*www.accobams.org*). The Committee thanked Donovan for attending on its behalf.

A Workshop on obtaining baseline cetacean abundance information for the ACCOBAMS area was held in Valsain, Spain from 17-19 December 2004. Cañadas, Fortuna and Donovan acted as the Steering Group. Previously, the ACCOBAMS Scientific Committee agreed that obtaining such data was the highest priority for research in the area and without it, it will be impossible to *inter alia* determine whether ACCOBAMS is meeting its conservation objectives. The first stage of the proposed project is obtaining baseline population estimates (stock structure and abundance) and distributional information in the ACCOBAMS area. The second stage will be to develop a long-term monitoring framework, both basin-wide and in identified local key areas. The workshop, chaired by Donovan, identified areas, species, potential methods and logistical requirements for a major acoustic and visual survey of the region and outlined a process for taking the project to completion. The full workshop report is available from ACCOBAMS and Donovan.

The 3rd meeting of the Scientific Committee of ACCOBAMS was held in Cairo, Egypt from 15-17 May. Donovan had been unable to attend and thanked Reeves for acting as an informal observer. Topics of interest to the IWC Scientific Committee included:

(1) a major abundance survey in the area;
(2) incidental catches in driftnets;
(3) interactions between dolphins and fisheries;
(4) anthropogenic noise;
(5) fin whales (*B. physalus*) (Workshop proposed for November 2005);
(6) vessel collisions (Workshop proposed for November 2005);
(7) conservation plans, particularly for common dolphins, bottlenose dolphins and harbour porpoises in the Mediterranean Sea and all Black Sea cetaceans;
(8) protected areas;
(9) web-based whalewatching database;
(10) live strandings;
(11) prey depletion;
(12) IUCN Red List status of cetaceans in the Agreement Area; and
(13) proposed amendments to CMS appendices.

The Committee thanked Donovan for his work with ACCOBAMS and **agrees** that he should represent the IWC at the next ACCOBAMS meeting.

4.2 International Council for the Exploration of the Sea (ICES)

The report of the IWC observer documenting the 2004 activities of ICES is given as IWC/57/5A. During the year, the ICES Working Group on Marine Mammal Ecology (WGMME) met and discussed various issues, however these were not relevant to discussions of the IWC Scientific Committee.

During the Annual Science Conference held in Vigo, Spain (September 2004) several theme sessions incorporated discussions on marine mammals:

(1) life history, dynamics and exploitation of living marine resources;

(2) recent advances in the oceanography and biology of the Iberian waters and adjacent shelf seas; and
(3) modelling marine ecosystems and their exploitation.

Further details under these topics are given in the observer's report. The Committee thanked Haug for the report and **agrees** that he should represent the IWC at the next ICES meeting.

4.3 Inter-American Tropical Tuna Commission (IATTC)

The 2005 meeting of the Scientific Council had not occurred during the IWC intersessional period. The Secretariat will ask Reilly if he will attend as the IWC observer at their next meeting.

4.4 International Commission for the Conservation of Atlantic Tunas (ICCAT)

The report of the IWC observer at the 14th extraordinary meeting of ICCAT held in New Orleans, USA is given as IWC/57/5E. Many topics were discussed and numerous recommendations made, although none directly relevant to cetaceans. The Committee thanked Centenera for attending on its behalf and **agrees** that Kell should represent the IWC at the next ICCAT meeting.

4.5 Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)

The report of the IWC observer at the 23rd meeting of the CCAMLR Scientific Committee held in Hobart, Australia, October 2004 is given as IWC/57/5B. Results from the 2004 IWC meeting relevant to CCAMLR were presented by Kock, including a request from the IWC Scientific Committee for CCAMLR to participate in the IWC Workshop on Sea Ice, which was held in Ulsan, 28-29 May and discussion of whale catches within the CCAMLR Convention area. The main items considered at the CCAMLR meeting of relevance to the IWC included status and trends of Antarctic fish stocks and krill, incidental mortality of marine mammals, ecosystem monitoring and management, and management under conditions of uncertainty.

CCAMLR will be participating in the International Polar Year (IPY) 2007/08 and this will include contributions to the Census of Marine Life (CoML). Countries conducting activities during the IPY, either as part of their national activities or specifically for the IPY include Australia, Argentina, Brazil, Chile, France, Germany, India, Italy, Japan, Republic of Korea, Russia, New Zealand, Norway, South Africa, Sweden, UK and USA. The CCAMLR Scientific Committee agreed that a synoptic survey in the South Atlantic region would be the most appropriate activity for CCAMLR in the IPY. Although focusing on krill, the survey would collect ancillary and biological data, including observations of marine mammals. The Scientific Committee of CCAMLR encouraged the participation of the IWC in both the planning and implementation of the cruise.

An intersessional Steering Group was established under Seigel (Germany) to progress the proposed IPY synoptic survey. The Antarctic CoML is likely to consist of a series of meridional transects around the Antarctic using vessels from a number of CCAMLR members. The Working Group on Ecosystem Monitoring and Management (WG-EMM) will provide standard protocols for measurements, which will include scientific acoustics and ship-based surveys for mammals.

The Working Group on Fish Stock Assessment (WG-FSA) highlighted the records in CCAMLR of encounters of killer whales (*Orcinus orca*) and sperm whales (*Physeter macrocephalus*) with the Patagonian and Antarctic toothfish long-line fisheries. One incidental whale mortality was observed in the 2003/04 season. Its identity is yet to be confirmed, but it is tentatively thought to have been an Antarctic minke whale (*B. bonaerensis*). It was found entangled in the mainline of the longliner *Piscis* in CCAMLR sub-area 88.1.

Discussion of the IWC-CCAMLR collaboration appears under Item 12.3.2 and in Annex K, item 8.2. Reports of the CCAMLR Scientific Committee and its Working Groups are available through the CCAMLR secretariat and on its website. Edith Fanta (Brazil) was elected as Chair of the CCAMLR Scientific Committee for the next two years. The Committee thanked Kock for attending on its behalf and **agrees** that he should represent the IWC at the next meeting of the CCAMLR Scientific Committee.

Reilly or Thiele will attend WG-EMM meetings on behalf of the Committee.

4.6 Southern Ocean Global Ecosystem Dynamics (SO-GLOBEC)

Details of SO-GLOBEC activities and collaboration with the IWC are given under Item 12.3.2 and in Annex K, item 8.2. The Committee thanked Thiele for promoting and coordinating the collaboration and **agrees** that she should continue in this work, in conjunction with the Southern Ocean Collaboration (SOC) Steering Group (Annex P(21)).

4.7 North Atlantic Marine Mammal Commission (NAMMCO)

The report of the IWC observer at the 12th meeting of the NAMMCO Scientific Committee held in Viðareiði, Faroe Islands, October 2004 is given as IWC/57/5G. The full report of the meeting will shortly be published in the NAMMCO annual report and is presently available on the NAMMCO website (*www.nammco.no*).

Preliminary results from the Icelandic research programme on common minke whale diet, and a new multi-species model incorporating common minke whales, harp seals and three fish species in the Barents Sea were reviewed. The Committee noted the lower than expected activity in the area of multi-species modelling and emphasised that progress will not be made unless significant additional resources are dedicated to it.

Advice for several cetacean species in West Greenlandic waters was requested from the Committee. Without a new abundance estimate for the area, the Committee was unable to comment on the sustainable yield levels for humpback whales. The Committee also could not review abundance, stock structure, migration and feeding ecology of killer whales in this area without additional information. The Committee welcomed the introduction of quotas for narwhals (*Monodon monoceros*) and white whales (*Delphinapterus leucas*) in West Greenlandic waters, but noted that the quotas still exceed the total removals recommended. The Committee reiterated its view that delaying the implementation of catch reductions will delay stock recovery and will lower available catches in the medium term.

The Committee evaluated the data collection and estimation procedures used in the Icelandic bycatch monitoring programme, and made several recommendations to improve the accuracy of bycatch estimation by Icelandic fisheries. The Committee outlined its priorities for 2005/06 and those relevant to IWC discussions can be summarised as:

(1) assessment of North Atlantic fin whales, with refinement of assessments for the EGI area, and development of assessment models for Norwegian stocks;
(2) assessment of narwhal and white whale stocks, particularly for West Greenland, in co-operation with the Scientific Working Group of the Canada/Greenland Joint Commission; and
(3) planning for the North Atlantic Sightings Survey in 2007.

The Committee thanked Walløe for attending on its behalf and **agrees** that he should represent the IWC at the next NAMMCO Scientific Committee meeting.

4.8 International Union for the Conservation of Nature (IUCN)

The IUCN Independent Scientific Review Panel on Impacts of Sakhalin II Phase 2 on Western North Pacific Gray Whales and Related Biodiversity delivered its report in February 2005, which is available online[1]. In accordance with IWC Resolution 2004-1 on the western gray whale (*Eschrichtius robustus*), Donovan participated on the panel. Recommendations from the panel are discussed under Item 10.4.5. A follow-up workshop was held in May 2005 to provide an opportunity for the Sakhalin Energy Investment Company, the potential lending banks and other stakeholders to discuss issues arising from the panel report. The workshop report is available at the IUCN website[2].

The IUCN Cetacean Specialist Group collaborated with the *baiji.org* Foundation, the Institute of Hydrobiology (Wuhan) and the Chinese Ministry of Agriculture to hold a Workshop on Conservation of the Baiji and Yangtze Finless Porpoise in late 2004. The full report is not yet ready, but a summary report is available online[3].

The IUCN Red List of Threatened Species (*www.redlist.org*) continues to be updated in the light of new information and changes in status and several cetacean entries are currently under review.

The Committee thanked Cooke for his report. No meetings of IUCN are expected in the intersessional period.

4.9 Food and Agriculture Organisation (FAO)

The 26th Session of the Commission on Fisheries (COFI) held in Rome, Italy, March 2005 marked a decade of implementation of the FAO Code of Conduct for Responsible Fisheries. The report of the IWC observer at this meeting is given as IWC/57/5C.

COFI expressed its condolences to the countries and families of the victims of the Tsunami. Many participants reconfirmed their support for previous requests to investigate the interaction between marine mammals and fisheries. However, others were concerned that the foremost aim of the IWC is the conservation and management of whales, and they expressed their concern that discussions of whaling in COFI might detract from other more important fisheries-related issues.

The Committee thanked Mae for attending on its behalf. No meetings are expected in the intersessional period.

The report of the IWC observer at the 21st session of the Co-ordinating Working Party on Fishery Statistics (CWP) in Copenhagen is given as IWC/57/5M. Issues of relevance to the Scientific Committee included agreement by the CWP on revised vessel classifications which are included in the 2005 International Standard Statistical Classification of Fishing Vessels (ISSCFV). The CWP received the report of the 2nd session of the FIRMS (Fisheries Resources Monitoring System) Steering Committee which preceded the CWP meeting, and included an invitation to the IWC to join FIRMS. FIRMS is a global information system on fisheries aimed at providing timely, reliable strategic information on fishery status and trends on a global scale. The FIRMS system includes the species, fishing technology, resources, fisheries, vessels, and management systems domains of information, which will be of use to the Scientific Committee in its work in estimating levels of bycatch. This matter is discussed further under Item 19.2 and in SC/57/Rep4.

4.10 North Pacific Marine Science Organisation (PICES)

The report of the IWC observer at the 13th annual meeting of PICES held in Hawaii, USA, October 2004 is given as IWC/57/5H. A one-day workshop held by the Marine Birds and Mammals Advisory Panel (MBM-AP) reviewed the region-specific trend of diet and feeding habits of marine birds and mammals, including cetaceans in the North Pacific and the following points were noted:

(1) diet composition of top predators varies between west and east regions of the North Pacific;
(2) diet composition of top predators has switched dramatically at decadal levels, probably related to regime shifts, El Niño and other climate factors; and
(3) marine birds and mammals may be useful as ecosystem indicators.

A workshop entitled 'Factors Affecting Distribution and Foraging Ecology of Top Predators in the Okhotsk Sea' will be held at the next PICES annual meeting. Following a review of MBM-AP activities over its five-year existence, it was agreed that they should in future focus on new activities such as:

(1) updating estimates of prey consumption for top predators;
(2) development of climate and ecosystem indicators;
(3) development of an understanding of the biogeography of top predators in the North Pacific; and
(4) improving technology for oceanography using top predators as sampling devices.

The Committee thanked Kato for attending the meeting on its behalf and **agrees** that he should represent the IWC at the next PICES meeting.

4.11 Eastern Caribbean Cetacean Commission (ECCO)

The work programme of ECCO for the year 2004/05 was intended to focus on Grenada and Carriacou. The annual meeting to elaborate on these plans/programmes was

[1] *http://iucn.org/themes/business/isrp/index.htm.*
[2] *http://www.iucn.org/themes/business/ISRP_Followup/ISRP_Followup_Workshop%20Report_Final_6June05.pdf.*
[3] *http://www.baiji.org/workshop_2004/report.html.*

scheduled for October of 2004. Due to the passage of hurricane Ivan and its devastating onslaught on Grenada, all planned activities and meetings had to be put on hold. A report on further developments will be ready for presentation to the next Scientific Committee meeting in 2006. The Committee thanked Lawrence for this information and **agrees** that he should represent the IWC at the next ECCO meeting.

5. REVISED MANAGEMENT PROCEDURE (RMP) – GENERAL ISSUES (SEE ANNEX D)

5.1 Finalise the guidelines and requirements for implementing the RMP

5.1.1 Develop the thresholds for defining 'acceptable' and 'borderline' performance for classifying the performance of RMP variants for Implementation Simulation Trials

Last year, the Committee recommended and the Commission endorsed the 'Requirements and Guidelines', for *Implementation*s, noting that further work was needed to determine the thresholds that define 'acceptable', 'borderline' and 'unacceptable' conservation performance for *Implementation Simulation Trials* (*ISTs*). SC/57/RMP1 presented calculations for these thresholds based on suggestions made last year. However, the author pointed out that applying them would lead to the 0.6 tuning of the *Catch Limit Algorithm* (*CLA*) performing 'unacceptably' when the initial depletion is 0.6.

The Committee concurred and **agrees** that the new approach described in Annex D (item 5.1.1) should provide the necessary threshold values when evaluating the conservation performance of each RMP variant for each *IST*. It also **agrees** that the approach should be evaluated intersessionally before final adoption by the Committee. The analyses required are detailed in Annex D (item 5.1.1) and the criteria evaluation will be conducted by Allison and Punt, under the guidance of an intersessional email group (see Annex P(31)).

5.1.2 Develop a list of agreed stock structure archetypes

The Committee **agrees** that the list of agreed stock structure archetypes should be developed as a number of case studies (e.g. for North Pacific Bryde's whales, North Atlantic fin whales) have been completed, thereby benefiting from the experience gained during the process.

5.2 Further develop the 'simple model filter'

The Committee had welcomed the development of the 'simple model filter' (Punt, 2003) as a computationally economical approximation of the RMP as an aid to developing *ISTs*.

The 'simple model filter' had been extended by Punt to be able to incorporate tagging data in parameter estimation. The result of applying it to western North Pacific Bryde's whales is discussed under Item 6.1.2.1. The Committee thanked Punt for this work which will prove extremely valuable in its future work.

5.3 Finalise the issue of spatio-temporal considerations

At previous meetings, options have been discussed for handling cases where whaling on migrating populations (e.g. North Pacific common minke whales) can cause difficulties in defining *Small Areas*. The Committee **agrees** a modification to Annotation 2 to the RMP (Annex D, Appendix 2) which provides for the possibility of some temporal and/or spatial restriction on whaling within a *Small Area* as part of an RMP *Implementation*. This is to make allowance for the possibility that *Small Areas* are specified in which whaling could take animals from stocks in proportions different to those present in such *Small Areas*. In such cases, simulations to test for the conservation performance of such an approach must be conducted so that whaling within a *Small Area* is assumed to occur in such a way as to maximise the risk with respect to depletion, while at the same time remaining consistent with operating procedures for the whaling activities proposed by the nation or nations concerned.

5.4 Finalise the issue of the CATCHLIMIT program for running it in trials situation

Given improvements in computing speed, the Committee **agrees** it is no longer necessary to adjust the convergence criteria for the CATCHLIMIT program to make it feasible for use in simulation trials; that would only be required if it turns out to be necessary when the program is actually used in specific trials. Hence, this issue does not need to be included on next year's agenda.

5.5 Proposal for revision of the RMP

Last year, the Committee was formally notified (IWC, 2005j, p.10) that for common minke whales in the North Atlantic, Norway intends to propose a change to the *CLA* of the current RMP. SC/57/RMP3 presented a progress report on their work to complete the development process. The Committee noted the new information. Comments by Committee members are reported in Annex D, item 5.5.

5.6 Other

SC/57/O21 (see Annex G, item 3.3.3) presented an example of an analysis showing that the dynamics of populations for multi-species models could, under certain scenarios, differ appreciably from those under conventional single species models. The authors suggested that this might have implications for the RMP, and that it might at some stage be informative to investigate the performance of the RMP using such models as operating models.

The Committee noted that the RMP trial structure had included scenarios such as changing carrying capacity that *inter alia* can be considered to reflect multi-species behaviour. It therefore **agrees** that there is no need to conduct additional trials to confirm that the conservation performance of the RMP was satisfactory. The current difficulties of being able to develop multi-species models with adequate predictive capabilities are well known (e.g. IWC, 2005b, pp.413-26). Only if such capabilities are realised, should attempts to refine the RMP to take explicit account of multi-species effects be considered. Naturally any such refinements would need to demonstrate performance superior to that of the existing RMP under an appropriate set of trials.

5.7 Work plan

As noted under Item 5.1.1, the Committee **agrees** that the intersessional evaluation of criteria developed to determine whether the conservation performance of an RMP variant is 'acceptable', 'borderline' or 'unacceptable' will be a priority item for next year.

6. RMP – PREPARATIONS FOR *IMPLEMENTATION* (SEE ANNEX D)

6.1 Western North Pacific Bryde's whales

6.1.1 Report from the intersessional Workshop on the pre-Implementation assessment *for western North Pacific Bryde's whales*

The Committee considered the report of the intersessional Workshop (SC/57/Rep3), chaired by Donovan. The Workshop's objective was to work towards completion of the *pre-Implementation assessment* for western North Pacific Bryde's whales. It had considered the aspects required under the 'Requirements and Guidelines' for *Implementations* (IWC, 2005k, p.80) to complete a *pre-Implementation assessment*, specifically:

(1) abundance estimates;
(2) catches;
(3) stock structure hypotheses;
(4) dispersal rates; and
(5) data for conditioning.

The Workshop had examined existing catch data and developed preliminary catch series for Japan (coastal and Bonin Islands), the USSR, the Philippines and China, Taiwan. It had identified several data sources as the basis for alternative catch series for simulation trials, and additional work needed to finalise the catch series for use in trials. Based on the stock hypotheses developed by the IWC (1999, p.116); together with additional genetic and non-genetic information, it identified five alternative stock hypotheses. Those were considered to be sufficiently inclusive that collection of new data during the *Implementation* process is unlikely to suggest a new stock hypothesis. The Workshop had agreed that the various stock hypotheses were not equally plausible, but did not assign plausibility weights to these hypotheses as this is scheduled for the 'First Annual Meeting' after it has been agreed that the *Implementation* process should begin. It identified several tasks to assist in assigning plausibility weights to trials.

Abundance data were reviewed and it had been agreed that the set of blocks surveyed in August-September would serve as the basis for using the early, as well as the most recent, survey data when estimating abundance and additional variance. Specifications were developed for calculations for computing the abundance estimates to be used for conditioning (and their variance-covariance matrix). Areas to be excluded when calculating abundance estimates for the offshore form of Bryde's whales to avoid including the small coastal form (or forms) were also identified.

The Workshop had identified information needed to estimate the rates of dispersal (defined as permanent transfer of individuals between breeding stocks) and mixing (temporary movement of animals spatially) and had established a small group to estimate mixing rates in sub-area 1. It had reviewed the specifications for the biological and technological parameters selected by the Scientific Committee in 1999 (IWC, 2000b, pp.10-11) and endorsed their use in future *ISTs*. It had also reviewed information pertinent to the *Maximum Sustainable Yield Rate* (*MSYR*) and identified work that might restrict the range of plausible values.

After reviewing the criteria for deciding whether the *pre-Implementation* process was complete and an *Implementation* could begin (IWC, 2005e, pp.85-6), the Workshop had agreed that provided its recommendations were followed, the *pre-Implementation* process could be considered as completed.

The Committee accepted the Workshop report, and thanked the participants for substantially advancing the *pre-Implementation assessment* for western North Pacific Bryde's whales.

6.1.2 Preparation for Implementation

6.1.2.1 PROGRESS ON *PRE-IMPLEMENTATION*

The catch series for use in *IST*s was progressed based on the recommendations of the intersessional Workshop (SC/57/Rep3). The catches reported as sei/Bryde's whales were split to species, and several alternative catch series were identified. A few remaining minor issues will be resolved before the 'First Intersessional Workshop'. The Committee **agrees** that the catch series to be finalised by SC/58 should form the basis for the North Pacific Bryde's whale *IST*s.

SC/57/PFI1 reviewed the abundance estimates from the 1998-2002 surveys to complete the *pre-Implementation assessment*. Additional variance was estimated. The abundance estimate for sub-areas 1 and 2 based on the 1998-2002 surveys is 26,172 under the assumption of different mean school sizes, and 25,852 when the mean school size is assumed to be independent of block; their CVs are about 40%. A possible explanation for the high additional variance was provided.

Annex D, Appendix 3 takes account of the possible systematic change in whale distribution between the two survey periods. All the interaction terms are significant, and support a systematic change in distribution between survey periods. A drop in the estimate of the CV for the total abundance from about 40% to about 35% suggests that the additional variance reported in SC/57/PFI1 includes variation due to non-random effects.

The Committee **agrees** that the estimates of additional variance in SC/57/PFI1 and Annex D, Appendix 3 are adequate for the purposes of developing *ISTs*. It also identified three refinements to the approach in SC/57/PFI1 that could form an improved basis for analyses presented to the 'First Intersessional Workshop'. They are detailed in Annex D, item 6.1.2.1.

The Committee noted that, although not required for the *pre-Implementation assessment*, it will be necessary for it to review and agree the abundance estimates (and their variance/covariances) to be used when applying the RMP. However, that step can only be finalised once specifications for *Small Areas* are completed.

SC/57/PFI2 described an approach using mark-recapture data to estimate distribution proportions for putative stocks/sub-stocks in sub-area 1. It was based on Japanese marking data, the 'simple model filter' approach of Punt (2003), and the specifications developed by the Committee to include mark-recapture data when conditioning *ISTs* for western North Pacific Bryde's whales.

The Committee thanked the authors of SC/57/PFI1 and SC/57/PFI2 for their work and looked forward to the results of additional analyses. It noted that if they are to be used, analyses related to SC/57/PFI2 need to be completed by the 'First Annual Meeting', while those related to SC/57/PFI1 need to be completed by the 'First Intersessional Workshop'.

The Committee noted that the intersessional Workshop had not specified the lower bound for $g(0)$ for use in trials

(the upper bound was agreed to be 1), but had agreed that the decision regarding this lower bound would be made this year taking account of evaluations reported in papers to the present meeting. No papers regarding the lower bound for $g(0)$ were received. The Committee therefore **agrees** that the lower bound for $g(0)$ for the purposes of *ISTs* will be 1.

The Committee also **agrees** that the *ISTs* will need to account for possible systematic changes in distribution in the future if the estimates of additional variation are to be based on the approach outlined in Annex D, Appendix 3.

6.1.2.2 RECOMMENDED ACTION

The Committee noted that all the recommendations of the intersessional Workshop relevant to completion of the *pre-Implementation assessment* had been met. It therefore **agrees** that the *pre-Implementation assessment* for western North Pacific Bryde's whales is complete and **recommends** that *Implementation* can commence.

The Committee noted that an *Implementation* will normally be completed in two years (IWC, 2005d, p.78) during two intersessional meetings and two Annual Meetings, subject to sufficient resources being available. The necessary steps, and the resources required to complete the *Implementation*, are detailed in Annex D, item 6.1.2.2. In particular, a 'First Intersessional Workshop' (after which no new data may be introduced) needs to be held to develop an appropriate *ISTs* structure and to specify the associated conditioning. The Workshop is planned to take place during 25-29 October 2005 in Tokyo. Financial implications are discussed under Item 21. A Steering Group was appointed (see Annex P(17)).

6.2 Review of information on the North Atlantic fin whale

Last year, the Committee agreed that there were sufficient data to warrant initiation of the *pre-Implementation assessment* for North Atlantic fin whales and recommended to the Commission that the Committee initiate the *pre-Implementation assessment*. The requirements for completion of a *pre-Implementation assessment* are outlined in IWC (2005e, p.86).

6.2.1 Review progress on the development of stock structure hypotheses as part of the pre-Implementation assessment *for North Atlantic fin whales*

SC/57/PFI3 summarised evidence from non-genetic data for stock structure of fin whales in the North Atlantic, based on: mark returns; morphometrics; pollutant levels; biological parameters; acoustic studies; and telemetry.

The Committee **agrees** with the conclusion of SC/57/PFI3 that the non-genetic data indicate a separation between the western, central and eastern North Atlantic. A separate stock hypothesised to occur in the Mediterranean has been confirmed using genetic information (Bérubé *et al.*, 1998).

SC/57/PFI4 presented the results from a genetic analysis of fin whales from the feeding grounds in the North Atlantic based on microsatellite variation. On a macrogeographical scale, the analysis confirmed that the North Atlantic fin whale is genetically structured on the feeding grounds. The genetic divergence of fin whales from different feeding grounds indicates separate breeding units and the low level of genetic divergence observed suggests a recent origin for the stocks.

Annex D, Appendix 4 outlined a set of stock structure hypotheses for North Atlantic fin whales based on inferences from genetic and non-genetic data. The Committee **agrees** that the data support consideration of additional stock structure hypotheses in which the East-Greenland–Iceland area is divided into East-Greenland-West Iceland and East Iceland areas. Further work related to identification and refinement of stock structure hypotheses was identified, *viz*:

(1) the data for each feeding ground should be used to test for departures from random mixing; and
(2) additional genetic data for fin whales found in waters off Canada and the Faroe Islands should be included in the analyses on which stock structure hypotheses are based.

6.2.2 Planning for completion of the pre-Implementation assessment

Issues to be addressed in completing the *pre-Implementation assessment* for North Atlantic fin whales at the Committee's 2006 meeting are detailed in Annex D, item 6.2.2. The Committee established an intersessional Working Group (see Annex P(16)) to progress this work.

The Committee **recommends** that IWC scientists attend the Workshop proposed by the NAMMCO Scientific Committee, given its focus on general scientific issues related to stock structure of fin whales and other non-management related issues such as the development of a final catch series. Financial aspects are discussed under Item 21. The Committee **agrees** that relevant scientists from the NAMMCO Scientific Committee be invited to the 'First Annual Meeting' at which stock structure hypotheses will be discussed further and used as the basis for *ISTs*.

It was noted that a timetable similar to that outlined in Annex D, item 6.1.2.2 for western North Pacific Bryde's whales would be required if the *pre-Implementation assessment* for North Atlantic fin whales is to be completed at the Committee's 2006 meeting, and if the Commission agrees to initiate the *Implementation*. In this regard, other tasks required of the Secretariat computing department may necessitate delaying the start of the *Implementation* until after the Committee's 2007 meeting.

6.3 Work plan

The Committee **agrees** on the following, in priority order:

(1) conduct the 'First Intersessional Workshop' for western North Pacific Bryde's whales; and
(2) finalise the issues related to completing the *pre-Implementation assessment* for North Atlantic fin whales.

7. ESTIMATION OF BYCATCH AND OTHER HUMAN-INDUCED MORTALITY (SEE ANNEX J)

7.1 Estimation of bycatch based on fisheries data and observer programmes

7.1.1 Review data from FAO

Last year, the Committee recommended that continued collaboration with FAO, particularly on the Inventory of Fisheries database, would be helpful to investigate fishery data that may allow better estimates of large whale bycatch. Northridge reported on intersessional collaboration with FAO. The Inventory of Fisheries is being compiled on a

regional basis and at its present stage will be most relevant for fisheries likely to have a large whale bycatch in the Northeast Atlantic and the Northwest Pacific. However, further work is required to produce the level of detail that would be most useful to the Committee. The Committee welcomed this work and **recommends** that it is continued. Specifically, it **agrees** that Northridge should continue work in collaboration with FAO, with the aim of integrating bycatch records into the Inventory of Fisheries.

It was noted that the information flow should be a two way process, with bycatch records held by the IWC being provided to FAO, and FAO able to assist the Committee by providing detailed information on the nature and scale of fisheries in areas where large whale bycatch might be an issue of concern.

In order to facilitate this, the Committee **agrees** that the IWC should join the FIRMS agreement, and it **recommends** that the Secretary implements this.

7.1.2 Review progress on standardised reporting in progress reports

The Committee reviewed a summary of the national progress reports to assess how well the revised reporting requirements had been adopted. The Committee **agrees** that the revised table provided data in a more useful format than previously. The Committee **encourages** countries who had not been able to submit data in the requested format this year to try to do so in future.

It was agreed that a fuller explanation of the codes that are used to describe the fate of entangled whales and how they were observed would be helpful, and gear codes should be updated periodically, as they are revised by FAO. To this end, a web link to the appropriate codes will be included in the national progress report guidelines for next year, provided a website with such information exists.

The Committee **agrees** that the distinction should be made in national progress reports between those countries that have monitoring schemes, where no records imply a low or zero bycatch rate, and others for which no such schemes exist and thus where the absence of records cannot be taken to imply a low or zero bycatch rate.

7.1.3 Determination of appropriate coverage rates for estimating cetacean bycatch

There had been no new papers presented on this topic this year, but it was noted that this issue was on the agenda of member states of the European Union, as recent legislation required them to make estimates of cetacean bycatch in selected gillnet and pelagic trawl fisheries. This will require some consideration of this topic by those countries and members of the Committee involved in such schemes are requested to report any progress to next year's meeting.

The Committee was reminded that in some areas certain types of fisheries are difficult to monitor using observers and further consideration of this topic is needed.

A preliminary worldwide overview of records of cetacean interactions with longlines was presented to the Committee (SC/57/BC3). Longline fisheries for large pelagic fish are widespread and have expanded in recent years. Documented mortalities of whales include sperm and humpback whales, notably in the South Atlantic and Gulf of Alaska. The Committee looks forward to seeing an updated version of the paper at next year's meeting. It was also suggested that where possible, records of encounters between longlines and whales should include information on whether the whales left with any lines attached, as this has implications for their future survival.

7.2 Estimation of bycatch based on genetic data

7.2.1 Review results from intersessional workshop on the market survey approach

At last year's meeting, the Committee had strongly recommended that the methodological workshop (on the use of market sampling to estimate bycatch) should take place as described in the proposal (IWC, 2005c, p.13). A Steering Group (Berggren, Donovan, Hammond and Zeh) was appointed, who contacted potential invitees to participate in a planning meeting that was to take place during autumn 2004. At that meeting, the intention was that information needs for the Workshop would be reviewed, papers needed to provide background for the workshop would be identified, a list of participants would be finalised and meeting logistics would be arranged. However, it was not possible to find dates when most of the invited participants to the planning meeting were available. The Steering Group therefore decided that the planning meeting and Workshop should be replaced by a two-stage Workshop of which an initial 2-day Workshop would be held immediately before the 2005 Scientific Committee meeting. The primary task of the initial Workshop was to identify information about the markets that would assist in evaluating market sampling approaches and allow a review of their relative precision. It was held 27-28 May 2005 in Ulsan, Republic of Korea (SC/57/Rep4).

The objectives of the two-stage Workshop were:

(1) to review available methods that have been used to provide estimates of large cetacean bycatches via market samples, including consideration of their associated confidence intervals in the context of the RMP;
(2) to identify information about the markets that would be required for a market sampling approach; and therefore,
(3) to provide advice as to whether market-sampling-based methods can be used to reliably estimate bycatch for use in addressing the Commission's objectives regarding total removals over time and if so, the requirements for such methods.

The initial Workshop concluded that market sampling is a potentially useful method to supplement bycatch reporting schemes. It also agreed that bycatch estimates from market surveys would be improved considerably if carried out in conjunction with the use of data from DNA registers on whales entering the market. Whilst the Workshop recognised the political sensitivity of market-related issues in an IWC context, it respectfully requested relevant governments to consider a collaborative effort to investigate these methods as a potentially valuable source of information for management and use in the RMP.

Mae reiterated the position of the Government of Japan that market related issues are a domestic matter and in view of this the contribution from Japan to these discussions will be limited. He noted the complexity of the Japanese market and that the distribution system in Japan is dynamic and constantly changing. In view of these issues of market complexity, and the likely costs involved in obtaining appropriate sample sizes, some members doubted the conclusion of the Workshop that market sampling was a promising approach. Kim noted that, at last year's Commission meeting, Korea had reserved its position on the

decision of holding the Workshop. Accordingly, the Government of Korea was not represented at the initial Workshop. Therefore, some texts in the workshop report (SC/57/Rep4) do not necessarily reflect the views of scientists from the Korean delegation.

Others noted that the discussions at the Workshop drew attention to the ways in which estimates from market surveys could be improved through a collaborative approach using a combination of official statistics, register data and market surveys. If data from DNA registers were available then the statistical precision of estimates would be improved considerably and only a relatively low level of sampling would be required. In addition, market surveys would not need to be conducted continuously, particularly if the estimates were in agreement with the reported figures.

The initial Workshop only considered the first two of objectives (1)-(3). Although the view of some members was that market surveys would not provide reliable estimates of bycatch, the Committee **agrees** that the planned follow-up Workshop would be valuable in order to evaluate this fully. The Committee also **agrees** that such a Workshop should only be held when the Steering Group determines that sufficient progress has been made on addressing the data requirement needs, and on developing simulation frameworks for sensitivity analyses and to test sampling designs prior to the Workshop (financial implications are discussed under Agenda Item 21). The Committee **agrees** to the proposal for a follow-up Workshop as described in Annex J. There are no financial implications for the Workshop itself.

7.2.2 Develop recommendations regarding use of market based approaches in an RMP context

A preliminary analysis of concordance between labelling and genetic identification of whale products on the Japanese market was presented. This had been conducted following a recommendation by the initial Workshop. The Committee welcomed the preliminary analysis and looks forward to further data at next year's meeting. It was noted that the presented breakdown by species of concordance between labels and genetic analysis would allow these data to be incorporated in simulation trials to test the extent to which product selection based on labelling might assist with market survey design. Mae stated that enforcement of food labelling regulations was the responsibility of the Government of Japan. However, the food labelling regulations were primarily designed for consumer protection and thus had not been introduced for the purpose of estimating bycatch.

SC/57/NMP6 provided an estimate of the proportion of J- and O-type common minke whale products purchased on Japanese markets from December 1997 to February 2004, using mixed-stock analyses. This approach was presented as an alternative to the capture-recapture analysis described in SC/57/BC5 (see below), for the purposes of estimating bycatch from market surveys. The authors concluded that if market proportions are also influenced by incidental takes of O-stock common minke whales, as assumed in past RMP simulations, then the estimated total bycatch would have to be several times larger than the scientific hunt to explain the observed market proportions.

In discussion in the Working Group, it was noted that previous analyses had demonstrated that some haplotypes (around 8%) are shared by whales in the Sea of Japan and Pacific Ocean and that the results of statistical tests would have been affected depending on whether these haplotypes were assumed to be J or O stock. The authors noted that the mixed-stock analysis used in SC/57/NMP6 is not biased by the existence of shared haplotypes but the precision of estimates is affected. Kim reiterated concerns about interpretations of population structure based on market samples where the locality and timing of origin was not known.

SC/57/BC5 used a series of market surveys in Korea to make inferences on the numbers of common minke whales entering the market, based on an updated genetic capture-recapture analysis from last year. This update avoided problems associated with multiple samples of meat from the same shop. The results yielded estimates of total supply for the five-year period 1999-2003 of 679 (SE=241) common minke whales using between-survey recaptures only, and 827 (SE=164) using both within- and between-survey recaptures. Although the standard errors of these estimates were relatively high, the authors noted that estimates of the number of individuals entering the market were significantly higher than the reported bycatch figure for this period.

Kim reiterated his concern over the uncertainty surrounding these estimates and therefore any implications from them.

The Government of Japan has conducted its own market research that started in 1995 when approximately 50 samples were collected. Subsequently, market surveys of around 600 samples a year have been conducted since 1999, including species identification and some individual identification. Mae drew attention to the position of Japan on these issues and noted that Japan would not be prepared to submit information from DNA registers for comparison with market samples. Kim reported that the Government of Korea had also conducted market surveys since 2003, but no decision had yet been made as to what data would be made available.

Some members noted that although market sampling techniques showed potential, further progress was unlikely to be made without the co-operation of national governments with respect to use of their DNA registers. Others referred to the results in SC/57/BC5 that had been obtained without access to such data that the precision of these methods would improve with increased sample sizes. Nevertheless, the Committee agrees that the power of the approach and the efficiency of market surveys would be improved considerably with collaboration with DNA registers. Access to diagnostic DNA registers would also reduce the need to understand market structure, although it is still necessary to understand the different pathways that products from reported and unreported sources might follow.

The Committee **agrees** that all the approaches to market sampling under discussion would be most effective if conducted with collaboration from national governments with respect to data from DNA registers. It respectfully requests such co-operation, although it recognises the political sensitivity of market related issues in an IWC context. The planned follow-up Workshop is intended to allow further discussion of data sharing and collaboration on methodology and all members are encouraged to participate.

7.3 Empirical analysis of the functional relationships between bycatch levels, fishing effort and population abundance

SC/57/NPM7 suggested methodology for the assessment of the J stock of North Pacific common minke whales. An integral component of the approach was the estimation of bycatch for years for which this information is not available. This was based on the assumption that the expectation for bycatch each year was proportional to the product of the population size with an annual index of effort of fixed-gear fisheries in which bycatches occur (effectively that bycatch-per-unit-effort is proportional to population size). The Bayesian structure of the model allowed for variation of bycatch about the level predicted by this model to be taken into account.

Kim presented data on fishing effort of stationary gear which consists of set, fyke and pound nets along the eastern coast of Korea. These data did not include gillnets and account for around 34% of the common minke whale bycatch along the east coast of Korea reported to the IWC.

The Committee notes that there is a need for a better understanding of the nature of bycatch in order to assess the reliability of the assumptions related to bycatch rates such as those used in SC/57/NMP7. This needs to include temporal and spatial information on the distribution of different types of gear as well as data on the seasonal and geographical distribution of bycatch. Soh indicated that the Korean authorities could consider collaboration on this work in a balanced way.

7.4 Information on and methods for estimation of cetacean mortality caused by vessel strikes

SC/57/BC1 presented two case studies of lethal collisions with large container ships involving a Bryde's whale in Ecuador and a sei whale off West Africa. Other information on ship strikes in the southeast Pacific and the eastern tropical Atlantic was reviewed. Unless whales become wrapped around the bow and are inadvertently taken into port, whale collisions with large ships often go unnoticed by crew members. Under-reporting of ship strikes is compounded by the absence of obligatory reporting, a deficiency in awareness of ship strikes and the lack of systematic necropsies of beached whale carcasses. The author noted that detailed examination of carcasses could assist in estimating the probability that a whale struck by a vessel would became draped on the bow.

The Committee agrees on the need to improve awareness of vessel strikes and reporting systems in order to gather more data. Concerns were expressed that in some countries, such as the USA, the penalty system may act as a deterrent to reporting of ship strikes. Matilla noted that the Hawaiian National Marine Sanctuary authorities were investigating systems for anonymous reporting of ship strikes. A recent US workshop on vessel collisions has been held and the report is available[4].

SC/57/WW8 reviewed collisions between whale-watching boats and whales. Collisions that either killed animals or caused serious injuries were more frequent with larger vessels, especially those travelling at speeds higher than 18 knots. In order to assess the risks to whales, information on the extent of the industries and the size and speed of the vessels involved would be helpful. This information could be collected in co-operation with the sub-committee on whalewatching. Many of the reported collisions occurred while whalewatching vessels were in transit and these data could be used to estimate likely collision rates for other vessels of similar size that regularly transit through whale habitats.

As in previous years, the Committee reviewed the information on ship strikes presented in national progress reports. It was noted that for at least one of these reports, the carcass involved had shown no external marks and it was only when it was flensed to the bone that the shattered skull revealed evidence of a collision with a ship. This further emphasised that flensing to the bone is often necessary in order to reveal that a stranded whale has been killed by ship strike. In Korea, a genetic sample of tissue left on the propeller of a vessel involved in a collision had been analysed and found to be from a common minke whale. It was noted that such analysis was a useful method for obtaining data on collisions with vessels.

ACCOBAMS is planning a Workshop on ship strikes, to be held in Monaco in November 2005. One reason for the Workshop had been the recognition of the threat to fin whales in the Mediterranean from vessel strikes. Panigada confirmed that he would be attending the Workshop and that the Workshop would also be addressing the question of how to estimate the number of whales involved in collisions with vessels. He also agreed to present the report of the Workshop to the Committee at next year's meeting. ASCOBANS is also collecting data on high-speed ferries within the region covered by the agreement. Kock agreed to contact ASCOBANS to find out the status of these investigations and report back any relevant information to the Committee.

7.5 Information on and methods for estimation of cetacean mortality caused by other human activities

At the 2004 meeting, the Committee had agreed that consideration of possible mortalities due to acoustic sources should be closely co-ordinated with the Standing Working Group (SWG) on environmental concerns. Although some data on the effect of seismic surveys on cetaceans had been presented at this year's meeting, there were no reports of mortalities.

7.6 Work plan

The work plan agreed by the Working Group on estimation of bycatch and other human-induced mortality is given as Annex J (item 10). The Committee's overall work plan is discussed under Item 19.

8. ABORIGINAL SUBSISTENCE WHALING MANAGEMENT PROCEDURE AND STOCK ASSESSMENT (SEE ANNEX E)

This Item continues to be discussed as a result of Resolution 1994-4 of the Commission (IWC, 1995). The report of the SWG on the Development of an aboriginal whaling management procedure (AWMP) is given as Annex E. The Committee's deliberations, as reported below, are largely a summary of that Annex, and the interested reader is referred to it for a more detailed discussion. Last year (IWC, 2005a), the Committee presented the Commission with its recommended *Gray Whale Strike Limit Algorithm* (*Gray Whale SLA*). The Commission endorsed the *Gray Whale*

[4] *http://hawaiihumpbackwhale.noaa.gov/special_offerings/sp_off/Vessel _collision_wkshp.html.*

SLA (IWC, 2005a, pp.10-11), which will now be used to provide management advice on eastern North Pacific gray whales (see Item 9.2). The primary issues at this year's meeting comprised:

(1) all aspects of the management of Greenlandic fisheries for common minke and fin whales;
(2) preparations for an *Implementation Review* for the bowhead whale; and
(3) management advice for the humpback whale fishery of St. Vincent and The Grenadines.

8.1 Greenlandic fisheries and the Greenland Research Programme

The urgent need for a Greenland Research Programme had been first identified in 1998. This is primarily due to the lack of recent abundance estimates and the poor knowledge of stock structure (IWC, 2004c, p.191). The Committee had informed the Commission that it would be extremely difficult, if not impossible, to develop an *SLA* for the Greenlandic fisheries that will satisfy all of the Commission's objectives. This is particularly important in the light of the Committee's grave concern at its inability to provide management advice for these fisheries (e.g. IWC, 2004c, p.191).

8.1.1 Stock structure, range and movement

8.1.1.1 GENETIC INFORMATION

The main questions for both common minke whales and fin whales off West Greenland revolve around how the abundance estimates derived from sightings made during surveys relate to the true number of animals 'available' to the hunters. It has been generally accepted for both species that the animals found off West Greenland probably do not comprise the total stocks (e.g. see review in Donovan, 1991; Born, 1999; IWC, 2000c). However, there is no information on the extent of these total stocks.

The Committee welcomed the report of the simulation studies funded last year (see Annex E, item 2.1.1 for a full discussion of this work). The Committee **agrees** that the currently available data have low power to reject any West Greenland samples as belonging to the putative West Greenland population (Annex E, Appendix 2). The SWG discussions developed into a broader examination as to how genetic studies may help it in its work.

The Committee **agrees** that the most valuable contribution genetic methods can make is if they can provide a lower bound for the size of the West Greenland common minke whale population (or rather the population or populations potentially available to be hunted in West Greenland), which can then be compared with estimates from sightings surveys and lower bounds from population models where total abundance may be estimated from the sex ratio of the hunt (see Annex E, item 3.1). Such genetic estimates would provide independent estimates of abundance (which would be valuable even if only a lower bound can be estimated).

The Committee therefore **recommends** that an assessment of the statistical power of various genetic approaches to estimate abundance be conducted intersessionally. Palsbøll, Skaug and Waples agreed to undertake this for four different approaches (Annex E, table 1) that use genetic data to infer abundance (either census population size or effective population size) given a realistic range of sample sizes, genetic markers and abundance estimates. Details are given in Annex E (Appendix 3) and the financial implications are discussed under Item 21.

The Committee then reviewed the available information on West Greenland fin whales (e.g. see SC/57/PFI4; Bérubé *et al.*, 1998). Although there is a reasonable amount of genetic information available from the North Atlantic, at present it is insufficient to determine whether the animals found off West Greenland comprise the total population or are part of a larger population.

8.1.1.2 CATCH DISTRIBUTIONS

Information on the distribution of catches of fin and common minke whales for the period 1990 to 2004 was reviewed (SC/57/AWMP10). Takes appeared to be clumped in the vicinity of the larger communities, although this was more evident for fin whales, with three major groupings (northern, central and southern), than common minke whales which showed more groups with less clear boundaries. Catches were generally in inshore waters for both species although in the central area fin whales were also caught offshore. For fin whales, there appeared to be more catches early in the year in the northernmost group; for common minke whales, the catch season was shorter further north. Overall there was some indication that the sex ratio of caught common minke whales changed slightly with latitude, with a higher proportion of males further north. Overall, the sex ratio for the common minke whale catch in West Greenland was constant over the period from 1990-2004 at about 76% female[5].

The Committee **agrees** that the results in SC/57/AWMP10 do not suggest marked differences in the sex ratio of the catch along the west coast of Greenland, although there is some evidence that it differs among communities. The question of the use of the sex ratio data in population assessment is discussed further below (see Item 8.2.2).

8.1.2 Abundance and trends

8.1.2.1 METHODS

The Committee received an analysis of the results of the photographic aerial strip-transect surveys carried out in 2002 and 2004 (and the experimental survey carried out in 2003). A considerable amount of time was spent by the SWG in discussing the methods used to read the photographs and analyse the results to arrive at population estimates. These detailed discussions can be found in Annex E (item 2.1.2).

One key feature of the analyses is the determination of the average time animals are visible at the surface. The SWG examined the approach given in SC/57/AWMP1 and modified the analysis as shown in Annex E (Appendix 4). The Committee **agrees** with the revised estimated average time of 6.9 seconds (CV=0.052), whilst noticing that this is probably slightly negatively biased.

There was considerable discussion in the SWG about the process used to examine the photographs from both the experimental survey in Faxaflói, Iceland[6] and from the surveys themselves[7] (see Annex E, Appendix 5 and the discussion of SC/57/AWMP2 in that Annex). The

[5] Sex data first became available in 1955, although in many years there were relatively high proportions of animals of unknown sex recorded. Over the period 1955-2004, the percentage of females in the catch (excluding animals of unknown sex) has almost always been over 60% with an overall (simple) average of about 72% (from data in Appendix 7).
[6] Some 22,000 photographs.
[7] Some 73,700 photographs.

Committee identified a number of issues with the process as described in SC/57/AWMP2 and 3 that it believed must be improved before it could consider the results from the photographic surveys acceptable form a methodological viewpoint. To this end, it developed the protocol for the examination of the photographs given in Annex E, Appendix 5. This is discussed further below.

8.1.2.2 SURVEY RESULTS

SC/57/AWMP3 described the results from an aerial digital photo-based strip-transect survey for marine mammals off West Greenland that was carried out over a total of 4.5 months in the late summers and autumns of 2002 and 2004. About 3.7% of the area was covered by images taken at sea state three or less. Photographs of two common minke whales and seven fin whales were found (other species were also seen). The author presented uncorrected estimates of animals at the surface of 46 (*CV*=0.74) common minke whales and 250 (*CV*=0.48) fin whales. He applied corrections for whales missed by observers and for animals not at the surface to arrive at an estimate of 510 (*CV*=0.75) common minke whales, which is significantly smaller than the revised estimate of 6,390 (*CV*=0.41) whales in 1993 (Hedley *et al.*, 1997). He corrected the fin whale estimate for animals not at the surface and obtained an estimate of 980 (*CV*=0.48) whales, which is similar to the estimate of 1,100 (95% CI 520-2,100) whales in 1987-88 (IWC, 1992, pp.595-644).

The Committee did not consider these estimates acceptable for a number of reasons related to both the examination of the photographs and the appropriateness of the correction factors applied.

As noted above, a protocol was developed for examination of the photographs. The Committee noted that whilst following the protocol will give more confidence in the number of whales identified on the images and the estimate of the area covered by the photographs, unless there are appreciably more sightings, in particular of common minke whales, any abundance estimates based on only a few more identified whale images on the photographs would constitute enormous extrapolations and probably be considered unacceptable. It noted that given the different sizes of common minke and fin whales, it believed that the problem of readers missing whales was greater for common minke whales. This is discussed further under Item 8.2.3.2.

The Committee also reviewed the surfacing rate estimate used to correct abundance estimates for West Greenland common minke whales both with respect to photographic and cue-counting surveys. SC/57/AWMP3 had used the value of 53 surfacings hour^{-1} with no associated variance used previously by the Committee and in conformity with corrections previously applied to visual aerial surveys. Details of the review are given in Annex E (item 2.1.2.2 and Appendix 6). The SWG had discussed whether estimates of surfacing rates should be based on data only for the area to which they will be applied. There was general agreement that this was the case, providing sufficient data are available. However, it was noted that when there are few data, there is great value in using comparable data for other areas. In its review, there was considerable discussion as to the appropriate way to quantify uncertainty from quite different studies.

The Committee **recommends** that if possible, the original data on which the preliminary estimate given in Annex E is based (and any other data on surfacing rates for common minke whales in the Northern Hemisphere) should be obtained and re-analysed to determine the various components of variance and hence the most appropriate measure of variance of surfacing rate to be used when estimating abundance. The SWG had not had time to thoroughly review the basis for the estimated correction factor used in SC/57/AWMP3 for fin whales. The Committee also **recommends** that this be reviewed, updated and re-analysed as possible. An intersessional Working Group under Kingsley was established with a view to providing the SWG with appropriate estimates (including variance) for both species at the next annual meeting.

While the Committee has identified a number of problems with these particular surveys, it **agrees** that if these can be overcome, in principle the photographic strip-transect method has potential value and can avoid several difficulties associated with visual surveys.

8.1.3 Preliminary consideration of management procedures

The Committee was pleased to receive a paper (SC/57/AWMP6) that outlines a multi-stock age- and sex-structured population dynamics model that allows for dispersal among putative populations. This model could form the basis of an operating model to evaluate candidate *SLA*s for common minke whales off West Greenland and hence explicitly models regions other than West Greenland. Further details are given in Annex E (item 2.2). This is somewhat different from SC/57/AWMP4 that has no explicit geographical structure but attempts to estimate the fraction of the West Greenland stock that is found in a larger area than just West Greenland using the sex ratio in the catches.

The Committee **agrees** that these papers will prove valuable in its attempt to develop an *SLA* for the Greenlandic fisheries.

8.2 Annual review of catch data and management advice for common minke and fin whales off Greenland

8.2.1 Catches

SC/57/AWMP4, 5 and 10 presented information on catches and the complete catch history is given in Annex E (Appendix 7). Catches of common minke whales from West Greenland in 2004 were 44 males, 129 females and two of unknown sex (four additional animals were struck and lost). Catches of fin whales were five males and six females (two additional animals were struck and lost). In 2003 the equivalent catches were 58 males, 117 females (seven additional animals struck and lost) for common minke whales and two males, four females (two additional animals were struck and lost) for fin whales.

8.2.2 Assessments

Two Bayesian assessment papers were presented. SC/57/AWMP4 provided a Bayesian assessment for the common minke whale stock of the West Greenland fishery. The primary feature used in this assessment was the fact that the fraction of females in the West Greenland catch has remained around 0.72 since the beginning of the hunt in 1948. This fraction is incompatible with abundance estimates from aerial surveys if West Greenland common minke whales comprise a single stock. More details of the analysis can be found in Annex E (item 3.2). The author estimated an equilibrium abundance of 17,500 (95% CI=13,700-21,800) individuals, a current depletion of 0.92 (95% CI=0.79-0.96), and an *MSYR* of 0.09 (95% CI=0.04-

0.10). He concluded that while there was no evidence that a West Greenland harvest at current levels poses a threat to the overall stock, the proposed assessment will not necessarily identify local depletion in West Greenland.

SC/57/AWMP5 provided a Bayesian assessment for West Greenland fin whales, using the historical catches and three abundance estimates from 1988 to 2003 in an age- and sex-structured population dynamics model. The model assumes density-regulated dynamics, and a population in dynamic equilibrium in 1922. It projects the population from 1922 to 2015 under the influence of the historical catches. Again, details of the analysis can be found in Annex E. The author estimated production in 2005 to be 12 (CI=11-17) and 2005 abundance to be close to equilibrium population size with depletion estimated to be 0.96 (CI=0.43-0.99).

The SWG also examined the results of some preliminary work carried out using a Schaeffer model. The results for common minke whales suggest that the estimates of stock status are highly sensitive to assumptions regarding the *CV* for the 2003 abundance estimate. The results for fin whales suggest that the data are uninformative about key model outputs such as the *MSYR*, current depletion and current replacement yield, and that Bayesian analyses for fin whales are very sensitive to the priors selected for the parameters of the model, particularly that specified for the extent of additional variance.

In reviewing the assessment work, the SWG made the following observations.

(1) The results of the Bayesian analyses are very sensitive to choices of priors, specifically the upper bounds for the priors for *MSYR* and the extent of additional variance for the survey estimates of abundance.
(2) The high values for the extent of additional variance imply that the model assigns little weight to the estimates of abundance. The results are therefore determined primarily by the assumed prior distributions and in the case of SC/57/AWMP4, the sex ratio data.
(3) The realised priors for some model parameters in Bayesian analyses differ substantially from the specified priors owing to the impact of the constraints imposed by the model structure. The low information content of the data implies that these constraints are the key reason why the posteriors for some parameters such as *MSYR* differ from the specified priors.
(4) The approach used in SC/57/AWMP4 to make use of the data on the sex ratio of the catch has the potential to determine a lower bound for the abundance of the total stock (rather than just that component that feeds off West Greenland). However, at present, the fits to the data on sex ratio are poor.
(5) The penalty imposed on equilibrium abundance in SC/57/AWMP4 is highly influential, including on the lower bound of equilibrium abundance and *MSYR*, but the tuning levels are essentially arbitrary.
(6) The production model assessments assume that the estimates of abundance pertain to absolute population size although this assumption is likely to be invalid to some (possibly substantial) extent.
(7) In the case of the fin whale assessment, the fits to the data on 1+ abundance are poor.

The Committee recognised the considerable effort expended by the authors in attempting to provide assessments for common minke and fin whales off West Greenland. However, it **agrees** that in the light of the observations listed above, none of the preliminary assessments can be used as the basis for management advice. It recalled the difficulty it had last year when it noted that it had advised that in the absence of an agreed abundance estimate for fin whales from the 2004 survey, it would likely recommend that the take of fin whales of West Greenland be reduced or eliminated. Some commented that under such circumstances and given the discussion under the abundance estimates, consideration should be given to suggesting that the fin whale catch be eliminated until an agreed abundance estimate is reached. This was taken into account in the discussion of management advice given below.

The Committee also **agrees** that the sex-ratio data should be incorporated into future attempts at assessments because they can in principle provide information about the lower bound for the total abundance of the stock. However, any assessment based on these data must examine the sensitivity of the results to assumptions associated with their inclusion. An intersessional Working Group (Annex P(5)) was established to develop and undertake appropriate analyses related to the inclusion of sex ratio data in assessments and hence to determining a lower bound for the abundance of the stock as soon as possible. The group should also consider similar issues for fin whales.

The Committee noted that use of such data depends critically on whether hunters are able to correctly determine sex of caught animals. It was informed that although there may be some errors when assigning sex to the catch, estimates of sex ratio by hunters and biologists are similar when comparisons have been made. The Committee **recommends** that if sex ratio data are to be used as the basis of assessments/management advice or for a future *SLA*, genetic methods should be used to confirm sex.

8.2.3 Management advice

8.2.3.1 INTRODUCTION

As it has stated on many occasions, the Committee has never been able to provide satisfactory management advice for either the fin or common minke whales off West Greenland. This reflects the lack of information on stock structure and abundance, and the absence of appropriate assessments. This is the reason the Committee first called for the Greenland Research Programme in 1998.

Despite receiving preliminary estimates of abundance from photographic surveys carried out in 2002 and 2004, the Committee **agrees** that, once again, it is in the deeply unfortunate position of being unable to provide satisfactory management advice on safe catch limits; **it views this as a matter of great concern.** The present uncertainties over the preliminary abundance estimates are such that the Committee does not consider them acceptable estimates. Although it has suggested further work with respect to the data collected on the photographic surveys, it cautions that there is no guarantee that this further work will result in significantly greater values, or, in the case of common minke whales, an agreed estimate. It notes that the Commission has set catch limits for the West Greenland fisheries of up to 175 common minke whales struck in each year for the period 2003-2007 with a provision that up to 15 strikes may be carried over from one year to the next and a catch of up to 19 fin whales for the same period.

8.2.3.2 COMMON MINKE WHALES

Taken at face value, the preliminary (and not accepted) estimate of abundance for common minke whales suggests

that about a 90% decline has occurred since the previous survey in 1993. However, the Committee has considerable doubts over this estimate (see Annex E, item 2.1.2.1) and there are several indications that such a decline has probably not occurred (e.g. the consistently high predominance of females in the catch suggests that the abundance estimate does not represent the total number of animals available to the fishery). Nonetheless, the Committee urges that considerable caution be exercised in setting catch limits for this fishery because it has no scientific basis for providing advice on safe catch limits. It noted that if an Aboriginal Subsistence Whaling Scheme (AWS) (see Item 8.5) was in place, this fishery would be at or near the place where the grace period would begin. This management advice will be re-evaluated next year in the light of the intersessional work recommended.

Given this, the Committee **strongly recommends** that a re-examination of the existing photographs be undertaken as a matter of urgency, according to the protocols given in Annex E, Appendix 5. **In conjunction with this, it strongly recommends** that preparations be made to carry out a cue-counting survey in the summer of 2006 targeted especially at common minke whales, so that if the intersessional group overseeing the re-examination of the photographs concludes that this will not result in an acceptable estimate, a survey can be carried out. The Committee recognises that the prevailing weather conditions in Greenland mean that there is no guarantee that a survey will result in sufficient coverage to allow an abundance estimate to be obtained in any one survey.

The Committee also **strongly recommends** that the sex ratio data be fully investigated *inter alia* to determine whether they can be used to obtain at least a minimum estimate for the total stock and be incorporated into an assessment model (see Item 8.2.2 above).

8.2.3.3 FIN WHALES

In 2004, the Committee had expressed special concern over the absence of an abundance estimate for fin whales since 1987/88 and had advised that in the absence of an agreed abundance estimate for fin whales from the 2004 survey, it would likely recommend that the take of fin whales off West Greenland be reduced or eliminated. This year the Committee had received a preliminary estimate (that was not considered acceptable, see Item 8.1.2.2 and the recommendation for reanalysis of the photographs given above) from the photographic surveys that was not appreciably different from the previously accepted estimate. Despite the fact that the Committee has more confidence in this preliminary estimate than it has for the common minke whale estimate (see above), it is not in a position to provide satisfactory management advice on safe catch limits. It therefore **urges that considerable caution be exercised in setting catch limits for this fishery.** Mindful of its recommendation of 2004 (see above), as interim *ad hoc* advice, the Committee advises that a take of 4-10 animals (approximately 1% of the lower 5th percentile and of the mean of the estimate of abundance) annually was unlikely to harm the stock in the short-term, particularly since this does not take into account the possibility that the fin whale stock extends beyond West Greenland (see Item 8.1). This advice will be re-evaluated next year in the light of the intersessional work recommended.

8.2.3.4 OTHER RESEARCH RECOMMENDATIONS

Last year, the Committee repeated its strong recommendation that samples for genetic analysis be collected from the catch as a matter of high priority and urged the Committee to encourage the Government of Denmark and the Greenland Home Rule authorities to assist with logistical and, if necessary, financial support. The Committee **repeats** its recommendation this year. It was pleased to be informed that 103 common minke whale samples, 8 fin whale samples and 4 samples of unreported species had been collected last year. The Committee **strongly recommends** that these samples be analysed in accordance with the advice of the intersessional Working Group on genetics.

The Committee **reiterates its great concern** at its continued lack of ability to provide management advice on these stocks, with serious implications for both the hunt and for the stocks involved. It **strongly urges** the relevant authorities to provide the necessary funds to allow all of the research recommendations given under Item 8.2 to be carried out. Should the necessary funding not be put in place to allow both (1) a re-examination of the photographs and (2) a cue-counting survey to occur if recommended by the Steering Group, it **agrees** that priority should be given to carrying out the survey.

8.3 Annual review of catch data and management advice for humpback whales off St. Vincent and The Grenadines

In recent years, the Committee has examined the stock structure of humpback whales in the North Atlantic in the context of the fishery of St. Vincent and the Grenadines. It has stated that the most plausible hypothesis is that the whales from St. Vincent and the Grenadines are part of the West Indies breeding population, numbering around 10,750 animals in 1992, but has encouraged the collection of additional data. This year, two papers were received providing more consideration of stock structure in this area.

SC/57/AWMP9 provided an update on a new assessment of North Atlantic humpback whales. A total of 3,615 biopsy samples were collected. The sample processing and data analysis should be completed in time for high-precision estimates of abundance to be available by 2007. The paper also hypothesised that the demographic population structure of this stock is probably complex, with whales from more than one feeding ground perhaps sharing the same winter breeding ground, or separate but uncertain breeding grounds.

The Committee was pleased to receive this report and expresses its continuing support for this programme.

SC/57/AWMP7 reported that one humpback whale landed as St. Vincent and the Grenadines in 1999 was matched to a specific catalogued individual photographed in the Gulf of Maine. This is the first direct stock assignment from this fishery and the most southeasterly sighting of a Gulf of Maine humpback whale. Based on its length, the authors believed that the second animal landed at the same time was probably a calf and, if so, a member of the same population.

The Committee welcomed this paper, noting that this strong additional information to that considered previously, strongly suggests that the animals found off St. Vincent and The Grenadines are part of the West Indies population.

The Committee also welcomed the updated report on catches submitted to the Secretariat. In 2004, there were no whales taken. In February 2005 there was a single male humpback whale taken, measuring 35ft in length.

The Commission has adopted a total block catch limit of 20 for the period 2003-07. The Committee agrees that particularly given the new information presented this year in SC/57/AWMP7, this catch limit will not harm the stock. The Committee also **repeats its recommendations** of previous years that wherever possible photographs and genetic material are collected from the catch. It was pleased to hear that two photographs (one from the 2003 catch and one from the 2005 catch) have been obtained and that arrangements will be made to send the photographs to the North Atlantic catalogue.

8.4 Planning for a bowhead whale *Implementation Review* in 2007

The Committee discussed planning for the 2007 *Implementation Review* for the Bering-Chukchi-Beaufort (B-C-B) Seas bowhead whales (*B. mysticetus*). The purpose of an *Implementation Review* is to determine whether any new information that has become available indicates that the present situation is outside the region of parameter space tested during *SLA* development. If this is the case, additional trials will be developed to test the performance of the *SLA* in this new region. If performance is found to be unacceptable under these new trials, revisions to the *SLA* will be required. In the case of the bowhead whale, a variety of new hypotheses concerning genetic population structure have been developed that have implications for management. Although there is little firm basis yet for assessing the plausibility of these hypotheses (see Item 9.1), they represent an untested region of parameter space. There is no new evidence that any other biological or demographic factors lie outside the region previously tested. The questions regarding stock substructure have stimulated considerable relevant research and analyses are expected to be completed in time for formulating management advice in 2007. Therefore, the Committee **agrees** to aim to complete the *Implementation Review* at the 2007 meeting whilst recognising that this did not preclude delaying completion to 2008 or later if circumstances warranted.

The Committee **agrees** to the following approximate timeline (more details are given in Annex E, item 4).

(1) *First intersessional Workshop*. This meeting will be held in or around March 2006. Its task will be to specify the basic structure and types of simulation trials needed for the *Implementation Review*. This meeting will also initiate discussions on the ranges of parameter values to be tested, but not the specific choices.
(2) *2006 Annual Meeting*. This meeting will review progress on trial design and coding. It seems appropriate that the stock structure discussions should occur in joint sessions of the AWMP and the BRG sub-committees, with this leading to a refinement of the trial structure and parameter value ranges.
(3) *Second intersessional Workshop*. This meeting will be held in or around October 2006. Coding of the trials must be completed before this Workshop. The purpose of this meeting is to review the coding of trials and their behaviour within the agreed parameter ranges. The Workshop will finalise trial structure.
(4) *Data availability*. In accordance with the Committee's Data Availability Agreement (DAA), all data relevant to management advice for the 2007 meeting should normally be submitted 6 months in advance of that meeting (i.e. probably in December 2006). However, given the collaborative nature of the analyses being undertaken, the Committee **agrees** that provided all collaborators concur, consideration should be given to allowing an extension to this deadline should it be required.
(5) *Third intersessional Workshop*. This meeting will be held in or around March 2007. The purpose of the workshop is to select specific parameter values for the designed trials, after confirming that the trial structure and coding revisions are satisfactory. After this meeting, the trials will be run by the Secretariat in advance of the 2007 Annual Meeting.
(6) *2007 Annual Meeting*. The primary task at this meeting will be to assess the relative plausibility of the trials chosen, examine the trial results, and evaluate continued management under the *Bowhead SLA*. If the Committee determines that the completed review indicates unsatisfactory performance of the *Bowhead SLA*, it will develop a workplan for its revision.

This timeline cannot be met without the imposition of certain deadlines. The Committee **agrees** that the trial structure and parameter ranges will be based only on evidence available at or before the 2006 Annual Meeting. Furthermore, the Committee **agrees** that choices for parameter values and trial plausibility judgments shall be based upon only the data available in advance of the 2007 Annual Meeting (see point 4 above). Decisions will be based on evidence that meets these deadlines. If new evidence becomes available subsequent to the applicable deadline, it shall not be used for the present *Implementation Review* unless completion of the *Implementation Review* is postponed to 2008 or later.

The financial implications of this plan are discussed under Item 21.

8.5 Scientific aspects of an Aboriginal Subsistence Whaling Scheme

In 2002, the SWG developed scientific aspects of an AWS intended for use in conjunction with the *Bowhead SLA* (IWC, 2003b, pp.154-5). These proposals were agreed by the Scientific Committee (IWC, 2003a, pp.19-23) and reported to the AWMP sub-committee of the Commission. At the 2003 and 2004 meetings, the Chair of the SWG discussed such matters with interested commissioners and representatives of the hunters. The Commission has not yet adopted the AWS and in particular the USA has expressed some concerns (IWC, 2005a, p.13). There was some discussion of this item by the SWG (Annex E, item 5).

The Committee again **recommends** the scientific components of an AWS to the Commission, noting that it forms an integral part of the long-term use of *SLA*s.

8.6 Work plan

The Committee **agrees** that the items below should be given priority during the intersessional period.

8.6.1 Greenland

(1) The photographs from the 2002 and 2004 surveys should be re-examined and advice be provided

throughout the process (a) on whether a survey should be undertaken in summer 2006 (see below) and (b) to develop an agreed method to obtain acceptable abundance estimates from the data, if possible. An intersessional e-mail group to provide such advice was established (Annex P(3)).

(2) The data on which the estimate of surfacing rate in Annex E, Appendix 4 is based (and any other data on surfacing rates for fin and common minke whales in the Northern Hemisphere) should be obtained and re-analysed to determine the various components of variance and hence the most appropriate measures of variance of surfacing rate when estimating abundance. An intersessional group to co-ordinate this was established (Annex P(4)).

(3) Preparations should be made to carry out a cue-counting survey in summer 2006 (see Item 8.2). A final decision on whether to conduct the survey will be taken by the intersessional group established under (1) above.

(4) The sex ratio data for common minke whales should be fully investigated *inter alia* to determine whether it can be used to obtain at least a minimum estimate for the total stock and be incorporated into an assessment model. An intersessional group to forward this work was established (Annex P(5)). This information should be provided to the intersessional group established under (1).

(5) An assessment of the statistical power of various genetic approaches to estimate abundance (Annex E, Appendix 3) should be completed. This will be carried out by Palsbøll, Skaug and Waples. Financial implications are dealt with under Item 21.

8.6.2 Bowhead whales

To meet the goal of finishing the bowhead *Implementation Review* at the 2007 Annual Meeting, two Workshops will be required (see Item 8.4), one in the forthcoming intersessional period. The USA has offered to host that Workshop in either Seattle or La Jolla in or around March 2006. The Workshop will specify the basic structure and types of simulation trials needed for the *Implementation Review*.

There is also a considerable amount of Secretariat computing work involved (Allison primarily). Given the unknown nature of the final stock structure hypotheses, it is difficult to estimate accurately the amount of Secretariat time required for the *Implementation Review*. This could be up to 15 months for the entire process (i.e. to the end of the 2007 review); it may be up to eight months between the first and second intersessional Workshops. This needs to be taken into account in the overall Committee work plan (see Item 19).

8.6.3 Priority topics for the 2006 meeting

(1) Review progress on the Greenlandic research programme (especially with respect to abundance, stock structure and the use of sex data in assessments) and attempt to provide management advice.

(2) Review progress on and refine design of trial specifications and coding for bowhead whales.

(3) Review information on the St. Vincent and The Grenadines fishery and provide management advice.

The Committee noted that this is a particularly heavy workload for the 2006 Annual Meeting. It notes that unless the SWG on the AWMP has a pre-meeting, it will require considerably more sessions than normally allocated at an annual meeting. This is discussed further under Items 18 and 19.

9. ABORIGINAL SUBSISTENCE WHALING STOCK ASSESSMENTS ON BOWHEAD, RIGHT, AND GRAY WHALES (SEE ANNEX F)

9.1 Bering-Chukchi-Beaufort Seas bowhead whale stock identity

The Committee considered the results of a USA-sponsored Workshop on B-C-B bowhead whale stock structure held in Seattle, February 2005 (Anon., 2005). The Workshop considered five stock structure hypotheses:

(1) the one-stock model presently accepted by the IWC;
(2) one stock with generational gene shift (GGS);
(3) two stocks with temporal segregation;
(4) two stocks with spatial segregation; and
(5) the two-stock Chukchi Circuit (CC) hypothesis.

The latter is a new hypothesis based on inference from Russian sighting and oceanographic data. It assumes a primary population that migrates from the eastern Bering Sea to the Beaufort Sea in spring, returns by a similar route in autumn, and is subject to harvest at Barrow in both seasons, with a second population that leaves the Bering Sea in late May and June and follows the Chukotka coast northward to the northern Chuckchi and western Beaufort Seas. In this hypothetical scenario, the second population would be vulnerable to harvest at Barrow in autumn, but not during spring.

SC/57/BRG10 re-examined the 'Oslo bump', a significant increase in genetic difference between pairs of whales sampled approximately one week apart at the Barrow autumn migration versus those sampled at other time intervals (Jorde *et al.*, 2004). Genetic data from 117 Barrow whales were screened for quality and analysed in generalised additive models. Pair-wise comparisons detected no significant effects in the spring migration. In the autumn migration, there was a significantly elevated genetic difference in pairs of whales taken about a week apart in the hunt.

SC/57/BRG4 carried out an analysis that was parallel to SC/57/BRG10, but adjusted for whale ages in a manner that was argued to be more appropriate. It found a weaker pattern of elevated gene difference in pairs taken about a week apart, which was no longer statistically significant at the 5% level. SC/57/BRG4 also emphasised that the effects of whale ages and spatio-temporal whale positions during migration are highly confounded, making it difficult to isolate the genetic patterns associated with each. The paper concluded that it was premature to reject any major hypotheses until more and better data become available. The importance of additional samples was emphasised, as the detection of the 'Oslo bump' was based on only 54 samples from the autumn migration. Further, genetic structure might be the result of a combination of factors and so not entirely explained by a single proposed hypothesis.

The Committee **agrees** that the 'Oslo bump' appears to be a real feature of the limited available data. However, additional data are necessary to confirm whether this pattern reflects a real characteristic of the B-C-B bowhead population. No single explanation has emerged to explain the effect.

SC/57/BRG19 described the development of a new and expanded panel of microsatellite loci from bowhead whales. The goal of the work was to produce at least 25 loci from bowhead whales that are variable, reliable and can be consistently scored, even in samples that are not of optimal quality. Preliminary assessments of variability suggest that as many as 20 of an initial set of 33 possible loci might be suitable for use.

SC/57/BRG21 reported recent progress on B-C-B Seas bowhead whale stock structure research, as requested by the Scientific Committee during its 2004 meeting (Øien, 2004, pp.23-4). Research was directed towards testing proposed stock structure hypotheses. The Committee expressed its appreciation to the USA for its Seattle Workshop and research programme. However, some concerns were raised as to whether the working schedule would allow for new data to become available for review prior to the 2006 meeting. If there is sufficient evidence against a single stock, then it will be important to identify the implications of that structure so that the new trial structure can assess the potential effects.

The Committee **agrees** that the focus of this extensive work programme should be to provide advice that is of direct relevance to the development, if necessary, of a revised trial structure for testing the *Bowhead SLA*.

SC/57/BRG16 provided an update on recent aerial photographic surveys of bowhead whales for photo-identification and photogrammetry. Surveys were conducted near Point Barrow, Alaska, during the spring migrations of 2003 and 2004. The photographs from these studies will provide a capture-recapture abundance estimate for comparison with the most recent estimate from ice-based counts, as well as more precise estimates of bowhead whale life-history parameters such as survival. A survey near St. Lawrence Island in the Bering Sea in 2005 was designed to photograph bowheads during the second half of the spring migration when most well marked medium- and large-sized whales are seen. The location was chosen to maximise the possibility of photographing whales from a Bering Sea stock that may not migrate past Point Barrow in spring, if such a stock exists.

SC/57/BRG17 described a preliminary characterisation of the external morphology of bowhead whales caught by Alaskan Eskimos. Such external morphometric data may be useful for stock structure investigations.

9.2 Catch data and management advice for the Bering-Chukchi-Beaufort Seas bowhead whale

9.2.1 Catch information

SC/57/BRG15 reported catch information for the 2004 Alaskan subsistence harvest. A total of 43 bowhead whales was struck resulting in 36 animals landed. The efficiency (the ratio of the number landed to the number struck) of the hunt was 84%, which is higher than the mean efficiency over the past 10 years (78%). Of the 36 whales, 13 were males, 22 were females and the sex was not determined for one whale. Of the 22 females, seven were presumably mature (>13.4m in length). Four of these were examined closely. Two were pregnant, one with an 11cm foetus and the other with a 409cm foetus, while the other two were not pregnant.

SC/57/BRG24 reported that one 12m male bowhead whale was taken as part of the Russian subsistence harvest in 2004. The weight of the animal was estimated at 30,400kg. The author confirmed that the length of the whale was exact, but that the weight was estimated from the amount of meat that was distributed. The Committee **recommends** that every effort be made to obtain genetic samples from Russian catches.

9.2.2 Management advice

The Committee **agrees** that the *Bowhead SLA* remains the most appropriate tool for providing management advice for this harvest, at least in the short-term. The results from the *Bowhead SLA* show that no change is needed to the current block quota for 2003-07.

The Committee also repeated last year's recommendation that an *Implementation Review* focusing on stock structure should be conducted with the goal of completing it at the 2007 annual meeting so that management advice at that meeting is based on the best science available then. The *Bowhead SLA* was developed and tested under a single-stock hypothesis. The review will examine the robustness of the *Bowhead SLA* with respect to plausible stock hypotheses via simulation trials. If shown to be necessary, this may result in changes to the *Bowhead SLA* (and see Item 8.4).

9.3 Catch data and management advice for the eastern North Pacific gray whale

9.3.1 Catch information

A total of 110 eastern North Pacific (ENP) gray whales (43 males and 67 females) were harvested by the native people of the Chukotka Autonomous Region in 2004 (SC/57/BRG24). Of the total, one gray whale was lost during towing and six exhibited a strong chemical (iodic) odour. The latter were not used for any purpose and tissue samples have been analysed to determine the cause. Harvested whales ranged in length from 8.0-14.0m (average 10.1m). The weight ranged from 6.0-23.0 tons (average 11.9 tons).

The Makah Indian Tribe was unable to conduct whaling on this stock in 2004 because of domestic litigation. A court ruled in 2004 that the Makah Indian Tribe needs a waiver of the US Marine Mammal Protection Act (MMPA). The Tribe applied for that waiver in February 2005.

SC/57/BRG6 was a preliminary report of the re-analysis of catch data from the Soviet aboriginal fishery of eastern Pacific gray whales from 1980-91. Data for this period have been summarised on an annual basis in previous reports to the Scientific Committee. However, SC/57/BRG6 re-analysed biological and technical parameters based on a large total sample of 520 females, 248 males and 89 foetuses. The Committee welcomed this report and **agrees** that this information should be considered at the next *Implementation Review*.

9.3.2 Management advice

Last year, the Commission endorsed the *Gray Whale SLA* for use in providing management advice. In this meeting, the Committee reaffirmed that the *Gray Whale SLA* remains the most appropriate tool for providing management advice for this harvest. The Secretariat has calculated strike limits for this stock given the agreed abundance estimate and catch history. The results show that no change to the current block quota is needed for 2003-07. An *Implementation Review* is scheduled for 2009.

9.4 Implications of the special pre-meeting on sea ice and whale habitat

SC/57/E13 and SC/57/E5 had been presented in the joint Workshop on high-latitude sea ice environments (SC/57/Rep5). Both papers addressed the potential effect of variability in sea ice cover on B-C-B bowhead whales and are summarised under Item 12.1.

Three important issues were identified in the Workshop:

(1) the effect of loss of sea ice on the census of B-C-B bowhead whales (related to the loss of the shorefast ice platform from which the census is conducted and the potential opening of commercial shipping routes in the Arctic);
(2) the possible importance of sea ice in structuring habitat for bowhead and gray whales either directly or indirectly through potential for competition between gray and bowhead whales and via the potential northward shift of other mysticete species (competition) and killer whales (predation); and
(3) the best way to incorporate large whale research, specifically IWC-related work into the International Polar Year (IPY) and Second International Conference on Arctic Research Planning (ICARPII) programmes (see Item 12.1).

Overall, the Committee was encouraged that there had been no apparent negative effect of global warming on bowhead whales. However, they also found it difficult to predict how bowhead whales might be affected by large-scale oceanographic changes in the future. Several areas of concern were discussed, including thermoregulatory issues and increased exposure to killer whale predation, competition with other species, ship traffic, noise, pollution and fisheries interactions. In addition to potential impacts on the census, a reduction in sea ice would probably affect the logistics of the harvest.

9.5 Catches by non-member countries

There were no catches of bowhead whales in the eastern Canadian Arctic in 2004. The carcass of one juvenile bowhead whale washed ashore near Arctic Bay in 2004, apparently the victim of a killer whale attack (Cosens, pers. comm.).

9.6 Work plan

The following work plan was proposed for the coming year:

(1) review new information on the stock structure of the B-C-B Seas stock of bowhead whales and on the progress of on-going research; and
(2) perform the annual review of catch information and new scientific information for the B-C-B Seas stock of bowhead and ENP stock of gray whales in order to advise the Commission as requested in Schedule Paragraph 13(b)(1) and (2).

10. WHALE STOCKS

10.1 Southern Hemisphere Antarctic minke whales (see Annex G)

10.1.1 Estimate abundance of Antarctic minke whales

10.1.1.1 THE 2004/05 SOWER CRUISE

SC/57/IA1 presented the report of the 2004/05 SOWER cruise. This was the 27th annual Antarctic cruise and represented the start of a new phase of research following the completion of the third circumpolar series of surveys (CPIII). The research region was in Area III (0°-70°E) and lasted 65 days. The Committee expressed its gratitude to the Government of Japan for providing the vessels to conduct the survey. It also thanked the officers and crew of the vessels, the Cruise Leader, Senior Scientist and the other researchers for their efforts to ensure a successful cruise. The main purpose of this cruise was to conduct experiments that address problems encountered with the analysis of or interpretation of previous IWC/SOWER cruises.

One such experiment was presented in SC/57/IA7, which is a report of the collaborative studies with the Japanese icebreaker, *Shirase*. The SOWER vessels surveyed for Antarctic minke whales in the near-ice area (35°-50°E) while the *Shirase* surveyed in the pack ice zone (40°-50°E). The Committee thanked the Government of Japan and the Japanese Antarctic Research Expedition for conducting this study.

If the data from the SOWER and icebreaker cruises are to be used to estimate the proportion of Antarctic minke whales within the ice field that are not accessable to the IWC/SOWER survey vessels, care must be taken to account for the fact that the design and search effort for the two types of vessels were different.

Other experiments conducted on the SOWER cruise included Antarctic minke whale visual dive time trials, trials of the Buckland-Turnock (BT) survey method, trials of adaptive line transect sampling, and addressing effects of the CPII track design on the abundance estimates as compared to the CPIII track design. A direct electronic data acquisition program was also evaluated. The Committee considered that all the experiments had been useful.

Insufficient sea time had been available to properly evaluate the BT mode experiment. However, there was some concern expressed that the high-powered binoculars used for tracking in BT mode were difficult to use. The results from a BT mode experiment is an estimate of $g(0)$ that accounts for animal reactive behaviour, if any, that does not rely on assumptions of surfacing rates and patterns. Given the potential value of the BT mode experiment in assisting in interpreting previous results, the Committee **recommends** that the BT mode experiment be continued.

Practical aspects of the protocol of adaptive sampling were easily implemented but due to time constraints and the low density of animals when conducting these experiments, data collected were too limited to analyse. However, the Committee **agrees** that adaptive sampling is of greater benefit for species that are found in low densities (e.g. blue and fin whales).

Sufficient data had been collected during the dive-time experiments. The Committee **recommends** that these data be coded and analysed intersessionally by an intersessional Working Group (Annex (P14)).

The automatic data entry system was also found to be successful so the Committee **recommends** such a system be more fully developed and tested during the next cruise.

Good coverage was achieved for two-thirds of the study area of the experiment to investigate effects of the CPII track design on the abundance estimates but it is not clear whether this level of coverage is sufficient to try to compare the two designs, particularly given inter-annual variation.

10.1.1.2 RESULTS FROM SIMULATED DATA

Last year, the Committee identified four additional factors that could potentially reflect heterogeneity in the real International Decade of Cetacean Research/SOWER

(IDCR/SOWER) data and should be added to the already existing simulation scenarios. SC/57/IA2 outlined how these factors have been incorporated into the simulated data, which have been provided to the IWC Secretariat. These data were used to examine the robustness of some of the methods under development: the integrated model method by Cooke (2002); and the hazard probability model by Okamura (SC/57/IA4), as well as more established analysis methods, the standard method (SC/57/IA14) and the direct duplicate method (SC/57/IA15). For all these methods, the percentage relative bias of estimated density of whales was small. The integrated model and hazard probability model had the smallest biases; these tended to be positive. The standard and direct duplicate methods had larger biases that were negative. The Committee welcomes these encouraging results.

The highest priority task for next year is to produce estimates of Antarctic minke whale abundance and thus the Committee **agrees** that analysing the standard dataset of the actual IDCR/SOWER data should be given higher priority than analysing further simulated datasets. However, these estimates will need to be assessed on the basis of the performance of the methods obtained from the simulation study. The Committee established an intersessional email correspondence group (Annex P(10)) on analysis methods used to estimate abundance of Antarctic minke whales using IDCR/SOWER data. The group should further develop the list of factors that should be simulated and the combinations of these factors that should be used, taking into account of the high priority allocated to analysing the standard dataset. Factors to consider including in future simulations are: varying the sample sizes, reducing the value of $g(0)$, cue dependent detection functions combined with other factors, and varying amount of effort within the study area that may be correlated with weather conditions. See additional terms of reference for this correspondence group in Item 10.1.1.3.

10.1.1.3 RESULTS FROM CRUISE DATA

The 2003/04 SOWER cruise surveyed the eastern part of Area V including the Ross Sea. SC/57/IA11 presented estimates of Antarctic minke whale abundance using standard IWC methods (Branch and Butterworth, 2001). The mean school sizes in the northern, middle and Ross Sea strata were 1.13 (*CV*=11.1%), 3.95 (*CV*=12.2%) and 1.35 (*CV*=7.0%), respectively. The abundance of Antarctic minke whales was estimated to be 77,120 (*CV*=30.8%) for closing mode and 101,766 (*CV*=23.3%) in independent observer (IO) mode. The combined estimate, having corrected for closing mode, was 98,522 (*CV*=18.9%). An updated estimate of *R* (the factor used to convert closing mode estimates to pseudo-passing mode) was calculated. This value, including all data from 1998/99, was estimated to be 0.88.

The Committee noted that on the 2003/04 survey the mean school size and sighting rates were higher in the middle stratum than in the Ross Sea southern stratum, which was considered unusual. Several members suggested that the unusual distribution of larger schools could have been related to ice conditions. An examination of satellite derived ice motion was currently being undertaken by Ensor, Matsuoka and others in an attempt to identify the processes involved.

The Committee **recommends** that the relationship between abundance and distribution of Antarctic minke whales and the ice extent be examined using data from the 2002/03 and 2003/04 surveys, and those of JARPA, which covered similar areas.

SC/57/IA16 presented preliminary estimates of abundance for CPI, CPII and CPIII obtained using a slightly modified standard method (Branch and Butterworth, 2001). When results from closing mode and IO mode were combined, the circumpolar abundance estimates were 594,000 (*CV*=12.8%), 769,000 (*CV*=9.4%) and 362,000 (*CV*=8.0%) for CPI, CPII and CPIII respectively. These estimates are negatively biased because some Antarctic minke whales may be north of 60°S, or inside the pack ice during the surveys and because some whales on the trackline were likely to have been missed. After simple extrapolation to account for differences in the latitudes surveyed during each circumpolar set (but not for increasing proportions of 'like minke' sightings), the ratio of the circumpolar estimates was 0.92:1.00:0.39, echoing previous preliminary findings of appreciably lower CPIII estimates. Estimates for each IWC Management Area also had low CPIII:CPII ratios (between 0.17 and 0.62), except for Area VI where the CPIII estimate was higher than in CPII.

SC/57/IA3 examined consistency over time of SOWER environmental covariates. It was clear that the method of determining 'visibility' has changed during CPII/CPIII, and a correction is necessary. Four simple ways were investigated, of which two were considered successful.

To facilitate the estimation of abundance using the CPI to CPIII data in the standard dataset, the Committee **recommends** that the intersessional email correspondence group on analysis methods (see Annex P(10)) assists the analysers (Branch, Bravington, Cooke, and Okamura) by developing what should be presented, what diagnostics are required and to create a set of rules, for example specifying how duplicates should be treated, how to pool the data, and other such data selection decisions. In addition, this group should determine diagnostics to ensure the comparability between DESS and the standard dataset.

10.1.1.4 ADDITIONAL VARIANCE

SC/57/IA5 presented the proposed statistical model for estimating additional variance, which is based on a combination of the methods in Punt *et al.* (1997) and Skaug *et al.* (2004). The performance of the additional variance estimation for IDCR/SOWER type surveys was investigated through simulation studies. The study found that estimates of the amount of random variation may be biased if the area-effects change systematically (and not randomly) between two circumpolar surveys.

The Committee **agrees** that consideration of the residuals over time might be used to assist in detecting spatial and temporal trends and the data from JARPA could possibly also be used to estimate additional variance. It also agrees that SC/57/IA5 was valuable and that the methods should be applied to the abundance estimates that will be presented at next year's meeting.

10.1.1.5 ESTIMATION OF ABUNDANCE USING JARPA DATA

SC/57/IA18 compared abundance estimates of JARPA survey data obtained using standard line transect methods and spatial modelling methods. Several vessels take part in the JARPA survey, where one vessel acts as a dedicated sighting vessel (SV) and the other vessels as sighting and sampling vessels (SSV). Vessels operate in closing mode, thus, in high-density areas effort is reduced. Standard line transect methods may be biased since effort is assumed to be located independent of density. The spatial model makes

no such assumption, but relies on good coverage throughout a study region. Results from four years of survey data in Area V were compared and found to be broadly similar.

It was suggested that combining all surveys together and including year as a factor might produce a more robust model. Concern was expressed that the variance of the sighting rate may be underestimated and that the moving ice edge could cause problems. It was also suggested that if this method was to be used in the future, the spatial model should be applied to simulated data to investigate the model's robustness.

Hakamada *et al.* (2005) investigated the effects of sampling activities, including 'skipping' (not covering the full daily distance planned in high density areas) and the use of closing mode, on abundance estimates when using data collected from SSV and SV. To correct for bias due to under-surveying high-density areas, the method developed by Haw (1991) was used. The consequent corrected abundance estimates averaged about 50,000 for Area IV and about 200,000 for Area V. No statistically significant change in abundance was detected.

In discussion, concern was expressed that the correction factors might change over time in response to variations in whale density and the extent of skipping. The most appropriate method of estimating variance in the sighting rate from the SSV was also discussed, as the SSV vessels surveyed relatively close to each other. The authors responded that they had checked for dependence of the correction factor on density and had not found any significant effect (Hakamada *et al.*, 2005). More details on these and other concerns, and responses to those are provided in Appendices 2 and 3 of Annex H.

10.1.2 Reasons for differences between Antarctic minke abundance estimates from CPII and CPIII

The Committee had planned to update the table on possible hypotheses explaining the differences between abundance estimates from CPII and CPIII (IWC, 2003d). However, there was insufficient time to complete this task. It is expected that updated abundance estimates from CPII and CPIII will be available next year and the Committee agrees to update the table after the abundance estimates become available.

10.1.2.1 IMPLICATIONS OF SEA ICE AND WHALE HABITAT

SC/57/IA6 used a GAM-based spatial model to account for environmental variables when estimating the abundance of Antarctic minke whales within a polynya present in Area II (0ºE-60ºEW). This analysis indicated that there appears to be a more complex response of the Antarctic minke whale distribution to environmental variables than what was believed before (e.g. high concentrations around the ice edge and decreasing towards the north). It was proposed that the oceanographic conditions associated with the Weddell Gyre in Area II could also be influencing the distribution of Antarctic minke whales instead of just sea surface temperature (SST) and sea ice extent as postulated by Kasamatsu *et al.* (1998).

Concerns were expressed about predicting density in a region outside the range of the observed data. The Committee suggested that this work be continued by including other environmental variables, if available, investigating the effects of using environmental variables alone, investigating the fit of the model by comparing the predicted patterns of abundance to the observed patterns of abundance in areas where there are data, considering combining data from all years to develop the predictive model and developing estimates of variance for the extrapolated abundance estimate. In addition, it was noted that if this method is to be used in the future, its robustness should be investigated by applying it to simulated data. The Committee **encourages** further work on this difficult issue.

10.1.2.2 POPULATION DYNAMIC MODEL METHOD TO ESTIMATE TRENDS AND POSSIBLE DIFFERENCES

10.1.2.2.1 REPORT FROM INTERSESSIONAL WORKING GROUP

At its 2002 meeting and each year after, the Committee established an intersessional Working Group to address issues concerning catch-at-age analyses for Antarctic minke whales in Areas IV and V. Results of work completed so far on the integrated statistical catch-at-age (SCAA) model are in SC/57/IA9 and results from the Adaptive Framework Virtual Population Analysis (ADAPT-VPA) model are in SC/57/IA17 (both discussed later). Two of the outstanding tasks that remained before final results could be obtained were addressed during this Scientific Committee meeting: a set of plausible stock structure hypotheses for Areas IV and V was developed, and a set of environmental time series was identified (details in Appendix 4 of Annex G). That Appendix also lists remaining issues that require consideration and intersessional work.

The Committee **agrees** that having results from both the ADAPT-VPA and integrated SCAA was extremely valuable and encouraged continued work on both approaches. It also **agrees** that the Working Group should continue as an intersessional e-mail group (Annex P(13)). The Committee further **agrees** that a request for data be made under Procedure B of the Data Availability Protocol to allow work identified in Appendix 4 of Annex G to proceed.

10.1.2.2.2 ABUNDANCE ESTIMATES FROM SOWER AND JARPA USED IN POPULATION DYNAMIC MODELS

The intersessional Working Group **agreed** that for this year, abundance estimates by Branch (2003; pers. comm.) be used for the IDCR/SOWER cruises and estimates by Hakamada *et al.* (2005) be used for the JARPA cruises. In the longer term, completion of the population modelling work is dependent upon the finalisation of a set or sets of abundance estimates for both these cruises.

10.1.2.2.3 RESULTS FROM PRELIMINARY ANALYSES

SC/57/IA9 reported on the statistical catch-at-age model, which is a general population dynamics model applied to Antarctic minke whale data from Areas IV and V that allowed for: multiple fleets; age- or length-based selectivity; different shaped selectivity patterns which can change by time, sex and fleet; ageing error; and changes over time in carrying capacity. The reference case analysis indicated a substantial increase in recruitment between 1930 and 1960, then a decrease between 1960 and the mid-1980s and relatively constant recruitment subsequently. Correspondingly, abundance increased until around 1970 and then declined. These results are similar to those obtained by Butterworth *et al.* (1999). The estimate of K in 1960 was higher than in 1930 by a factor of 10. K was estimated to have decreased roughly by half between 1960 and 1980.

Sensitivity analyses showed the following: a significantly better fit was achieved when allowing for changes in K over time; selectivity varied with length or age for the JARPA catches; and apparent inconsistencies between the JARPA age composition data and the commercial age-length keys. Problems were encountered if the assumption was made that growth had not changed over

time. Hatanaka commented that growth rate may have changed over time and that the commercial catches were closer to the ice edge, which may have influenced their selectivity.

SC/57/IA17 reported advances in the application of ADAPT-VPA to Antarctic minke whales in Areas IV and V. They had applied the methodology of Butterworth *et al.* (1999) to abundance estimates (from both IDCR/SOWER and JARPA surveys) and catch-at-age data (both commercial and scientific) for Areas IV and V. The primary focus was a joint analysis of the two Areas under the assumption that there was a single stock, with year-to-year variability in how it was distributed. The model was most sensitive to the value of the natural mortality *M*. This was linked to the IDCR/SOWER survey trends suggesting higher estimates of *M*, and the JARPA survey trends suggesting lower estimates.

The trends in recruitment and population size in SC/57/IA17 agreed well with the corresponding reference case results in SC/57/IA9. However, some differences between results of the ADAPT-VPA (SC/57/IA17) and the SCAA (SC/57/IA9) were noted. For example, omitting the JARPA abundance data had a large effect in the ADAPT-VPA but not in the SCAA. The difference between the trends indicated by the revised JARPA and IDCR/SOWER abundance estimates for Area IV is clearly of concern. Further, the ADAPT-VPA approach needs to be extended to take account of the differences in selectivity patterns between the Japanese and Russian fleets indicated by SC/57/IA9. In addition, possible differences in selectivity patterns at large ages between JARPA and the commercial catches need to be investigated further.

The authors of SC/57/IA9 commented that their model's estimates of recent trends are dependent upon assumptions about temporal changes in carrying capacity (*K*) and the relative weight given to different data sources. Thus such models are unlikely to entirely resolve differences between CPII and CPIII.

10.1.2.3 OTHER

SC/57/O21 examined whether predator-prey interactions alone could broadly explain observed population trends of the major species without resorting to environmental change hypotheses. As a first step, a model was developed that included krill, four baleen whale species (blue, fin, humpback and Antarctic minke) and two seal species (Antarctic fur and crabeater). The study inferred that:

(i) species interaction effects alone can explain observed predator abundance trends, although not without some difficulty;
(ii) it was necessary to consider predator species other than baleen whales to explain the observed trends, with crabeater seals being particularly important and in need of improved abundance and trend information;
(iii) the Atlantic/Indian region showed major changes in species abundances, in contrast to the Pacific which was much more stable;
(iv) baleen whales need relatively high growth rates to explain the observed trends; and
(v) the previous estimate of some 150 million tons for the krill surplus (Laws, 1977) may be too high since his calculations omitted density-dependent effects on feeding rates.

The Committee recognised that investigating interactions between species is important and welcomed contributions on this issue. The considerable discussion on the issues related to this model and the interpretation of its results is summarised in Annex G (item 3.3.3). These discussions include: the inclusion of other species in the model; pooling over the two species of krill; incorporating inter-annual changes and a correlation between the level of competition and good and poor krill years; the fit of the data; the effects of setting bounds on the parameters; the interpretation that the crabeater seal box also represents all other krill predators; the effect of assuming a top-down model in contrast to a bottom-up model; and the effect of the restriction of the study area which is only part of the habitat for some species in the model. It was noted that just because one model is consistent with the data, this is not a reason to accept its underlying hypotheses as the only plausible hypothesis. Many other hypotheses may also lead to models that fit the data, including a combination of top-down and bottom-up hypotheses.

The Committee noted that in many regions, assessments of numerous species are starting to be considered within an ecosystem framework. To consider an ecosystem framework for assessments of large whales, topics such as ecosystem models, competition between different large whale species and between large whales and other species must be discussed. The Committee also recognises the need for collaboration with other organisations to ensure that the Committee has the necessary expertise available. The Committee recalled the views of its previous workshop (IWC, 2004g) and **agrees** that ecosystem modelling should be added to the agenda next year and invites members to contribute papers on this issue (and see Item 19).

10.2 In-depth assessment of western North Pacific common minke whales, with a focus on J stock

10.2.1 Report from intersessional Steering Group

SC/57/NPM4 reported the activities of the intersessional steering group that were preparing for an in-depth assessment of western North Pacific common minke whale, with a focus on the J-stock. The Group met at the end of last year's meeting to discuss data availability issues and ways to proceed with the intersessional work (IWC, 2005h). The intersessional work focused on three areas: update of information and data; availability of data under Procedure B; and analyses conducted. Papers resulting from these preparations are discussed in detail in Annex G (item 4) and summarised below.

10.2.2 Distribution and abundance

In response to a request from last year, SC/57/NPM15 investigated the relationship between common minke whale distribution and oceanographic conditions in Korean waters. Data from commercial whaling records and sightings surveys around the Korean Peninsula from March to October during 1977-2004 show that common minke whales occur in areas with an annual mean SST range of 12-20°C. Common minke whale distribution was in the temperature range 13-25°C from March to July in the seas to the south and east of the Korean Peninsula. It was also noted that the abundance of common minke whales may be influenced by the abundance of prey organisms such as anchovy and zooplankton.

The Committee welcomed this review.

SC/57/NPM13 reported an investigation of the distribution and abundance of common minke whales based on catch and effort data from whaling in the waters around the Korean peninsula from the 1960s to the mid 1980s. Abundance indices were generally high from March to June with a peak in May. A lower secondary peak occurred in September. Potential migration paths and relative densities are discussed in detail in Appendix G.

SC/57/NPM3 and SC/57/NPM8 provided provisional abundance estimates of common minke whales from Korean surveys. The Committee welcomed this information along with a cruise report from April-May 2005. These are discussed in detail in Annex G (item 4.2) and the Committee looks forward to receiving revised estimates in the future.

A historical review of changes in the large whale species targeted by hunting off the Korean peninsula was presented. It suggested that the waters off Korea were historically abundant whale habitats as featured in the Bangudae petroglyphs from prehistoric times, various logbooks of foreign whaling vessels that harvested in Korean waters in the 19th century and bycatch data after 1990. Large whale species declined before the ban on whaling.

The Committee thanked the authors for this review and noted the plan to bring a revised version to a future meeting.

SC/57/NPM1 reported the results of a sighting survey in the Sea of Japan in spring 2004. Permission to survey in the Russian Exclusive Economic Zone (EEZ) was not granted so, during 11 May-29 June 2004, the research vessel, *Shonan-maru* No.2, covered the same area as in 2003. Abundance estimates are not yet available.

In discussion, it was noted that the large number of strata included in the survey design may lead to higher variances than are appropriate. Future survey design should aim to maintain equal coverage in the survey blocks so that, if appropriate, data can be pooled over blocks during analyses. This should minimise problems with large variance estimates and provide greater flexibility in analysis.

The Committee noted that the data from Japanese surveys conducted prior to 2002 had not been analysed to provide estimates of abundance. As shown in IWC (2005f, p.225), all these surveys had very low numbers of primary sightings, at least in part due to the timing and the small size of the areas surveyed. From 2002, the number of vessels used on surveys was increased, leading to improved coverage and to data that were sufficient for analysis. The Committee **encourages** that these data be analysed and presented at the next meeting.

10.2.2.1 PLANS FOR FUTURE SURVEYS

SC/57/NPM2 presented a plan for sighting surveys in the North Pacific to be conducted in summer 2005 and spring 2006. Permission to survey in the Russian EEZ to the east of the Kuril Islands and the Kamchatka Peninsula has been granted by the Russian Federation for summer 2005. The last survey in the Russian EEZ east of the Kuril Islands was in 1990; this will be the first time that a dedicated sightings survey has been conducted in the waters east of the Kamchatka Peninsula. Two research vessels will survey from 23 July to 20 September 2005. A survey is also planned in the northern Sea of Japan in spring 2006. Japan will make an application to survey in the Russian EEZ before the acceptance deadline. The survey is planned to be in standard IO passing mode with the priority species being the common minke whale. The tentative dates are 12 May to 30 June 2006.

The Committee thanks the Russian Federation for granting permission to conduct the sighting survey in their waters during 2005 and **requests** that permission is also granted for the 2006 survey. The Committee **encourages** the development of practical ways to investigate movements of animals from the Sea of Japan into the Sea of Okhotsk and North Pacific. The Committee noted that Miyashita, a highly experienced scientist on sighting surveys, would be in charge of the cruises and **agrees** that he should act as the Committee's representative for the purposes of oversight under the RMP.

SC/57/IA21 reported Korean plans to conduct a sightings survey using the vessel *Tamgu* 3, 10 April-29 May 2006, following recommendations from the Committee. Standard one-team IWC methods for conducting sighting surveys will be employed. If circumstances allow, biopsy sampling will be undertaken. The Committee was pleased to see these plans and noted that the timing was appropriate. As only one platform is being used $g(0)$ cannot be estimated. It was suggested that the survey should focus on blocks that have not yet been surveyed or had received little coverage. The Committee noted that Sohn and An, who are experienced in conducting sighting surveys, would be on the cruise and **agrees** that they should act as the Committee's representatives for the purposes of oversight under the RMP.

The Committee noted that it is still in the process of preparing for an in-depth assessment and it **encourages** that all work to generate abundance estimates continue so that it will be in a position as soon as possible to conduct the assessment. In this respect, a number of issues were raised.

Despite the completion of a number of surveys in recent years, the Committee noted the low survey coverage, particularly in sub-areas 6 (50%) and 10 (20%). The Committee **recommends** that future surveys fill these gaps. The Committee also **recommends** that the Commission requests the relevant authorities of the Russian Federation to grant permission for survey vessels to enter EEZ and territorial (coastal) waters. The Committee **encourages** collaboration between Russian, Japanese and Korean scientists to facilitate conducting surveys in as much of these sub-areas as possible. In addition, although the surveys being conducted are providing increasing coverage of the area, some unsurveyed areas are likely to remain and consideration needs to be given as to how such areas will be treated. For example, it is difficult to survey the waters very close to the Korean and Japanese coasts.

A review of the timing of all the surveys is also needed to avoid problems when combining estimates. Consideration will also need to be given as to how the data will be used to estimate trends in abundance.

10.2.3 Stock structure

SC/57/NPM10 updated previous studies of haplotype diversity in the mitochondrial control region using 305 samples from common minke whales bycaught in Korean waters 1998-2005. PCR/direct sequencing data revealed that:

(1) haplotype frequencies showed no difference across the years analysed;
(2) the haplotype diversity and nucleotide diversity were 0.898 and 0.00670, respectively; and
(3) with no pooling there were no significant local differences, whereas using two haplogroup classifications based on single nucleotide partitions, referred

to as A4 and A5, differences were significant. Preliminary results from analyses of genetic diversity using six microsatellite loci from samples from bycaught common minke whales from Korea were also presented. These results show the possibility that there are two or more subpopulations, in accordance with the mitochondrial DNA analyses.

It was noted that care is needed in interpretation of the results of these studies because of the small sample sizes. The FST values in the microsatellite study seem too small to be significant and application of Bonferroni corrections may show that the results are not actually significant. In addition, the basis and reasons for the definition of groupings A4 and A5 was questioned.

SC/57/NPM5 presented results of genetic investigations into the population structure of western North Pacific common minke whales from coastal waters of Japan and the Republic of Korea based on products purchased on the retail markets between 1999 and 2004, updating analyses presented in Lavery *et al.* (2004). Comparisons between the two market divisions (Japan and Korea) and among the four market/stock divisions (J and O haplogroups within each market) contradicted a number of assumptions about stock structure and incidental takes used in previous RMP *IST*s. The authors concluded that the results support the hypothesis of multiple coastal stocks in the waters of Korea and Japan.

Other members reiterated their previously expressed concerns about the use of market samples to make inferences about stock structure due to the lack of data on the origin of the market purchase (i.e. the date and location of where and when the animal was bycaught). They also referred to methodological problems with the analysis. This and related issues are discussed further in Annex G (item 4.3).

In conclusion, some members of the Committee believed that the results presented at this year's meeting provided evidence of population structuring within J-stock. Others disagreed and believed that it was too early to come to such a conclusion. The Committee **agrees** that further work is required and believes that collaborative studies would be the most productive way to further understanding of stock structure of common minke whales in this area.

The Committee was informed that some collaborative studies between Korea and Japan are ongoing and it **encourages** further collaborative work between Japanese and Korean scientists. The Committee looks forward to the presentation of results from genetic analyses of animals from Korean and Japanese bycatch at next year's meeting.

The Committee also noted that a large difference in the peak of conception for animals in the J- and O-stocks has been shown. This and other non-genetic information will need to be taken into account when considering stock structure.

10.2.4 Biological parameters

SC/57/NPM12 presented an investigation into variations in length and sex ratio by location, using data from 320 common minke whales bycaught in Korean waters from 1998 to 2004. The authors concluded that there is probably some spatio-temporal segregation by length and sex, in that most bycaught animals are small in size but their sex ratio differs by month and year.

The Committee **agrees** that the strongly varying sex ratio by season is indeed suggestive of segregation by sex, and thus integrating genetics into studies of variation in length and sex by month/year and location would be informative.

SC/57/NPM14 presented a study of age and growth in common minke whales bycaught in Korean waters from April 2002 to May 2004. This is discussed further in Annex G (item 4.4).

10.2.5 Total takes

SC/57/BC5 reported on a mark-recapture estimate of the total number of common minke whales entering the Korean market, regardless of their source. The best estimate was 827 whales (SE=164), which suggests that more animals are entering the market than from recorded bycatch alone. The difference between the total market supply and the recorded bycatch is imprecisely estimated and could be improved by comparing the results with data from DNA registers. Further discussion of this paper and points arising from it are in Annex J.

SC/57/NPM6 provided an estimate of the proportion of J- and O-type common minke whale products purchased on Japanese markets from December 1997 to February 2004, using mixed-stock analyses, to set plausible bounds of total takes over time. This paper is discussed in more detail in Annex J. Based on grouping the market individuals into mtDNA haplogroups as described previously by Baker *et al.* (2000), the proportion of J-stock individuals on the Japanese market was estimated to be 45.5% (SE=4.3%) over the seven-year study. There was no significant difference in this proportion after the 2001 change in regulations controlling the sale of bycatch. A minimum total take of 616 J-stock common minke whales over the seven-year survey period was estimated using the estimated stock proportions and the known Special Permit take of 740 from the O-stock.

Responses to this paper are given under Item 7.2.2.

10.2.6 Assessment methodology

SC/57/NPM7 put forward a Bayesian framework for the assessment of the J-stock of common minke whales. The approach makes use of catch and commercial Catch Per Unit Effort (CPUE) information and, in particular, applies a set net effort-based model to estimate bycatch in years for which these data are not available. Pending finalisation of the actual data that might be used for input, an illustrative application of the approach was provided. The results were shown to be particularly sensitive to the commercial CPUE data used.

The Committee noted that the assessment model would need to be updated with the new data on abundance and total takes and adapted in the future depending on the results of discussions on stock structure. Work is currently being undertaken to provide these new data.

The Committee discussed the use of catch or bycatch per unit effort (CPUE) as an index of abundance for assessment. The Committee **agrees** that actual data on fishing effort from each fishery with significant bycatch should be used, and that these would need to be disaggregated by season, area and gear type. The bycatches themselves should also be disaggregated to the extent possible, such that a Generalised Linear Model (GLM) standardisation of the kind commonly used in the analysis of fishery CPUE data could be applied. The Committee **recommends** that the required data be made available. GLM standardisation is also important for the commercial CPUE data, but in particular disaggregation by area is required, given the shift in effort from the Sea of Japan to the Yellow Sea between

the earlier and later years of the series. The Committee recalled the extensive discussions of the use of CPUE data in earlier years and the potential problems when using this type of data, and **agrees** that the problems identified in the report of the 1987 Workshop on the Use of CPUE Data (IWC, 1989) should be considered before further developing a CPUE-based assessment. It was noted that CPUE series had nevertheless been analysed and effectively used for common minke whales in the Barents Sea using indices for individual vessel.

Estimates of absolute abundance are critical for the in-depth assessment. As recommended in Annex G, item 4.2, future surveys should aim to cover as wide a range as possible to improve coverage. Information on the proportion of animals moving from the Sea of Japan into the Sea of Okhotsk, about which there is great uncertainty, would be very valuable.

The Committee **agrees** that any decision on the most appropriate assessment method should wait until a range of such methods have been evaluated.

10.2.7 Other

In response to a request from the intersessional Steering Group, Kim provided a brief summary of the historical trends in Korean stationary fishing gear. There have been dramatic increases in both the number and the area covered by fishing gears since the early 1990s, but sharp decreases since the early 2000s, due to restructuring of the fisheries industry to reduce fishing effort in Korea. The Committee **welcomes** this information.

10.2.8 Future work

The Committee **agrees** that the material presented at this meeting was a significant advance and thanked Korean scientists in particular, for their hard work during the previous year. However, it was clear that large information gaps still remain. For example, the CPUE data are limited and difficult to interpret, there are large gaps in coverage in sighting surveys that provide estimates of abundance, stock structure is still unclear, and there is no information on bycatch in countries other than Japan and Korea. The Committee recognises that a quantitative assessment may be several years away. However, there was a need to proceed with some urgency, particularly because of the Committee's concern about the effect of bycatch on the status of the J-stock. Some members noted that evidence presented to date showing relatively low abundance and high bycatch had not allayed this concern.

The Committee **recommends** that the work identified in its report continue as expeditiously as possible. The results of the Steering Group's (Annex P(11)) deliberations on a future work plan can be found in Annex G, Appendix 6.

10.3 Southern Hemisphere whale stocks other than Antarctic minke and right whales (see Annex H)

10.3.1 In-depth assessment of Southern Hemisphere humpback whales

The Comprehensive Assessment of Southern Hemisphere humpback whales has been discussed since 1999 (IWC, 2000d). At this meeting, substantial progress has been made and the Committee expects to complete the assessment in 2006.

The Committee had discussed whether to associate the historical feeding stocks of Southern Hemisphere humpback whales (Areas I–VI) with the more recently assigned breeding ground classifications (A-G, X; IWC, 1998a). Since no consensus on the appropriate association was reached, the Committee **agrees** at present to continue to refer to the feeding grounds by their number and the breeding grounds by their stock letter.

10.3.1.1 REPORT OF THE INTERSESSIONAL GROUP

The Committee received a report from the intersessional group to summarise the state of knowledge of Southern Hemisphere humpback whale stocks (Annex H, Appendix 7). It thanked the group and **recommends** that its work continues until the Comprehensive Assessment of this species is completed. It also **agrees** that the table (SC/57/SH11) with summarised information be published on the Commission's website[8].

10.3.1.2 DISTRIBUTION AND ALLOCATION OF HISTORIC CATCHES

The Committee examined information on humpback whale historic catches in the Southern Ocean during the period following World War II with emphasis on IWC Areas IV, V and VI (SC/57/SH6).

Last year, the Committee proposed that the allocation of historic catches from the Antarctic Peninsula be investigated in light of new information on stock structure (IWC, 2005g, p.244). After some discussion, the Committee agreed that the A/G border in the feeding grounds requires modification. Two scenarios were suggested. The first apportions all catches to the west of 50°W and south of 60°S to breeding stock G, while the second apportions all catches to the west of 50°W and south of 50°S to G (fig. 1 in Annex H). The Committee **agrees** that the 100°W-70°W core area for stock G be extended eastward to 50°W.

The key remaining issue for the catch series is to assign the 1959/60 and 1960/61 catch information presented in SC/57/SH6 to the correct stocks. Currently, they have been allocated based on the proportion of the reported catches. It was suggested that all catches provided in SC/57/SH6 be compared with the IWC database, with resolution of any differences in either catch numbers or area assignments. It is probable that the IWC database requires updating in terms of positional information (at the highest resolution possible) for the 1959/60 and 1960/61 *Slava* and *Sovietskaya Ukraina* catches; the breakdown of these catches into smaller areas will be possible for some, but not all, catches. The likelihood of determining the locations of the 7,177 Soviet catches from the *Slava*, *Sovietskaya Ukrania* and *Sovietskaya Rossia* expeditions for which there are currently no location data requires investigation.

The Committee noted that funding is already available for a meeting of a small group (Annex P(1)) to finalise the incorporation of the Soviet catches into the IWC database. The Committee **recommends** that this meeting take place within the next six months and that the existing group of scientists proposed last year be expanded to include Clapham and Findlay. This meeting should further review and verify the fleet cruise tracks, so that the feasibility of apportioning unknown humpback whale catches on cruise tracks can be assessed. The Committee **recommends** that the humpback whale catch series should be finalised by January 2006 and made available on the IWC website for use in the population dynamics modelling (see Item 10.3.1.4).

[8] *http://www.iwcoffice.org/commission/sci_com/scmain.htm.*

10.3.1.3 NEW INFORMATION ON ABUNDANCE, RATES OF INCREASE AND STOCK STRUCTURE

10.3.1.3.1 ANTARCTICA

The Committee received a number of papers on this topic. These included the examination of the movements of humpback whales around the Antarctic Peninsula (SC/57/SH2), a genetic analysis of the relationship between two feeding areas (west coast of the Antarctic Peninsula and the Magellan Strait) and breeding stock G (SC/57/SH3), and a study of the relationship of humpback whale density and chlorophyll-a concentration in the Gerlache Strait (SC/57/SH8).

An update on data collection from IDCR/SOWER humpback whale samples from Areas I, II and III was provided to the Committee. A total of 92 samples are available and analysis should be completed and presented by the next annual meeting. The sample sizes that exist for Areas I, II and III are relatively small. If the genetic data contrasting wintering regions and potential corresponding feeding grounds are to be useful for the assessment of Southern Hemisphere humpback whale stocks, it is necessary that biopsy sampling during future Antarctic cruises be given the highest priority. Recognising the complexities and issues of survey design and priorities for cetacean work by the IDCR/SOWER cruises in the Antarctic environment, the Committee **urges** that the collection of tissue biopsy samples from Antarctic humpback whales be given greater priority than at present.

It was noted that a proposal for access to samples collected during IDCR/SOWER cruises from Areas IV, V and VI was approved some time ago. In 2003, it had been agreed that half of all of the IDCR/SOWER samples would be transferred to the Southwest Fisheries Science Center in the USA (IWC, 2004b, p.50), although the samples have not yet been shipped. The Committee **recommends** that priority be given to the transferring of these samples (Zerbini will oversee this process).

A summary of the genetic analyses of 287 humpback whale samples obtained during JARPA surveys at the feeding grounds of Areas IIIE, IV, V and VIW was presented (Pastene *et al.*, 2005). Focus was given to testing the geographical ranges proposed by the Committee for stocks C, D, E and F[9] in the Antarctic feeding grounds (IWC, 2005g, p.236). Results of mtDNA analysis showed that whales in these geographical ranges are genetically differentiated, suggesting some structure of the humpback whales in the feeding grounds. However, analysis based on six microsatellite loci, while exhibiting some degree of genetic heterogeneity, was unable to discriminate among these potential stocks. It was suggested that different degrees of fidelity to breeding areas between females and males could explain such results. Analysis of mtDNA suggests that the historical sector of mixing between stocks D and E at 110-130°E has been occupied more by the D stock in recent years.

Estimates of abundance and rates of increase for humpback whales from JARPA cruises were presented (Matsuoka *et al.*, 2005). There was substantial discussion on issues related to potential sources of bias from JARPA data (Annex H, item 6.3.1), with different views being expressed (Annex H, Appendices 2 and 3). It was noted that the JARPA review is currently scheduled for mid- to late-2006 (SC/57/O2). The Committee **agrees** that issues associated with the interpretation of the JARPA data should be considered at the JARPA review meeting. However, it also encourages submissions that will help inform the discussion and consideration in the meantime.

Details on the discussion of these papers are found in Annex H, item 6.3.1. The Committee welcomed them and **recommends** that these studies be continued in the future.

10.3.1.3.2 SOUTH AMERICA

The Committee received two papers from South America. These included the first photographic matching of a humpback whale from Brazil to South Georgia (SC/57/SH1). Information from photo-identification data showed that whales feeding in the Magellan Strait migrate to Ecuador, Costa Rica and Panama with strong site fidelity to the latter locality (SC/57/SH10). Details of these studies can be found in Annex H, item 6.3.2. The Committee welcomed the presentation of these papers and **recommends** that these studies be continued in future years.

10.3.1.3.3 AFRICA

The Committee received SC/57/SH13, which evaluated the significance of the division of breeding stocks between regions in the South Atlantic and Western Indian Ocean (stocks A, B, C and X). As discussed in Annex H (item 6.3.3), the situation is complex and at present no change to the sub-region nomenclature is recommended. There is no value in trying to redesign the boundaries without clear definition and degree of gene flow for the various sub-regions. Based on the total evidence and on the direct observation of dispersal of identified individuals, it seems that in at least some localities gene flow is ongoing across present boundaries. The minimum gene flow that is required between two localities in order to include them within a single management unit has not been established. The Committee welcomed the work presented and **recommends** that these studies be continued in future years.

10.3.1.3.4 OCEANIA

The Committee received three papers under this item. The report of the 6th Annual Meeting of the South Pacific Whale Research Consortium (SC/57/SH9), noted numerous new matches made between existing catalogues in this region, demonstrating a significant degree of interchange between over-wintering grounds. Of particular interest was the discovery of matches between French Polynesia and other areas of the South Pacific: Cook Islands (1), Tonga (5) and New Caledonia (1). A new catalogue from American Samoa provided new matches with French Polynesia, the Cook Islands and Tonga, despite a relatively small number of fluke photos. This further demonstrates the complexity of interchanges between the various populations of humpback whales in the South Pacific region.

The Committee received an updated analysis of the population structure of South Pacific humpback whales and the origin of the eastern Polynesian breeding grounds (Olavarria *et al.*, 2005). The significant geographic differentiation reported supports the recognition of at least five subpopulations (breeding grounds) of humpback whales across the South Pacific, each one corresponding to a specific winter breeding ground. The most isolated humpback whale subpopulation within the South Pacific is found in waters off Colombia. The differentiation of mtDNA diversity between the Indian Ocean breeding ground (Western Australia) and the South Pacific grounds (except with Colombia) was low. The significant

[9] According to the sub-committee's decision (Annex H, item 6), these are equivalent to Areas IIIE, IV, V, VIW.

segregation observed among breeding subpopulations is partially consistent with the six IWC Antarctic management stocks, largely corresponding with one or more tropical breeding ground, supporting a further division of breeding stock E at least into two units. The question of the origin of the breeding areas in eastern Polynesia remains unresolved.

SC/57/SH12 presented preliminary new abundance (6,555 ± 389 whales) and rate of increase (10.6 ± 0.5%) estimates for the eastern coast of Australia. The rate of increase agrees with those previously obtained for this population and demonstrates the continuation of a strong post-exploitation recovery. It was noted that there was no expectation that the Committee would accept the estimate but rather that it would provide feedback to the authors of the paper, who would then bring a final estimate to the Committee next year.

Further discussion of these papers is described in detail in Annex H, item 6.3.4. The Committee welcomed these papers and **recommends** that these studies be continued in the future.

10.3.1.4 POPULATION DYNAMICS MODELLING

Four papers were presented under this item. SC/57/SH15 presented a Bayesian assessment of breeding stocks D and E (western and eastern Australia) using a model that allows for mixing on their feeding grounds. The Base Case estimates current abundance relative to the pre-exploitation population size (K) to be 0.46 for stock D and 0.29 for stock E. Projections into the future assuming a zero harvesting scenario show (in terms of the median) near complete recoveries to pristine levels in some 15 years for stock D and some 20 years for the currently more depleted stock E. A posterior distribution for the maximum growth rate parameter r was developed. It was suggested that this prior be used for similar Bayesian assessments of other Southern Hemisphere humpback whale populations for which little or no information on increase rates is available. Two other papers used this prior to assess the status of the stocks B (western Africa), C (eastern Africa), G (western coast of South America) (SC/57/SH16) and A (eastern South America) (SC/57/SH17). Current abundance estimates for breeding stocks A, B and G are low (0.25K, 0.09K and 0.25K respectively), whilst the current abundance estimate for breeding stock C is much further recovered at 0.79K. Projections under a zero harvesting strategy estimate breeding stock C to be fully recovered by 2020, whilst breeding stocks A, B and G will be fully recovered only by about around 2030. Details on the discussion of these papers are to be found in Annex H, item 6.4.

The Committee noted that while the data available for breeding stocks D and E dominate updates of prior inputs for growth rate in the Bayesian assessment of these populations, this is not the case for breeding stocks A, B, C and G. Estimates of future trends for all four of these and of the current status for B, C and G are heavily dependent on extrapolation of growth rate information for stocks D and E through the use of a posterior distribution from the latter as a prior for the former. This process could be improved by the use of hierarchical meta-analysis for stocks B, C and D, but nevertheless that would be based on as few as two estimates for the growth rate parameter r from stock D and stock E if only other Southern Hemisphere humpback whale populations are taken into account. For this reason, the Committee cautions that estimates given above for stocks B, C and G should not be regarded as very reliable.

SC/57/O21 described a multi-species model based on feeding ground information (from IDCR/SOWER population estimates) for absolute abundance rather than the breeding stock-based estimates used in the models presented above. The model's results suggested that the population growth rate would slow sooner in the future than is suggested by the single species models. Details on the discussion of this paper are to be found in Annex G, item 3.3.3.

The Committee welcomed the presentation of these papers and **suggests** that further work be done to refine the input data for the models and the modelling framework.

10.3.1.5 ANTARCTIC HUMPBACK WHALE CATALOGUE

SC/57/SH7 summarises the progress of the Antarctic Humpback Whale Catalogue (AHWC). During the 2004/5 contract period, the AHWC catalogued 445 photo-identification images representing 315 individual humpback whales, including 50 previously known individuals. These submissions bring the total number of catalogued whales to 2,238. Matches made during the contract period to previously sighted individuals include resightings between the Antarctic Peninsula and Ecuador (7) and Colombia (1); between Ecuador and Colombia (2); between Chile and Ecuador (2); the first documented re-sighting of an individual between Brazil and the Scotia Sea (1); and between Eastern Australia and Antarctic Area V (1). Trans-equatorial migration is confirmed by some of these resightings. It was noted that the website has been revised in accordance with IWC policy, and users may now choose to search a public database or log in as a contributor. It was noted that the IDCR/SOWER cruise was one of the very few contributors of Antarctic photographs outside of the Antarctic Peninsula and the Committee **recommends** continued collection of photographs to establish ties between the feeding and breeding grounds.

The Committee stressed the important contribution the catalogue makes to its work and **recommends** that it be continued. Financial implications are discussed under Item 21.

10.3.2 Assessment of Southern Hemisphere blue whales

10.3.2.1 NEW INFORMATION

A number of papers on blue whales (*B. musculus*) were presented to the Committee. They included reports of projects on blue whales off Southern Chile, where there is increasing research on the species (SC/57/SH5, SC/57/SH14, SC/57/O19). The Committee welcomed the presentation of these papers and **recommends** that these studies be continued.

The Committee considered the report of the intersessional group to summarise the state of knowledge of Southern Hemisphere blue whales. This was in a similar format to the humpback whale summary table referred to under Item 10.3.1.1. It was noted that available information was limited and that continued submission of abundance, trend estimates and stock structure information was welcomed. A number of sources of further information were identified and these have been incorporated into the table. The Committee **recommends** that the work of the intersessional group continue to complete this table.

10.3.3 Work plan

The Committee **agrees** that completion of the Comprehensive Assessment of Southern Hemisphere humpback whales is a high priority and that it should proceed as described in Annex H, item 6.8. This will

include an intersessional Workshop that will be partly funded by the government of Australia (for details see Annex H, Appendix 7[10]) and will focus on:

(1) advancing the Comprehensive Assessment of Southern Hemisphere humpback whales to near completion using the best available data; and
(2) reviewing the abundance, population structure and status of Southern Hemisphere humpback whales breeding populations and their relationship to feeding grounds in the Southern Ocean.

This will facilitate the completion of the assessment by the end of the next annual meeting. The Committee **recommends** that the Workshop take place and thanked the Government of Australia for its offer. Financial implications are discussed under Item 21.

Completion of the Comprehensive Assessment also requires the finalisation of a final catch series for Southern Hemisphere humpback whales. The Committee **recommends** that this work be undertaken at an intersessional meeting in Cambridge.

The Committee **agrees** that the Comprehensive Assessment of blue whales should be initiated in 2006, as previously recommended (IWC, 2005g, p.244). In this regard, Branch will try to:

(1) provide new abundance estimates from recent IDCR/SOWER cruises;
(2) provide an updated catch series split by sub-species and area;
(3) collate positional data from sighting, catch, acoustic sources, and satellite tags;
(4) revise the assessment by Ichihara and Doi (1964) of pygmy blue whales; and
(5) examine the feasibility of using IDCR/SOWER cruises to estimate the proportion of blue whales outside the Antarctic survey region.

Financial implications of the work plan are discussed under Item 21.

10.4 Other small stocks – bowhead, right and gray whales (see Annex F)

10.4.1 Small stocks of bowhead whales

SC/57/BRG11 described molecular genetic relationships among bowhead whales in eastern Canadian Arctic and West Greenlandic waters. The objective of the study was to investigate whether or not the Hudson Bay/Foxe Basin (HB-FB) bowhead whales are genetically distinct from the Baffin Bay/Davis Strait (BB-DS) animals. The ultimate goal will be to provide information for the management of the subsistence harvest of bowhead whales in the eastern Canadian Arctic. On the basis of the microsatellite analyses, Igloolik (HB-FB) samples were significantly differentiated from the Pangnirtung and Disko Bay (BB-DS) samples. Several mechanisms could have contributed to these results, including: geographic partitioning, age and reproductive status segregation, temporal segregation, selective mating strategies/success, or some combination of these factors. The subsequent discussion of SC/57/BRG11 on the relationship between bowhead whale stocks in the Arctic is given in Annex F (item 4.2.1).

SC/57/BRG8 described temporal changes of the genetic structure of the Spitsbergen stock of bowhead whales based on bones collected on raised beaches on Svalbard. The authors were unable to detect any temporal haplotype structure in the historical Svalbard population. In the future, they plan to extend the dataset with 200 additional samples from Svalbard and the Norwegian mainland. Rosenbaum indicated that a plan had been established to merge historical and current data sets from the eastern Canadian Arctic stocks with the data presented in SC/57/BRG8.

10.4.2 North Atlantic right whales

North Atlantic right whales are among the most endangered of all the large whales, with a remaining population of around 300 individuals. The population appears to be in decline, largely due to anthropogenic impacts such as ship collision and entanglement (IWC, 2002d). SC/57/BRG13 summarised recent research and management activities for this species. Reproductive rates have improved substantially in recent years and a total of 27 calves have already been identified in 2005. However, the status of this population continues to be a major concern in light of the high anthropogenic mortality. The Committee **repeats its previous recommendation** on this population (e.g. IWC, 2005c, p.32), i.e. that it is **a matter of absolute urgency** that every effort be made to reduce anthropogenic mortality in this population to zero. There were eight deaths in the past year, including six since November 2004. A precise cause could not be attributed in all cases, but four were known or suspected ship strikes and one was the result of entanglement. The USA has developed a strategy to address ship strikes through new operational measures for the shipping industry and education and outreach programmes.

Although calf counts have been high in recent years, survival rates have not been updated since the 2002 Workshop on right whale survival estimation (Clapham, 2002; IWC, 2003c, p.247). The Committee noted the importance of updated survival estimates and **recommends** that such an analysis be performed.

As noted in previous years, some North Atlantic right whales are only seen on their breeding ground, suggesting that some potential feeding areas remain unidentified.

SC/57/BRG7 described efforts to estimate the age of North Atlantic right whales based on allometric relationships visible in lateral photographs of their heads. Changes in the curvature of the rostrum and the height of the dome were the best predictors of age in the external anatomy of the head of right whales. The accuracy of age prediction decreased with age: it was maximal for calves and minimal for whales older than 8yrs. Mean coefficients of variation of repeated measurements ranged from 0.31 to 4.11%. The Committee commends the authors on this useful study and notes that now the technique has been developed on a group of known-age animals, it can potentially be applied to other right whale populations.

SC/57/BRG20 evaluated the results of Rastogi *et al.* (2004), which explored the impact that Basque whaling had on historical population sizes of North Atlantic right whales and bowhead whales. Both species had been severely hunted and, with the exception of one of the bowhead populations, neither has shown signs of recovery. The topic presented by Rastogi *et al.* (2004) was of considerable importance given that present management of North

[10] Although the proposal was first presented to the Plenary session, it is included as an Appendix to the Annex at which it was first discussed.

Atlantic right whales is focused on recovery to estimated pre-exploitation population sizes. The Committee considered that SC/57/BRG20 illustrated a number of errors in the work ranging from study assumptions and study design to analysis and interpretation. It concluded that Rastogi *et al.* (2004) have drawn inappropriate conclusions about pre-exploitation and 16th century right whale populations based upon genetic data from a single individual right whale.

The Committee **agrees** that the results of Rastogi *et al.* (2004) should not be used to estimate pre-exploitation size, recovery targets and levels of pre-exploitation genetic diversity for North Atlantic right whales.

10.4.3 Southern Hemisphere right whales

SC/57/BRG2 presented updated estimates of demographic parameters for Southern right whales on the south coast of South Africa. Aerial counts of right whale cow-calf pairs between 1971 and 2003 indicate an annual instantaneous population increase rate of $0.069/year^{-1}$ over this period. Observed calving intervals ranged from two to 23 years, with a principal mode at three years. The model of Payne *et al.* (1990) produces an estimate for adult female survival rate of 0.990 with a 95% confidence interval of (0.983, 0.997). First year survival rate was estimated as 0.734 (0.518, 0.95). The current population is estimated as some 3,400 animals.

The Committee welcomed the results of this study, which illustrates the great value of long-term monitoring. As it has in previous years, it **recommends** that this extensive programme be continued.

SC/57/BRG12 reviewed published catch data and the sighting distribution of southern right whales in the eastern South Pacific, off the coasts of Chile and Peru. The primary goal was to address a gap in knowledge identified in the 1998 Workshop on the status of right whales (Best *et al.*, 2001). Historical winter catches were primarily near central Chile (30°S), between Coquimbo and Valparaíso. Feeding grounds have not been well established for this population.

SC/57/ProgRep Australia described inshore aerial surveys for southern right whales off southern Australia in the winter and spring of 2004. Two 'short' flights on the southern Western Australia coast and one 'long' flight along the coast into South Australia were performed. The latter was used for the yearly comparison of the 'Australian' population. The number recorded on the 'long' flight in 2004 was not as high as expected given the previous strength of that three-year cohort in 2001. Nevertheless, significant positive increase rates were obtained for 'all' animals and cow-calf pairs in that data series. For cow-calf pairs, the increase rate for the period 1993-2004 was 6.4% (p=0.004) and the 95% CI remained wide (1.71-11.23%). The Committee welcomed this report and **recommends** that this monitoring programme and other long-term monitoring programmes be continued.

SC/57/O5 reported southern right whale sightings during the 2004/05 JARPA survey in Area V. Three individuals were sighted in three groups.

10.4.4 Other small stocks of right whales

SC/57/O3 reported North Pacific right whale sightings during the 2004 JARPN II survey. Four individuals were sighted in two groups, southeast of the Kamchatka Peninsula.

10.4.5 Western North Pacific (WNP) stock of gray whales

SC/57/BRG23 summarised the distribution and abundance of western gray whales off the northeast coast of Sakhalin Island, Russia in 2004. Aerial, vessel and shore-based surveys were carried out by the Russian programme during summer and autumn. There was a higher inshore distribution of gray whales compared to 2003, with sightings in the 'offshore' area having declined from 12 to three animals in aerial surveys, and from 50 to nine animals in vessel-based surveys. In the near-shore Piltun feeding area, the number of sightings increased from 27 to 49 sightings (aerial), from 47 to 63 (vessel-based) and from 70 to 122 (shore-based). The cause of observed gray whale redistribution is unclear but was most likely a reflection of prey availability. The main feeding season lasted two months, from the third 10-day period of July through to the end of September.

SC/57/BRG25 summarised efforts to study benthic communities in the two primary feeding grounds off the northeastern Sakhalin coast. Although some previous preliminary data were available for the benthic fauna at Piltun, the 'offshore' area had not previously been studied. Whales feeding at Piltun were found mainly within a shallow-water benthos complex dominated by amphipods and isopods. Mobile, deposit-feeding amphipods were dominant and distinguished by their eurybiotic nature, short life cycle and high growth rates. The 'offshore' feeding area was characterised by the seston-feeder amphipod, *Ampelisca eschrichti*.

SC/57/BRG9 described Russian efforts to photo-identify western gray whales on the northeastern Sakhalin shelf, 2002-2004. Photo-identification studies were conducted from the vessel *Nevelskoy* in 2002-03 and *Oparin* in 2004. Over the three years, 121 individuals had been identified. There was an apparent increase in the number of large groups in 2004 relative to the previous year.

SC/57/BRG1 presented the 2004 results of the on-going Russia-USA research programme on the western gray whale population summering off northeastern Sakhalin Island. A total of 92 whales (including seven calves and two previously unidentified non-calves) were identified from photographs leading to a 1994-2004 catalogue of 140 photo-identified individuals. Between 1995 and 2004, 23 known reproductive females had been documented. However, over the course of this study six calves had already been weaned by the time they were first encountered. Therefore, if all six of these 'independent' calves had mothers other than the 23 known reproductive females, the maximum number of calf bearing females could be as high as 29 individuals. Genetic samples collected from these whales will be used to determine the identity of the mothers. There are plans to produce and publish a western gray whale photo-identification catalogue (140 animals) before next year's meeting.

SC/57/BRG22 presented an analysis of western gray whale photo-identification data collected in the Piltun feeding ground, Sakhalin, during 1994-2003. This analysis had also been presented to the World Conservation Union (IUCN) independent scientific review panel (ISRP) for western gray whales in 2005 (Reeves *et al.*, 2005), discussion of which is provided below. An individually-based, stage-structured model was fitted to the data, to estimate vital parameters and to project the population forward under different assumptions. The population was estimated at 102 animals aged 1+ in 2004 (90% CI 94-110).

The 1+ survival rate was estimated as 0.97 (0.96-0.98), while the 'yearling' survival rate (i.e. from the first to the second summer of life) was estimated at 0.73 (0.61-0.83). The population is estimated to have been increasing at approximately 3% (90% CI 1-5%) per annum during this period. Projections forward to 2050 indicate that if the current situation continues, the population is very likely to continue to increase as long as there are no additional deaths. However, projections under the assumption of one additional female death per year indicate that the population would decrease and quite likely become extinct by 2050.

To date, Piltun and the 'offshore' area are the only two feeding areas known in the Okhotsk Sea. All photographs of western gray whales found outside of the Sakhalin Island feeding ground have been successfully matched to the animals using the Piltun area.

SC/57/BRG18 described the sighting and ultimate entanglement death, of a juvenile female gray whale in Tokyo Bay. The animal was sighted repeatedly from mid-April until its recovery in a coastal set net on 11 May 2005. This was despite the fact that central and local authorities had given instructions to fisheries operating in the vicinity of Tokyo Bay not to disturb the animal and to try to release it if it became entangled. The whale was 7.81m in length and estimated at 1.5 years and was thought to be a recently weaned animal on its second northbound migration from the wintering ground to the northeast coast of Sakhalin.

SC/57/BRG14 provided an update on the genetic analysis of western gray whales. Western gray whales have been shown to be significantly different from the eastern population using mtDNA analysis and nuclear markers. However, the differentiation between the populations is greater for females than it is for males. This finding, coupled with the high number of mtDNA haplotypes in the western population, especially among males, raises the possibility of low levels of male dispersal from the east into the west.

Sohn summarised the second year of shore-based surveys on western gray whales off the coast of Korea. Five researchers participated in the survey in 2004, with three individuals on watch at all times, rotating through three observation stations. Surveys were conducted 21-30 December 2004, however no gray whales were sighted.

The Committee welcomed the news that the Russia-USA programme has produced a catalogue of individuals identified to date that is near to publication. It noted that the catalogue would be available to all interested parties (contact R.L. Brownell). It **agrees** that the Russian scientists working on photo-identification as part of the oil companies' research work should compare their photographs with those in the catalogue, and that potential new whales should be reviewed by a group of experts (including scientists from both programmes) before being added to the catalogue. After the publication of the catalogue, the Committee **strongly recommends** that researchers from the two programmes work as quickly as possible to share and compare all their photographs, agree on a single catalogue that is updated regularly and collaborate on future data collection and analyses. As has been found elsewhere for other species, the Committee believes that conservation efforts for the western gray whale can be best achieved by collaboration rather than by completely separate photo-identification programmes.

The modelling work in SC/57/BRG22 has emphasised the critically endangered status of this population and in particular the potentially detrimental effect of the death of even one additional female per year. Given this, the Committee **recommends** that every effort be made to ascertain whether the animal that died recently in Tokyo Bay was a previously identified animal. This could be achieved by:

(1) comparison with the photo-identification catalogues; and
(2) comparison with the DNA catalogue held at the Southwest Fisheries Science Center (SWFSC), California on behalf of the Russia-USA programme.

Given the difficulties in standardising microsatellite loci between laboratories, the Committee **recommends** that arrangements be made for a sample from the Tokyo Bay animal to be sent to the genetic archive of the joint Russia-USA programme (i.e. the SWFSC). It **urges** the appropriate CITES authorities to facilitate this.

The Tokyo Bay entanglement illustrated the need for an education campaign for fishermen and others throughout the gray whales' potential range, to provide information on the need for every effort to be made to release incidentally caught whales and how this might best be achieved and the importance of taking photographs and/or collecting a sample from stranded or bycaught whales and providing them to the appropriate authorities. The Committee **urges** relevant Governments to try to implement these ideas.

Similarly, the Committee **recommends** that efforts be made in all of the range states to organise stranding networks, aerial surveys and beach surveys, particularly during the period of the northern migration (animals migrating north alone for the first time are probably the most vulnerable).

Finally, the Committee welcomes and supports the report of the ISRP (Reeves *et al.*, 2005) that had included five members of the IWC Scientific Committee (Brownell, Cooke, Donovan, Moore and Reeves). It commended SEIC[11] for requesting this review and IUCN for facilitating the process. Despite some difficulties, it believes that this process represented an important step forward for western gray whale conservation.

The Committee strongly supports efforts to build upon this in the future and to develop a framework for collaborative research, monitoring and mitigation efforts between oil companies, independent experts, national programmes and authorities and the IWC and other intergovernmental organisations. In this regard, it **strongly urges** that other companies in the area co-operate with this process.

An important addendum to the ISRP report (Reeves *et al.*, 2005) was the need for a comprehensive strategy to save western gray whales. The panel noted that while their review had necessarily focussed on the Sakhalin feeding region in Russian waters, gray whales spend approximately half their time in other waters in eastern Asia (Japan, the Republic of Korea, the Democratic People's Republic of Korea and China). The results from SC/57/BRG22 emphasise the need for mitigation measures for the many potential threats to the western gray whale throughout its range. There are a number of groups that already play a role in discussing and reviewing the population status and management and research needs for this population,

[11] Sakhalin Energy Investment Corporation, a consortium of companies developing oil and gas reserves in the region.

including the IWC Scientific Committee, the Russian Group for Strategic Planning of Gray Whale Research, the joint Russia-US programme, the IUCN Cetacean Specialist Group and other national programmes that may form the basis for developing a strategy. The importance of involving scientists, authorities and other stakeholders in the range states was recognised. The Committee **recommends** that the IWC plays an active and facilitating role in the process.

10.4.6 Work plan

The work plan for the coming year is to review new information on the WNP stock of gray whales, right whales and the small stocks of bowhead whales.

10.5 Future SOWER cruises (see Annex G)

10.5.1 Report from Intersessional Workshop

Last year, the Committee agreed that the objective of any future programme should be:

> to provide information to allow determination of the status of populations of large whales that feed in the Antarctic waters. The programme will primarily contribute information on abundance and trends in abundance (including of Antarctic minke whales), learning from both the successes of past IDCR-SOWER cruises and the difficulties in interpreting previous results (IWC, 2004b, p.35).

A Workshop (SC/57/Rep1) held in October 2005 continued work on the development of a future SOWER research programme. The Workshop agreed that the long-term goal for a future programme is to provide circumpolar estimates of abundance and trends in abundance for large whales that feed in Antarctic waters. It also agreed that the short term goal for a future programme is to undertake research on priority species including to: (a) undertake experimental surveys to provide information useful in developing optimal survey design and methodology and addressing problems with previous IDCR/SOWER surveys; and (b) provide estimates of abundance for smaller areas (in conjunction with stock structure studies), which will be potentially useful in investigating long term trends.

The Workshop agreed that the following species priorities should be assigned in order from highest to lowest:

(1) Antarctic minke and blue whales;
(2) fin whales;
(3) humpback whales;
(4) sei and right whales; and
(5) sperm whales.

The Workshop recommended that the Scientific Committee should consider its report as a set of guidelines for the development of an initial proposal for a future programme and that Scientific Committee members should provide papers to allow for efficient progress to be made on the development of a proposal for the long term programme.

The Committee **agrees** with the Workshop's long and short term goals for a future programme. In addition, the Committee **recommends** that the sightings surveys, as conducted previously, should not immediately be continued, and that in the short term the goals of the cruises should address questions and problems that have arisen during the previous CP surveys and should investigate different data collection and analysis methodologies that could be used to collect abundance and trend data for the large whale species that feed in Antarctic waters.

10.5.2 Recommendations for future SOWER cruises

10.5.2.1 2005/06 SEASON

For the practical purposes of planning, the Committee assumed that the Japanese Government would continue to provide vessels and assistance at the present level, even though it was recognised that no decision has been taken and that this represents a major investment from the Japanese Government. After evaluating potential experiments to address problems with previous analyses, new methods to collect less biased future data and other data needed to complete assessments of large whales in the Antarctic (Appendix 2 of Annex G), the Committee **agrees** the priority of research for the 2005/06 cruise is as follows (with highest priority assigned to the first item):

(1) Antarctic minke whales: Experiments designed to address problems with analysis and interpretation of CPII and CPIII Antarctic minke whale abundance estimates (BT mode, satellite tagging, collaborative research with icebreaker);
(2) a fin whale survey feasibility study north of 60°S;
(3) humpback biopsy and photo-identification studies; and
(4) continuation of blue whale research.

It was noted that the priority rankings of several experiments were conditional, for example, because of the uncertainty of being able to acquire the necessary equipment such as satellite tags and user-friendly high power binoculars. The research to be completed during the 2005/06 cruise is dependent on the completion of a number of tasks (listed in Appendix 2 of Annex G). The Committee **recommends** that these tasks be completed and the Tokyo planning meeting:

(1) facilitate a full evaluation and possible review of its relative priority ranking; and
(2) finalise the research to be conducted on the 2005/06 cruise.

The Committee **recommends** the IWC/SOWER Steering Group (Annex P(12)) complete the planning of the 2005/06 SOWER cruise.

Morishita stated that due to current budget difficulties, it now should not be assumed that the Japanese Government will be able to continue to provide vessels and assistance at the previous level. A decision will be made later.

10.5.2.2 LONG TERM

There was insufficient time available for the Committee to develop firm long term plans to fulfil the objectives of the SOWER programme. It was noted that feedback from the fin whale feasibility study planned for this year's cruise would provide information useful for the next step of designing a long-term plan for SOWER research. To promote discussion next year, the Committee **recommends** that, time allowing, the Planning Meeting produce an outline of a potential long-term plan and present this to the next year's meeting. In addition, the Committee **recommends** that members also submit proposals on this to next year's Committee meeting. Together these could be used to develop a proposed long-term plan for the SOWER research.

10.6 Other

10.6.1 Report from a non-IWC sponsored workshop on sperm whales

Bannister presented SC/57/IA8, Summary of Report of Cachalot Assessment Research Planning Workshop, Woods

Hole, Massachusetts, USA, 1-3 March, 2005[12]. Thirty six scientists from nine countries had participated. At its 2005 meeting, the Committee had accepted the initiative to begin preparing the background for an eventual in-depth assessment of sperm whales, noting that considerable progress is being made on improving basic knowledge of sperm whales; at that time it looked forward to the report as a useful way of integrating current understanding of the species.

The Workshop had three terms of reference, developed by a Steering Group within the IWC Scientific Committee:

(1) identify and evaluate new methods, identify critical tests of such methods, and describe how these might be conducted, especially using combinations of new methods simultaneously;
(2) identify relevant spatial scales and formulate plans for regional field studies to address key uncertainties relevant to an eventual in-depth assessment; and
(3) develop a research programme that would be necessary and sufficient as the basis for an in-depth assessment of sperm whales, including research coordination and funding mechanisms.

The Workshop's context was set by an overview of Whitehead's global assessment (Whitehead and Planck, 2002). Recent research was reviewed under the headings: population structure and movements, abundance and distribution, life history, population ecology, human interactions, field studies and future work. In addition to developing a systematic list of research topics and priorities, several items were identified as highest priority. These included: developing provisional hypotheses about population structure; obtaining information on female survival rates; improving historical catch data; exploring further the effects of differential exploitation by sex; improving methods to correct abundance survey data to account for bias; and refining population modelling approaches. The need for regular and substantive interaction between modellers and field researchers was emphasised. Three coordinating tasks were identified, including the need for a second Workshop in two years time.

The Commitee thanked the organisers for providing the report, and **agrees** that it should consider sponsoring the second Workshop.

10.6.2 Consideration of proposals for further in-depth assessments

North Pacific sei whales and Southern fin whales were suggested as candidates for future in-depth assessments. North Pacific sei whales were suggested because the IWC has not conducted an in-depth assessment on this species in over 30 years and takes of this species have resumed under JARPN II. Southern fin whales were suggested because they may be an important predator in the Antarctic ecosystem, takes of this species may be resumed (SC/57/O1) under JARPA II and there is some reason to believe that historical assessments may have underestimated the extent of depletion at the time of protection (SC/57/IA13). It was noted that new data on North Pacific sei whales are currently being collected under JARPN II and it is noted that new data on Southern fin whales will be collected during the 2005/06 SOWER survey. To evaluate which species should be considered for future in-depth assessments, the Committee **recommends** papers be presented at future meetings that discuss the reasons why an in-depth assessment should be conducted and the status of the necessary data (distribution and abundance, stock structure, biological parameters, total takes and assessment methods).

10.6.3 Historic abundance estimation: genetic methods

Last year, the Committee discussed a study by Roman and Palumbi (2003) which used genetic diversity in mtDNA to infer historical levels of abundance of 240,000 humpback, 360,000 fin and 265,000 common minke whales in the North Atlantic. The Committee agreed that these figures, which greatly exceeded previously reported estimates of pre-whaling abundance for at least humpback and fin whales, had considerable uncertainty associated with them and could not be considered reliable estimates of immediate pre-whaling population size. A Working Group listed a series of questions that needed to be addressed in order to resolve this discrepancy (IWC, 2005i) and an intersessional e-mail group was established to continue discussion of this issue.

Although some progress was made on a few of these issues (see below), this has not been sufficient to reconcile the genetic estimates with those from analysis of catch data.

10.6.3.1 GENETIC ISSUES: CORRELATING GENETIC DIVERSITY WITH EFFECTIVE POPULATION SIZE

Palsbøll summarised a report on progress in Palumbi's laboratory in the last year. New analyses of the mitochondrial control region mode of mutation based on multiple models of mutation and new data on baleen whale phylogeny and divergence times had revealed no significant change in their abundance estimates. Estimates of genetic diversity obtained from the cytochrome *b* locus (also in the mitochondrial genome) were compared to the original estimates obtained from mtDNA control region sequences. The cytochrome *b* locus was estimated to evolve about 5-7 times slower than the mtDNA control region, which is consistent with the 5-7 times lower estimates of diversity at this locus. The estimates of abundance are thus similar to that obtained for the mtDNA control region. These data were collected from Antarctic minke whales and may be biased by the large genetic variation in this population and the long branches leading to highly divergent control region lineages. Palumbi's lab is working on a phylogenetic estimate of the control region mutation rate based on overlaying the control region data on the cytochrome *b* genealogy; this should correct for multiple mutations in the mtDNA control region by using the cytochrome *b* sequences as a base line. A limited data set collected from humpback whales detected very low levels of variation among cytochrome *b* sequences compared to the mtDNA control region. The importance of additional cytochrome *b* sequences from humpback whales to make more headway with regard to the discrepancy between common minke and humpback whales was stressed.

Palumbi's laboratory was also collecting data from the mtDNA control region, mtDNA cytochrome *b* and nuclear data (10 loci) in 142 gray whale samples. They were likely to have preliminary estimates ready in the near future. They were undertaking new analyses on non-equilibrium estimates of population fluctuation based on genetic data. The data show long-term increases of population size in

[12] A final version of the workshop report is currently being prepared and will be available through the principal sponsor, the US Marine Mammal Commission (*www.mmc.gov*), or through the convenor, Dr. T. Smith (*tsmith@whsun1.wh.whoi.edu*).

Antarctic minke whales but with no signal of Ice Age fluctuations. The analyses revealed a steady population size in North Atlantic fin whales and population expansion in North Atlantic common minke whales. However, Palsbøll commented that the former conclusion is not reliable given the strong signal of expansion that he and his collaborators have observed in their fin whale data set from this ocean.

Humpback whales appear to have mainly stable population sizes over time but the estimates are highly variable. Palumbi had felt that this might reflect pulses of gene flow rather than pulses of population size. A Bayesian version of this latter analysis will be implemented to obtain confidence limits. There is no evidence of historic population crashes and that the analyses suggest that long-term average population size is lower than recent effective population size, at least in the case of the Antarctic minke whale.

Palsbøll commented that Palumbi's observations that the population expansions were pre-Pleistocene in origin, would mean that Roman and Palumbi's estimates would be, if anything, negatively biased (i.e. there would need to have been even more whales in the North Atlantic to explain the observed level of diversity). This analysis depended critically upon an estimate of mutation rate. If the true rate is significantly higher than that used in Palumbi's analysis (as many people believe), then the resulting estimates would drop sharply.

10.6.3.2 STATISTICAL RELIABILITY OF CATCH RECORDS

SC/57/O7 revisited the problem of estimating the pre-exploitation sizes of the two populations of North Atlantic humpback whales. Several sources of uncertainty in the underlying data and in population models were considered. One factor considered was the uncertainty in the estimated catches of North Atlantic humpback whales given by Smith and Reeves (2003). The sensitivity of the results from the model to this uncertainty was explored by considering extreme scenarios for the historical catches created by considering four sources of uncertainty:

(1) the effect of interpolating landings between years because of incomplete data series;
(2) statistical uncertainty associated with the estimate of barrels of oil per whale;
(3) statistical uncertainty with the ratio of numbers struck but lost; and
(4) the possibility that catch estimates for the years prior to 1850 were grossly underestimated because of limitations in data sources.

Upper bounds on catches considering each of the four factors ranged up to 43,000, and considering all factors simultaneously led to upper bounds of the order of 69,000. This value is 135% of the best estimate of historical catches of 29,000 whales, and implies a notional upper limit on pre-whaling abundance of 80,000, the present abundance plus total catches.

These upper bounds on catches and other uncertainties with the data for these populations were used to estimate pre-whaling abundance using different sets of data and model assumptions. As expected, the pre-whaling abundance estimates for both populations were below the 'notional upper limit'. For all models considered, including those that explored the extreme scenarios of catches, total pre-whaling abundance was still substantially below the estimate of average abundance over evolutionary time scales given by Roman and Palumbi (2003).

10.6.3.3 OTHER ISSUES

There was no reported progress on any of the other issues outlined last year.

The Committee **agrees** that this Working Group should continue during the coming year (see Annex P(32)). It noted that there are a number of new genetic analyses that are being undertaken that *inter alia* will provide considerably better estimates of mutation rate, one of the most critical (and uncertain) factors in the Roman and Palumbi article. It looks forward to receiving this information next year.

10.7 Work plan and budget request

10.7.1 Sub-committee on in-depth assessments

The Committee acknowledged the heavy workload of the sub-committee this year. There was considerable discussion on how best to relieve this workload. It was agreed that the highest priority next year is to try to finalise abundance estimates of Antarctic minke whales from the CPI to CPIII time series. The Committee therefore **agrees** that sufficient time should be allocated to achieve this. Consideration should be given to work on the North Pacific common minke whale in-depth assessment, to occur outside the sub-committee, at least for next year. The best way to achieve this will be discussed by the Convenors after the meeting (and see Item 19).

The priority topics under this Agenda Item will thus be in priority order:

(1) produce agreed abundance estimates of Antarctic minke whales;
(2) continue development of the catch-at-age analyses of the Antarctic minke whales;
(3) continue preparation for an in-depth assessment of WNP common minke whales, with a focus on J stock;
(4) develop recommendations for future SOWER cruises, both for the short- and long-term; and
(5) continue to examine and then attempt to agree on reasons for differences between minke abundance estimates from CPII and CPIII.

Annex G (Appendix 6) details tasks identified to produce estimates of abundance of Antarctic minke whales. Annex G (Appendix 4) details tasks to continue development of the catch-at-age analyses, where the goal is to complete these analyses at the 2007 meeting. The financial implications are discussed under Item 21. Annex G (Appendix 5) details tasks to continue preparations for an in-depth assessment of WNP common minke whales, with a focus on J stock.

11. STOCK DEFINITION (SEE ANNEX I)

11.1 Review progress on the Testing of Spatial Structure Models (TOSSM) project

In 2003, the Committee instigated the TOSSM project (IWC, 2004b, pp.27-8; IWC, 2004f, pp.469-85). The main aim of this project is to develop simulation tools that can be used to examine the performance of current and future genetic population structure techniques. The focus is on management implications, where the genetic techniques are used to suggest management boundaries, which in turn are used to set or subdivide catch limits according to some rule; the performance of different genetic methods is ultimately to be assessed in terms of how well a simulated management regime performs if the suggested boundaries are used. The Committee's experience of studying population structure, e.g. in developing *Implementation*

Simulation Trials (*ISTs*) for common minke whales in the North Pacific, has shown that genetic data do not usually provide unequivocal evidence of specific boundaries for use in management. Furthermore, few boundary-placement techniques have been subject to simulation testing. Even those that have, cannot be considered to have undergone the level of extensive simulation testing to incorporate uncertainty that has been a feature of, for example, the IWC's work on the RMP and AWMP. This is perhaps not surprising, given the scope and complexity of developing suitable genetically-specified simulation datasets.

The Committee has identified the following six work modules, each of which has to be completed before the simulation performance testing can actually begin:

(i) genetic simulation;
(ii) biology and population dynamics;
(iii) sampling;
(iv) catch strategy;
(v) adaptation of boundary-settings methods for testing; and
(vi) integrating all of the above to allow a complete test to be run.

The chosen vehicle for *Implementation* is the freely-available software RMETASIM developed as a result of the Workshop, which required some modifications to cope with whale-specific life history patterns and with harvesting. By the 2004 meeting, much progress had been made on those modifications and on the detailed specification of the above modules. Three technical priorities were identified last year, and following intersessional work by the TOSSM Core Group (Martien, Tallmon, Tiedemann), all three are expected to be complete by 1 July 2005. This will essentially complete modules (i), (ii), and (iii), at least for the simple demographic archetypes that are to be considered initially. It will then be possible to generate simulated genetic datasets suitable for boundary-setting methods; some further work will be required on (iv)-(vi) before the methods' performance can be tested. Although it was hoped last year that some such datasets would be ready for this year's meeting, delays beyond the Core Group's control have prevented this.

The Committee welcomed the progress made, and thanked the Core Group for their efforts. Future plans for the project are presented under Item 11.4.

11.2 Review of statistical and genetic issues relating to population structure (including DNA quality issues)

A number of methodogical papers were discussed (see Annex I). SC/57/SD1 described the initial development of an allele-matching model for analysing population structure, for use when the existence of subpopulations is uncertain and *a priori* assignment of samples to hypothesised subpopulations is problematic. The total genetic correlation is partitioned between a subpopulation component and a covariate-linked component unrelated to population structure. The authors plan to apply the method to B-C-B bowhead whales in the coming year. The Committee noted the promise of the approach, made a variety of methodological suggestions and **strongly encourages** its continued development and application for the 2006 meeting.

SC/57/SD2 presented further results of close-kin analyses, using new data in the North Atlantic common minke whale DNA register. The register was screened for pairs of apparently closely related individuals. The most closely related pairs were then screened at 15 additional microsatellite loci, and these loci were used to test the hypothesised relatedness. Preliminary results showed that the distances between parents and offspring were often large, and that the number of confirmed parent-offspring pairs was higher than expected given the estimated abundance and assumed mortality rate. Further work is required to investigate the statistical significance of this finding, and its sensitivity to demographic assumptions. The Committee noted the power and cost-effectiveness of the approach (expensive extra genotyping is only needed on those animals most likely to be informative) and **strongly encourages** its further development.

SC/57/SD5 reported further investigations into the extent of bias in the Boundary Rank procedure when applied to unevenly-sampled clines. The Committee noted that the TOSSM/RMETASIM framework is approaching the point at which it can be used for testing the full management implications of boundary-setting procedures, and **recommends** that this framework be considered for future simulation tests.

Genetic data quality

At the 2004 meeting, the Committee's discussions on bowhead whales had highlighted a number of issues related to quality of microsatellite data and caveats about its interpretation, ranging from DNA handling issues to e.g. ascertainment bias and mis-scoring, to the implications for population structure analyses. A review was proposed for 2005, and the preparation of a review paper was encouraged. Although work began on this intersessionally, it proved to be too large a task. The Committee noted, however, that several review papers have appeared in recent published literature. Palsbøll offered to compile a list of appropriate references for the 2006 meeting.

11.3 Definition of unit-to-conserve and the implications for management

The point of this item is to allow consideration of various possible definitions of unit-to-conserve, and their corresponding implications for management (see IWC, 2002c, p.49). No papers were received this year, but the Committee received a verbal summary of recent thinking in the academic literature about definitions of 'population'. Two paradigms can be identified: the evolutionary paradigm which is concerned with levels of gene flow, which scales with the *absolute number* of effective migrants per generation; and the ecological paradigm, which is concerned with the *per capita* rate of migration per generation. A number of proposed definitions of 'population' within each paradigm are shown in Annex I but few if any of the definitions are operational, in the sense of providing a quantitative criterion for separating 'populations' in a management context. This emphasises the importance of a process such as TOSSM to bridge the gap between empirical data related to population structure, and management objectives such as avoiding local depletions. Despite the absence of an operational definition of 'population', a number of possible criteria might be used to make the definitions in Annex I quantitative and operational; some suggested criteria may be found in Annex I.

The Committee noted that these or similar criteria might prove valuable in:

(1) adapting existing methods for analysing population structure to TOSSM;
(2) actually applying such methods; and
(3) aiding experimental design and sample size calculations.

From the IWC perspective, there are a wide variety of possible temporal and spatial scales that could be of interest for management. In addition, there are some population structures that are persistent in space and/or time, but that do not correspond to breeding stocks: for example, matrilineal philopatry as exhibited by 'feeding stocks' of humpback whales. The Committee's aim has therefore been to get to a point where it can provide advice to the Commission about likely levels of depletion on a range of different temporal and spatial scales, and for different types of population structure. This has been the principle underlying TOSSM. By experimenting with different criteria during the adaptation of existing methods to TOSSM, the Committee will gain experience about which criteria tie in best with management objectives.

In recent years, new analytical methods (and increases in available data) have allowed for considerable increases in the power for detecting population structure. Given large enough sample sizes and numbers of loci, there is now a realistic possibility for some whale species of detecting significant genetic differences that, while genuine, are actually not important in demographic terms: i.e. where the migration rate is too high to warrant separate management. This is a considerable change from a few years ago, when the available data and methods very typically were not powerful enough to detect a migration rate that is low enough to warrant separate management, but high enough to blur the genetic signal.

High power to detect very weak population structure has another potential downside: care must be taken not to confuse small artefacts (e.g. non-random sampling, family structure, data errors) with a true signal of population differentiation. This emphasises the need for careful attention to experimental design, sampling protocols, and data quality control, as well as the importance of understanding the biology of the target species.

Finally, the Committee noted the importance of regular and repeated communication with population geneticists, to bridge the evident gap between academic methods development and the practical conservation/management issues that the IWC faces.

11.4 Work plan and draft agenda for 2006

11.4.1 Further work on TOSSM

The IWC has extensive experience of complex simulation exercises similar to TOSSM, such as the development of Management Procedures for the RMP and AWMP. To avoid costly back-tracking, it is important to do some 'full runs' early on - that is, to make sure that the entire set of steps can be completed together for a fairly simple scenario - before spending too much attention on polishing individual details. Although some background work is still needed, TOSSM has now reached the 'full run' stage. Once initial 'full run' results are in hand, it will be time to discuss preliminary results with non-IWC developers of population structure methods, who form an essential part of the TOSSM process.

The Committee believes that the most efficient way forward is to hold an intersessional Workshop after completing the background work and some 'full runs'. Preparatory work will include adapting about four existing population structure methods to TOSSM, as well as one or more methods developed by Committee members. The Workshop will also involve non-IWC population geneticists who have developed population structure methods, and will present feedback on preliminary tests of those methods, along with development of further datasets and simulation scenarios. The Workshop objectives are:

(1) present results of preliminary runs using existing adapted methods;
(2) discuss adjustments to the first sets of simulated data;
(3) discuss how to better adapt existing boundary-setting methods;
(4) discuss other boundary-setting methods that might be tested in TOSSM; and
(5) decide on priorities for further simulated datasets (e.g. more complex population archetypes, more realistic genetics, simulation of physical tags).

A date sometime in March 2006 would leave enough time to:

(1) complete the background work beforehand; and
(2) implement some of the Workshop recommendations before the next annual meeting, so that a more useful set of test results can be considered.

Tiedemann offered to host the meeting at the University of Potsdam, including free meeting facilities and the provision of computing power for generating extra datasets during the meeting. The Committee thanked Tiedemann for his offer and **strongly endorses** the proposal for a Workshop. The full proposal is given in Appendix 2 of Annex I, along with a timetable and lead personnel for pre-Workshop preparations. Financial implications are discussed under Item 21.

11.4.2 Draft agenda for 2006

The priority issues for next year's meeting are:

(1) review statistical and genetic issues relating to stock definition;
(2) review progress on TOSSM;
(3) unit-to-conserve; and
(4) review of genetic data quality issues.

12. ENVIRONMENTAL CONCERNS (SEE ANNEX K)

12.1 Sea ice and whale habitat Workshop

As agreed last year, a Workshop entitled 'High Latitude Sea Ice Environments: Effects on Cetacean Abundance, Distribution and Ecology' was held in Ulsan, South Korea from 28-29 May 2005. The aim of the Workshop was to review information on sea ice environments in the Arctic and Antarctic, and to develop means of incorporating sea ice and similar data into analyses and models used by the Scientific Committee in its work.

The report of the Workshop is given as SC/57/Rep5. The Workshop provided an excellent opportunity for scientists who typically work at either pole to meet and exchange information on sea ice variability with respect to whale habitats. The three invited talks provided information on the present understanding of decadal changes and current conditions at both poles. Common themes included:

(1) the extreme variability in sea ice conditions at both poles;
(2) the complexity of both polar ecosystems; and
(3) the great dearth of sea ice data, especially at scales relevant to cetacean habitat assessment, with regard to retrospective and forward-looking investigations.

Research tools are now available that can augment future studies including:

(1) passive acoustic recorders, both short and long-term instruments (i.e. sonobuoys and moored recorders);
(2) satellite telemeters for attachment to cetaceans, augmented with oceanographic instrumentation (e.g. CTDs, fluorometers); and
(3) sea ice analytical tools to provide routine application at the temporal and spatial scale of whale habitats (i.e. days to months; 1 to 1,000s km).

The Committee **recommends** the application of these tools to future cetacean research in the Arctic and Antarctic and **encourages** researchers to continue the collaborative exchanges initiated at the symposium.

The Workshop identified a number of high priority intersessional projects targeted at issues in polar regions. Two Arctic projects were proposed. The first focuses on retrospective analyses of sea ice conditions, using both satellite-derived data and traditional ecological knowledge (TEK) to collate with extant records of B-C-B bowhead and ENP gray whale population dynamics. The second project seeks to investigate health status in both populations with regard to variability in sea ice. The Antarctic projects focus on:

(1) areas of high Antarctic minke whale density;
(2) shelf break position correlation with whale distribution;
(3) data-rich regional comparison of variables affecting distribution;
(4) analysis of Antarctic minke whale distribution and relative proportions inside and outside the pack ice;
(5) integration of historical and recent whale catch/sighting data; and
(6) support for the completion of the Southern Ocean Collaboration Database.

Finally, it was noted that the Integrated Analysis of Circumpolar Ecosystem Dynamics (ICCED) initiative in the Southern Ocean and the International Polar Year (IPY) afford unprecedented opportunities for collaborative multi-disciplinary research in polar regions. The aforementioned tools provide the means to fully integrate cetacean studies into broad-scale programmes of marine ecosystem research in ways not imagined only a few years ago. For these reasons, the Committee **strongly recommends** the integration of cetacean research into these two programmes.

The Committee expressed its deep appreciation to Thiele and Moore for their hard work in organising and convening the Workshop. The Committee **endorses** the findings and recommendations in the report of the Sea Ice Workshop. Financial implications are considered under Item 21.

12.2 Review of the report of the Habitat Degradation Workshop

The Committee was pleased to receive the report (SC/57/Rep2) of the IWC Workshop on Habitat Degradation which was held at the University of Siena, 12-15 November 2004. The Workshop was financed by the Government of Austria, the Environmental Investigation Agency, ASMS-Ocean Care and the World Wide Fund for Nature.

The main discussion of the Workshop report took place in the SWG on environmental concerns and the reader is referred to Annex K for a more detailed summary of the Workshop. This summary presents the main conclusions of the Workshop and its recommendations.

In its conclusions, the Workshop had stressed the importance of undertaking work relating habitat conditions to cetacean status in the context of conservation and management. It recognised that this is a particularly complex area of study, requiring both theoretical developments in modelling approaches and a commitment to long-term interdisciplinary data collection programmes.

The Workshop noted that the framework it had developed (see fig. 3 of SC/57/Rep2) provided the basis for a long-term approach to investigating the significance of habitat degradation for cetaceans. However, general application of the framework will require a much longer-term view to be taken by management and research bodies. This would eventually result in major improvements in advice to resource managers for conservation and management of cetaceans with respect to predicting the effects of habitat degradation and the effects of many anthropogenic activities, as well as the development of appropriate mitigation measures. The Workshop noted that the continuation of the present *ad hoc* and usually insufficient processes (such as 'Environmental Impact Assessments' based on short-term limited datasets) would be unsatisfactory.

In order to facilitate the development process, the Workshop agreed that the primary focus should be on populations for which it was believed there was the most chance of success, i.e. those for which good information is available on both cetaceans and their habitat over a reasonable time period. The Workshop recognised that overall there are few cetacean populations studied with broad sampling programmes covering sufficiently long time frames.

The Workshop also stressed the value of long-term monitoring of both cetaceans and key aspects of their habitat at appropriate temporal and geographical scales. Baseline data on natural variability in cetacean populations and their habitat are a prerequisite to determining whether anthropogenic changes in the habitat are important to the conservation of cetacean species. Obtaining suitable information on the biotic and abiotic features of habitat will require interdisciplinary efforts and co-operation. It agreed that where possible, collection of cetacean data, as well as data on their environment, should be conducted simultaneously. It also noted that spatial modelling approaches are particularly valuable in integrating data on cetacean distribution and abundance with data on their habitat.

The Workshop also stressed the need to better understand the feeding and reproductive behaviour of cetaceans. With respect to the former, this particularly includes the relationship of cetacean distribution with their prey. As suggested in the report of the SOWER 2000 Workshop (IWC, 2000e, pp.319-46), this will include fine-scale research on feeding strategies and prey selection. It also requires much better knowledge of the distribution, behaviour and abundance of prey species which will require better cooperation with other disciplines, especially physical and biological oceanographers and fisheries scientists.

Newer technologies such as satellite tagging (including environmental sensors), remote sensing and new initiatives for developing ocean-based observing systems (e.g. in the USA and Europe) have the potential to provide broad-based data sets on both cetaceans and their habit.

The Workshop also made a number of recommendations (see item 12.2 of SC/57/Rep2); the key recommendations are summarised below.

The Workshop strongly recommended that effort be put into further consideration of the framework including:

(1) linking of the different types of models, e.g. through data on vital rates;
(2) developing ways to model how stressors affect features of the habitat or individuals directly; and
(3) developing ways in which spatial modelling approaches can better incorporate dynamic variables.

Attention must also be given to trying to determine the relative importance of natural versus anthropogenic environmental changes on the dynamics of cetacean populations.

The Workshop also strongly recommended the continuation (and where necessary, initiation) of long-term studies, both of cetaceans as well as key biotic and abiotic features of the environment. In this regard, the Workshop recognised that this may require a change in emphasis of both management and research agencies. In the present climate there is often reluctance to invest in long-term programmes. The Workshop stressed that the issue of cetaceans and habitat degradation will only be resolved by long-term multidisciplinary datasets. This will also require a change in the way many institutes evaluate scientists. At present, this is often on the basis of the number of publications. It is often a feature of long-term monitoring programmes that they do not result in several publications per year despite the fundamental importance of the work. This may discourage high calibre scientists from committing to such programmes to the detriment of cetacean conservation.

The Workshop also recognised the difficulties in developing (and measuring) suitable indices both of habitat quality and response in cetaceans. It recommended that further work be undertaken in this regard, particularly with respect to:

(1) identifying key features of cetacean habitat;
(2) reviewing methods used to assess cetacean nutritive status in both live and dead specimens, with a view to future standardisation of techniques; and
(3) developing indices of cetacean response to various stressors.

Other recommendations concerned the importance of interdisciplinary research, the development of standard necropsy protocols, the importance of considering the representativeness of information collected via strandings programmes; appropriate long-term preservation of tissues; the use of metadatabases to improve collaborative research and data/information sharing and the development of habitat restoration science and technology.

The Committee thanked Simmonds, the Convenor, and the Workshop participants for their report and **endorses** its conclusions and recommendations. The Committee **agrees** that it will review progress on habitat degradation recommendations in 2008.

There was considerable discussion of aspects of the report in the SWG and this can be found in Annex K (item 7). Issues discussed included: the value of properly archiving older studies and datasets (including searching the grey literature); the choice of case studies to which to apply the framework; the integration of noise into habitat models; the value of strandings schemes; the need for standardised protocols for pathology (particularly with respect to possible acoustic trauma); and the need for 'control' datasets from 'normal strandings' for comparisons to suspected acoustic traumas.

The Committee recognised that pathology should not be examined only in cases where acoustic trauma is suspected. Therefore the Committee **agrees** that management agencies and pathologists should follow equally rigorous, standardised pathology protocols in fresh, natural strandings as they do in atypical mass stranding events when acoustic trauma is suspected, especially in those areas identified as 'controls'.

12.3 Habitat related issues

12.3.1 Steering Group report on POLLUTION 2000+

SC/57/E12 presented an interim report on POLLUTION 2000+. Three papers have now been published (Tornero *et al.*, 2005; Tornero *et al.*, 2004; Wells *et al.*, 2004) and another is in review (Hall *et al.*, in press).

With respect to the bottlenose dolphin sub-project, the Steering Group has made progress on the process of identifying a relatively highly polluted area inhabited by bottlenose dolphins. Unfortunately, sampling bottlenose dolphins in the initially proposed area, the Mediterranean, proved to be impractical in terms of both sample size and costs, after considering the results of a feasibility study. However, samples from bottlenose dolphins from Biscayne Bay, Florida, USA and New Brunswick, Georgia, USA have been collected by US scientists, and the Steering Group will evaluate whether one of these provides a suitable alternative.

Progress on the remaining analyses required under the harbour porpoise sub-project has been very slow due to administrative and logistical issues (e.g. in obtaining permits) that obstructed the shipping of samples from the USA to Europe. Although it seems that these problems have now been overcome, the results from the analyses will not be available until next year.

The Steering Group is also examining the possibility of extending the sample size of harbour porpoise tissues collected under POLLUTION 2000+, by investigating retinoid levels in harbour porpoises from the UK and/or from the northeast Atlantic.

The Steering Group has developed an intersessional workplan to finalise Phase I of the project and report the results to the Committee and the Commission next year. The Steering Group will also evaluate whether it believes Phase II of the project should proceed, and if so, will bring a workplan and associated budget to the Committee for consideration next year.

The Committee **endorses** the POLLUTION 2000+ programme and the intersessional workplan. It **strongly recommends** continuation of the programme and **agrees** that the work of Phase I should be completed by next year's Scientific Committee meeting.

12.3.2 Progress report of the Southern Ocean Collaboration Working Group

The IWC Southern Ocean Collaboration Working Group (IWC SOC) conducted field work and analysis during the intersessional period. The IWC SOC commenced field work with Southern Ocean Global Ecosystem Dynamics (SO-GLOBEC), Commission for the Convention on Antarctic Marine Living Resources (CCAMLR) and other research programmes in 2000, and the benefits from this ecosystem-focused research are now being realised. The field collaboration has given the IWC an important role in the synthesis and analysis phase of these programmes, with IWC SOC members now participating in ecosystem modelling and analysis projects that should improve the understanding of the links between whales and the environment in this region.

Six papers from IWC SOC were presented at this year's meeting, using data from the IWC SOC Database. A spatial analysis of sea ice habitat for whales and seasonal availability of sea ice habitat types was presented in SC/57/E1; SC/57/E2 provided an update of the progress made with the completion of the SOC database; and SC/57/E3 provided a summary of field and analysis work conducted intersessionally, including the group's involvement in the development of the science planning for the Integrated Analysis of Circumpolar Ecosystem Dynamics (ICCED) initiative (long term follow on to SO-GLOBEC) and a number of collaborative analysis projects, including circumpolar modelling and analysis of whale and seabird time series with environmental variables. In addition, SC/57/E4 provided an update on field work carried out under the IWC SOC (international collaboration on multidisciplinary ecosystem research cruises); SC/57/E10 presented a preliminary analysis of whale presence in the Ross Sea from acoustic instruments, one of the first along-track acoustic surveys in sea ice; and SC/57/SH4 provided important new data from year-round acoustic monitoring instruments on seasonal patterns in blue whale distribution off East Antarctica. The Committee welcomed this updated information, and **strongly encourages** continued collaboration in the Southern Ocean. Financial implications are considered under Item 21.

12.3.3 State of the Cetacean Environment Report (SOCER)

SC/57/E8 (SOCER 2005) provided information on issues of environmental concern for the polar regions, as well as globally. The editors noted that the Arctic and Antarctic papers summarised in the SOCER provide evidence for global warming-induced melting of sea ice and oceanographic and ecosystem changes. Pollutant data emphasised that the polar regions are not pristine and the toxicity of some pollutants may even be enhanced in these low-temperature regions. Global issues included growing international concern about effects of noise on marine life, including cetaceans; concerns about potential threats posed by diseases in the marine environment; and changes in the distribution of cetaceans and their prey resulting from global warming. Next year, the Indian Ocean is the SOCER's priority region. The SOCER report can be seen in full in Annex K, Appendix 2.

12.3.4 Arctic issues

The SWG had considered a number of papers on Arctic issues and details of those discussions can be found in Annex K (item 8.4).

Two papers (SC/57/E13 and SC/57/E5) addressed the potential effect of variability in sea ice cover on B-C-B bowhead whales. In the first, a preliminary examination of bowhead whale body condition with reference to sea ice coverage showed a positive correlation of body condition with reduced sea ice, perhaps because a reduction of sea ice enhances feeding opportunities for bowhead whales. In the second, an examination of trends in sea ice cover over 24 years (1979-2002) for four large (~100,000km^2) and 12 small (~10,000km^2) habitats used by bowhead whales revealed significant changes in sea ice cover for three of the large and five of the small areas. This evaluation of sea ice cover at spatial and temporal scales linked to bowhead whale natural history provides a basis for research on specific regions critical to investigation of the effects of climate change on this pagophilic species. However, the biophysical links between reduction in sea ice, primary production and availability of food for bowheads in the Arctic requires investigation.

SC/57/BRG3, in conjunction with Moore (1999), provided provisional results of a passive acoustic monitoring study northeast of Barrow, Alaska. Results indicated that gray whales remained in the western Beaufort Sea through early winter 2004, with calls detected again less than three months later. This unusual occurrence of gray whales in the western Beaufort Sea may indicate a shift in seasonal migration and habitat use that could result in competition between bowhead and gray whales.

Anon. (2005) described coordination of International Research Programmes in the Arctic. The International Polar Year (IPY 2007-2008) and the Second International Conference on Arctic Research Planning (ICARPII) provide unprecedented opportunities for cetacean researchers to collaborate on multi-disciplinary projects in the Arctic. Research plans evolving from these programmes seek to address priority gaps in knowledge from the Arctic Climate Impact Assessment (ACIA) (see also SC/57/Rep5). The Committee **recommends** that the IWC pursue formal ties to these international research programmes, and that participation from their oceanographers and ecologists be encouraged in whale research.

12.3.5 Anthropogenic noise

SC/57/E9 presented the latest in a series of updates on noise pollution and the limitations of mitigation measures, as well as alternative technologies (e.g. marine vibrators instead of airguns). After discussion, the Committee **strongly encourages** producers of high intensity noise (e.g. sonar and seismic operators) to share information on noise source characteristics and to work with cetacean scientists to investigate the impacts of these activities. The Committee was informed of a workshop (entitled 'A Workshop to Identify Potential Impacts and Mitigation Strategies for Offshore Hydrocarbon Industry Activities with Respect to Marine Mammals and Other Marine Fauna in the Gulf of Guinea (Central West Africa)') that will be convened by the Wildlife Conservation Society (WCS) and the hydrocarbon industry. It will take place at the end of June 2005, where data and information about industry activity will be shared, and mitigation strategies will be discussed. One of the reasons this meeting is being convened is because of the extensive oil and gas development in West Africa, potentially overlapping with numerous critical habitats for marine mammals (e.g. the coastal waters of Gabon and the

Gulf of Guinea are important humpback whale breeding, calving, and nursing grounds).

The Committee welcomed this information, **endorses** the workshop and looks forward to receiving its report, which is directly related to next year's work plan.

The SWG also considered SC/57/E16 which examined the use of sound in drive fisheries and whaling operations. SC/57/E16 noted that fishermen in different parts of the world have used sound to herd various species of small cetaceans to mass strand, or into harbours to be killed. This supports the growing body of evidence that anthropogenic noise can affect cetaceans. The paper also reviewed the use of ASDIC (Anti-Submarine Detection Investigation Committee) sound (i.e. sonar) by whalers to hunt large whales (baleen and sperm whales). The reported reaction to ASDIC by baleen whales was consistent with reactions observed by Nowacek *et al.* (2004) when they played a synthetic alerting stimulus to North Atlantic right whales.

The Committee **agrees** that detailed information on acoustic sonars be obtained whenever possible; all sonars do not have the same acoustic characteristics. This holds true for seismic surveys as well. Detail on the type, number and configuration of airguns is needed to evaluate source capabilities and the potential impact on cetaceans.

The Committee noted that mass strandings are often preceded by 'milling' events, where a group of normally pelagic small cetaceans enter shallow water and circle continually or move haphazardly in a tightly packed group. Touhey (2003) reported using the combination of herding with small vessels and acoustic deterrents to prevent milling events from becoming stranding events. It was suggested that this approach be expanded to other regions where 'milling' events are known to occur. In addition, efforts are needed to document such attempts by a scientific team independent of the rescue team. The Committee **agrees** that this work is important and **recommends** that it be expanded.

Following last year's recommendations, a two day pre-meeting Workshop assessing the potential for seismic surveys to impact cetaceans was proposed for next year. The Workshop should review and characterise information on seismic sound sources, attenuation and their effects on cetaceans as well as review relevant case studies and current mitigation and monitoring strategies. A Steering Group was formed (Annex P(18)) and Rosenbaum was appointed as Convenor (Annex K, Appendix 3). The Committee **endorses** the pre-meeting Workshop and **agrees** to the terms of reference.

12.3.6 Other

The SWG also discussed three other habitat-related papers. The first (SC/57/E7) described the use of biopsy samples to investigate the feeding ecology of ENP killer whales; the second (SC/57/E11) reported on predicting concentrations of elements (e.g. mercury, arsenic) in tissues (e.g. liver, kidney) using epidermal samples; and the third (SC/57/E15) presented information on metal concentrations in common minke whales from Korean waters. These are summarised in Annex K (item 9).

12.4 Work plan

12.4.1 SOCER

SOCER will summarise information from publications related to cetacean ecology, life history and other biological and management issues globally and will focus on the Indian Ocean for 2006.

12.4.2 Sea ice

The Committee proposed emphasis on the high priority intersessional projects identified during the Sea Ice Workshop. Financial issues are considered under Item 21.

12.4.2.1 ARCTIC

The Arctic projects focus on:

(1) retrospective analyses of sea ice conditions, using both satellite-derived data and traditional ecological knowledge (TEK) to collate with extant records of B-C-B bowhead and ENP gray whale population dynamics; and
(2) investigation of heath status in B-C-B bowhead and ENP gray whale populations with regard to variability in the extent of sea ice coverage.

12.4.2.2 ANTARCTIC

The Antarctic projects focus on:

(1) areas of high Antarctic minke whale density;
(2) correlation between shelf break position and whale distribution;
(3) data rich regional comparison of variables affecting distribution;
(4) analysis of Antarctic minke whale distribution and relative proportions inside and outside the pack ice;
(5) integrating historical and recent whale catch/sighting data; and
(6) support for the completion of the SOC Database.

12.4.3 Seismic Workshop

The SWG proposed a two-day Workshop in advance of the 2006 Annual Meeting to assess the potential impact of seismic surveys on cetaceans. The rationale, initial terms of reference, draft agenda and suggested invited participants are provided in Annex K, Appendix 3. The Committee **endorses** these plans.

12.4.4 Disease

Last year, the SWG proposed that the topic of disease be the focus of the 2007 meeting. The Committee **agrees** that the focus in 2007 should be the emerging issue of biotoxins produced by harmful algal blooms and their potential impact on cetaceans. Harmful algal blooms have been documented as the cause of numerous mass mortalities in marine mammal populations and have been increasing in frequency and expanding to global geographic distribution. It was noted that ICES is developing plans for a workshop on diseases.

13. SMALL CETACEANS (SEE ANNEX L)

13.1 Review of the status of the finless porpoise (marine populations)

In recent years there has been concern about the status of finless porpoises (*Neophocaena phocaenoides*) with evidence for a localised decline in abundance, fragmentation and degradation of habitat and high bycatch levels.

13.1.1 Distribution and stock structure

Marine populations of the finless porpoise are restricted to shallow, tropical and temperate waters (Annex L, fig. 1). Currently, three subspecies are recognised: *N.p.*

phocaenoides (the tropical marine form, distributed from the Persian/Arabian Gulf eastward to at the least the Taiwan Strait area), *N.p. asiaeorientalis* (the Yangtze River form, which some researchers believe may extend outside the river into estuarine and even marine waters of the East China Sea) and *N.p. sunameri* (the northern temperate marine form, which occurs in waters of Japan, Korea, and northern and central China). There is morphological variation (including variation in dorsal ridge size and shape) amongst the three subspecies, leading some authors to suggest species level differentiation. The subspecies of finless porpoise that occurs in the Yangtze River was reviewed in 2000 (IWC, 2001b, pp.274-5) and was not considered during this meeting.

Geographically localised studies of the distribution, cranial morphology and genetics of finless porpoises have suggested that there are at least five distinct populations in Japanese coastal waters and despite limited coverage and sample sizes, studies elsewhere in the species' range provide evidence for additional populations. The Committee concluded that finless porpoises may exhibit multiple populations over relatively small distances (as occurs off Japan), and that there are likely to be numerous small and vulnerable populations along their coastal range. The Committee **recommends** that genetic and morphometric studies of finless porpoises be conducted to assist in clarifying taxonomy and population structure in the genus *Neophocaena*. The Committee **agrees** that predictive habitat models which recognise potential variability among populations will help to better target resources for field surveys and sample collection. In this regard, the collection of detailed environmental variables during field surveys will be valuable. It further **recommends** that fine-scale surveys be carried out with particular emphasis on targeting effort to areas where the least is known (e.g. the northern rim of the Indian Ocean (including the Arabian/Persian Gulf) and the Indo-Malay Archipelago).

13.1.2 Abundance

The Committee reviewed the results of recent boat-based and aerial line-transect surveys to estimate abundance carried out in five areas, Japan, Korea, Hong Kong, Bangladesh and the Arabian/Persian Gulf. The Committee welcomed estimates from two new areas and noted the apparent decline in abundance in two other areas (Inland Sea of Japan and Persian Gulf). Given certain methodological concerns, the Committee **agrees** that most of the abundance estimates were minimum estimates (see Annex L). The Committee also noted that combined visual and acoustic surveys may result in improved estimates in the future. Given the complexity of the inshore habitat in many parts of this species range and the difficulty in surveying small cetaceans in these areas, the Committee **recommends** that a workshop be carried out to try to develop and standardise survey methodology, including the use of passive acoustics. There is long term merit in training and involving local scientists to conduct studies such as this.

13.1.3 Life history

Information on the life history parameters of finless porpoises derives primarily from stranded and bycaught animals from Japanese and Chinese waters, although new studies have begun in Korea. Growth parameters are generally similar to those of other phocoenids. Males appear to reach longer asymptotic lengths than females. Calving in finless porpoises occurs seasonally and the duration of this period differs between areas. Continued collection of data to allow estimation of life history parameters in other areas, using standardised methodology will allow more rigorous inter-population comparisons. Given the issue of inter-individual variation in reading and interpreting Growth Layer Groups (GLGs) for age determination, the Committee **recommends** that inter-calibration exercises occur between the different researchers working on this species.

13.1.4 Ecology and habitat

Finless porpoises are almost exclusively found in shallow continental shelf waters, particularly nearshore but also in offshore areas if waters depths are sufficiently shallow (i.e. <50m). Habitats include mangrove swamps, estuaries, sheltered bays and open waters with sandy, muddy or rocky bottoms. Some limited evidence indicates that local distribution patterns may be modulated by the occurrence of other small cetacean species in the same area. Finless porpoises consume a wide variety of prey species that include fish, cephalopods and crustaceans (SC/57/SM1, SM3, SM6, SM17), with some evidence of ontogenetic variation. As these porpoises have a range that includes a narrow coastal strip over a long coastline, they are exposed to a wide diversity of anthropogenic activities. Although potential threats have been identified, their impacts at the population level remain unknown. The Committee **encourages** further work to assess the potential impacts of contaminants and other anthropogenic influences on finless porpoises in all parts of their range.

13.1.5 Directed and incidental takes

No large scale commercial hunts for this species have been recorded. Some local hunting has occurred in the past and probably continues to some extent today. Furthermore, a few tens of finless porpoises have been live-captured for public display and research in Japan, China and Thailand.

Incidental mortality is probably substantial throughout the species' range. Catches are known to occur in a broad range of fishing gears including both active (trawls, beach seines) and passive (e.g. gillnets) fishing gear and also as a result of fishing with explosives and (in the Arabian/Persian Gulf) nets set for dugongs (*Dugong dugon*). There is generally little or no bycatch monitoring of these fisheries and coupled with the limited information on the size of their source populations it is difficult to quantify the population level impacts. A recommendation on bycatches is given under Item 13.1.6.

13.1.6 Consideration of status

The finless porpoise is listed as 'data deficient' by the IUCN. The species is in no immediate danger of extinction, but some populations for which the status has been assessed (such as in the Inland Sea of Japan) are apparently declining. Incidental mortality in fisheries is likely to be the biggest source of direct mortality but other anthropogenic influences such as chemical pollution, depletion of prey species and loss of habitat may all have impacts. Throughout most of the species' range, human populations are increasing and becoming more industrialised, suggesting that anthropogenic pressures will continue and intensify. Given the possibility of population structuring over relatively small geographical regions, the Committee **re-iterates its recommendation** that genetic and morphometric studies of finless porpoises be conducted to assist in clarifying taxonomy and population structure. It also noted that the range of this species includes areas that

support intensive coastal gillnet fisheries and that large bycatches have been documented in some fisheries. The Committee **recommends** that the magnitude and effects of such bycatches be investigated as a matter of priority.

The Committee recognises that inadequate information exists on the distribution of this species throughout much of its range and **recommends** that surveys be carried out with particular emphasis on targeting effort to areas where the least is known. The Committee **agrees** that the northern rim of the Indian Ocean (including the Arabian/Persian Gulf) remains an extensive area where our knowledge of the status and biology of finless porpoises is extremely poor.

13.2 Progress on previous recommendations

IWC Resolution 2001-13 (IWC, 2002a, p.60) directs the Scientific Committee to review progress on recommendations and resolutions relating to critically endangered stocks of small cetaceans on a regular basis.

13.2.1 Baiji

The baiji (*Lipotes vexillifer*) is the world's most endangered cetacean. Its range is restricted to the Yangtze River and the population size is believed to number in the low tens of individuals. The Commission has requested that the Government of China report progress on the conservation of the species to the Scientific Committee on an annual basis. No new information was received this year. However, it was noted that an international Workshop on the conservation of the baiji and Yangtze finless porpoise took place in late 2004 in Wuhan, China (workshop report available from *www.baiji.org*). The Workshop operated under the assumption that the Chinese authorities had decided to proceed with capture operations to remove some baiji from the Yangtze River into the ox-bow reserve and/or into a dolphinarium. The Committee was also informed that Yangtze finless porpoises would not be removed either before or after baiji were introduced into the reserve.

The Committee noted the news from the Workshop but also recalled that recommendations made at previous international workshops and those made by the Committee (IWC, 2001c) had not commonly been followed, including the recommendation to remove Yangtze finless porpoises from the Shishou Tian-e-Zhou oxbow semi-natural reserve before introducing baiji into it, because of concerns of inter-species interactions. The Committee did not discuss the pros and cons of *ex situ* versus *in situ* approaches but **agrees** with the conclusion of the Workshop that any captured dolphins should be placed in the oxbow under soft-release (i.e. temporarily monitored in a holding-pen (or pens) prior to their release) conditions. The Committee also **agrees** that the recommendation for a range-wide baiji survey should be implemented as a matter of urgency and any capture efforts be targeted on the most threatened areas while concomitant *in situ* conservation work should be pursued in areas ostensibly subject to lower levels of risk.

13.2.2 Vaquita

The Committee has followed with great interest the progress on conservation efforts on behalf of the vaquita (*Phocoena sinus*), an IUCN listed 'critically endangered' species endemic to the upper Gulf of California, Mexico. Several members of the Committee are members of the International Committee for the Recovery of the Vaquita (CIRVA). This year, the Committee received information on the use of passive acoustics to study habitat use and a brief review of progress on conservation actions recommended in the third report of CIRVA (Rojas-Bracho *et al.*, 2004) presented at last year's meeting, including the establishment of a closed area for gillnetting. The Committee welcomed progress with acoustic research on vaquita distribution and on promotion of the CIRVA recovery plan and noted that results of the acoustic study provide additional evidence of the need for urgent implementation of the plan. The Committee was informed that on 5 June 2005, the President of Mexico stated that it had been agreed to declare the highest vaquita concentration area as a refuge for this species. The Committee wholeheartedly **welcomes** this news and thanked the President of Mexico for this important conservation measure.

13.2.3 Harbour porpoise

The Committee had reviewed the status of harbour porpoises (*P. phocoena*) in the North Atlantic in 1995 and agreed that reported bycatch levels justified concern about sustainability. In 2001, a joint IWC/ASCOBANS Working Group had provided scientific advice to ASCOBANS on a simulation modelling approach that might allow ASCOBANS to develop algorithms to meet their conservation objectives (IWC, 2002c, p.59). The Committee then considered and endorsed an alternative approach for developing a relatively simple, but spatially explicit, model or models with the objective of determining bycatch levels that would allow small cetaceans to recover to, or be maintained at above, 80% of carrying capacity. This approach has now been incorporated as part of the current EU funded SCANS-II (Small Cetaceans of the European Atlantic and North Sea) Project which will advise the European Community and ASCOBANS. The Committee **agrees** that it may be appropriate to re-instate the joint IWC-ASCOBANS Working Group, as suggested by the observer from ASCOBANS, when the results from the modelling work become available. SC/57/SM13 describes a planned project as part of SCANS-II to determine appropriate limits for small cetacean bycatch (concentrating initially on harbour porpoises) in the European Atlantic and North Sea. The Committee **welcomes** this development and looks forward to receiving updates at subsequent meetings.

*13.2.4 Humpback dolphin (*Sousa *spp.)*

The genus *Sousa* was the subject of an extensive review in 2002 (IWC, 2002c). Jefferson reported that substantial progress had been made on implementing the recommendation for a global study on the systematics of the genus using molecular techniques. The Committee **welcomes** news of a workshop on conservation and research needs in early 2004 and encourages efforts to assess the status of *S. chinensis* in China, Taiwan.

13.2.5 Irrawaddy dolphin

The Committee addressed the status of Irrawaddy dolphins (*Orcaella brevirostris*) in 2000 (IWC, 2001c). It concluded that densities appeared to be low in most areas and that several populations were believed to be seriously depleted and threatened with extirpation, particularly in freshwater areas of their distribution. Subsequently, five geographically isolated populations have been classified in the IUCN Red List as 'critically endangered' due to small population sizes and continuing declines in abundance. In 2000, the Committee recommended that all live captures should cease 'until affected populations have been assessed using accepted scientific practices' (IWC, 2001b, p.266). The Committee noted that the proposal to transfer Irrawaddy

dolphins from CITES Appendix II to Appendix I was approved at the 13th CITES Conference of Parties in October 2004.

The Committee welcomed new information on opportunistic and dedicated surveys in two previously unsurveyed regions – northwest Australia and the mangrove channels of the inner Sundarbans Delta in Bangladesh. It noted that other unknown populations almost certainly exist within the range of the species and **expresses concern** about observations reported in SC/57/SM4 of potentially unsustainable bycatches in a drift gillnet fishery for elasmobranchs.

13.2.6 Other recommendations

The Committee welcomed a preliminary attempt at compiling a global review of interactions between cetaceans and longline fisheries (SC/57/BC3). Although longline fishing has generally been viewed as being benign to cetaceans, a large variety of species have been incidentally hooked or entangled by this fishery. Small and medium sized cetaceans appear to be more vulnerable. The Committee noted that a large number of additional cetacean species and countries could be added to the existing compilation and it **commends** plans by the authors of the paper to conduct a more comprehensive review in the future.

The Scientific Committee has been unable to complete a full assessment of the status of Dall's porpoise (*Phocoenoides dalli*) populations as directed by IWC Resolution 2001-12, in the absence of necessary information. The last reviewed abundance estimates in 1991 for Dall's porpoises affected by the Japanese harpoon fishery were 217,000 (*CV*=23%) for the Central Okhotsk Sea (*truei*-type) and 226,000 (*CV*=15%) for the Southern Okhotsk Sea (*dalli*-type). Catch statistics from the Japanese Fisheries Agency website for January-December 2003 were 7,412 individuals for the *dalli*-type and 8,308 individuals for the *truei*-type, which represent 3.4% and 3.7% of the 1991 abundance estimates for both types, respectively. Directed takes of Dall's porpoise have exceeded the Scientific Committee's recommended anthropogenic mortality limit of 2% of abundance (IWC, 2002c, p.58) for over 15 years, and the fishery remains the largest directed hunt for small cetaceans in the world. The Committee **repeats its previous recommendation** that directed takes be reduced to a sustainable level as soon as soon as possible.

13.3 Consideration of revision of IWC cetacean list

The present IWC list of recognised species of cetaceans does not include two very recent changes in cetacean taxonomy, specifically the description of a new beaked whale species (*Mesoplodon perrini* sp. n., Dalebout *et al.*, 2002) and the replacement of *M. bahamondi* (Reyes *et al.*, 1995), on the basis of morphological features of the skull, mandible and teeth and phylogenetic analysis of mtDNA sequences (van Helden *et al.*, 2002) with the senior synonym *M. traversii* (Gray, 1874). The Committee **recommends** that the list (presented in full in Annex L, Appendix 2) be updated as follows:

(i) Bahamonde's beaked whale (*M. bahamondi*) (change to *M. traversii*, recognise common name spade-toothed whale); and

(ii) Perrin's beaked whale (*M. perrini*) (recognise species).

13.4 Takes of small cetaceans

Information on small cetacean catches in 2001-04 is given in Annex L (Appendix 3) and it was noted that the data were incomplete. The Committee **urges** member governments to ensure that complete figures are reported to the Commission in a timely manner. The Committee **recommends** that the bycatch reporting tables for small cetaceans in the Progress Reports include the responsible fishing gear type, as is the case with large whales. The Committee also noted that the species identity of small cetaceans (directed take or bycatch) may be determined by genetic analysis of samples obtained during market surveys. The Committee recognised the potential of this approach to supplement official bycatch reports and agreed on the need to address potential biases of the technique.

An increase in strandings associated with a marked increase in fisheries entanglement of a small population of bottlenose dolphin (estimated to contain 80 individuals based on mark-recapture photo-identification studies) in Rio Grande do Sul, Southern Brazil is of concern, with model predications indicating a likely decline (SC/57/SM8). The Committee **recommends** that the status of this population be assessed as a matter of urgency.

13.5 Work plan

The Committee reviewed its work plan and schedule of priority topics. The work plan for the coming year includes as a priority a review of the status of small cetaceans of the Caribbean and western tropical Atlantic. Full details are given under Item 19 and in Annex L. A minority statement is given in Annex S.

14. WHALEWATCHING (SEE ANNEX M)

14.1 Report of the intersessional Working Group

Based on the work of an intersessional group, a number of definitions were developed to help clarify discussions on whalewatching activities. A glossary of types and categories of whalewatching, recommended by the Committee, is presented in Annex M, Appendix 2.

The intersessional Working Group on further development of precautionary approaches as a science-based framework for management of whalewatching was not convened during the intersessional period. The Committee **agrees** that this issue remains a high priority. Recognising the importance of the Workshop on Science for Sustainable Whalewatching held in South Africa in 2004 and of continued progress in the development of a scientifically based framework for the management of whalewatching, the Committee **agrees** that the report be made available through a link on the IWC website[13].

14.2 Biological impacts of whalewatching on whales

SC/57/WW3 summarised several studies on the impacts of whalewatching activities on cetaceans (Scheidat *et al.*, 2004; Goodwin and Cotton, 2004; Buckstaff, 2004; Orams, 2004; Bejder and Samuels, 2003; Bejder, 2005). The studies are summarised in Annex M, item 6. Parsons agreed to provide a review of relevant papers next year.

[13] *http://www.iwcoffice.org/conservation/whalewatching.htm.*

SC/57/WW5 reviewed recent key research and considered implications for future whalewatching research and management (Lusseau, 2003; Lusseau, 2004b; Constantine *et al.*, 2003; Constantine *et al.*, 2004; Williams *et al.*, 2002; Erbe, 2002; Bejder and Samuels, 2003). The studies are summarised in Annex M, item 6.

Given the innovative, quantitative methodologies in the papers reviewed, particularly those that examine linkage between short and long-term impacts, the Committee noted that the presence of key invited participants would have greatly enhanced the work of the Committee. The Committee therefore **recommends** that Invited Participants (such as Bejder, Lusseau and Samuels, who were invited but unable to attend this year) with this level of expertise be invited and funded to attend next year's meeting.

SC/57/WW7 described the increase of whalewatching efforts on humpback whales along the Bahia and Espírito Santo State coast, an area encompassing the main breeding ground of this species in Brazil. Edict 117/96 (modified by Edict nº 024-08/02/2002) regulates whalewatching in Brazilian waters. Article nº4 foresees restrictions on whalewatching only inside Marine Protected Areas (MPAs); Article nº5 states that any commercial tour vessel operating inside MPAs where cetaceans regularly occur must provide interpretative information on these animals and their conservation needs to passengers on a permanent basis. Due to the increase in the occurrence of humpback whales along the Bahia State coast outside of the MPAs, the authors suggest the Edict be changed to encompass the full range of the breeding area. The Committee welcomed this report and **supports** the proposal for revised legislation. In addition, the importance of presenting data on impact studies at next year's meeting was noted. Details of the study and discussions are in Annex M, item 6.

A land-based study to assess vessel impacts on Risso's dolphins (*Grampus griseus*) in the Azores, an important feeding, breeding and nursery area for the species, is nearing completion. Results indicated that Risso's dolphins significantly decreased their resting behaviour when the number of boats in the area increased, responding to the presence of boats as soon as they were present in the bay. In addition, their resting period shifted to midday, when the average number of boats in the area was relatively low, possibly adapting to a less favourable situation.

14.3 Review of published whalewatching guidelines and regulations

SC/57/WW2 detailed the present state of whalewatching regulations in Argentina. The first whalewatching regulations for Península Valdés were created in 1984 by adapting laws from other countries and several aspects of the regulations presently are not applicable. In 2004, Instituto de Conservacion de Ballenas/Whale Conservation Institute (ICB/WCI) organised a meeting with whale-watching company owners, boat captains, government officials and researchers to discuss ways to improve the current laws and to minimise the impact on the animals. Participants at the workshop agreed that the process to update the law could take years and proposed to create a Voluntary Code of Conduct that would be in effect for the short term. The Committee **welcomes** this approach to reducing the impacts of whalewatching since it integrates the stakeholders involved in whalewatching activities. Details of the code and discussions are in Annex M, item 7.

SC/57/WW3 presented studies on the effectiveness of whalewatching guidelines and regulations (Lusseau, 2004a; Scarpaci *et al.*, 2003; Scarpaci *et al.*, 2004). The studies are summarised in Annex M, item 7.

SC/57/E8 addressed concerns about tourism in Antarctica. As whalewatching may be an added stressor in the region and treaty nations are interested in developing a regime for tourism management, it was suggested that the Committee consider collecting data on whalewatching activities in the area. The Committee **agrees** that information on whalewatching activities and research conducted from whalewatching vessels in Antarctica should be presented at next year's meeting and that members should actively solicit papers for review.

The compendium on whalewatching guidelines and regulations around the world (Carlson, 2004) is being updated and will be posted on the IWC's website when complete. It was noted that the Instituto de Conservacion de Ballenas/Whale Conservation Institute had translated the compendium to Spanish. The author thanked the group for this enormous and very useful work and suggested that the Spanish version be linked to the IWC website.

14.4 Development of the scientific foundation of whale-watching guidelines

SC/57/WW1 reviewed 48 scientific peer-reviewed and grey literature articles involving impacts of whalewatching on cetaceans, characterised by species, location, methods and potential sources of impact, including vessel distance, speed, direction and noise. The aim of the review was to highlight available research results that could facilitate the development of scientifically based regulations. Results indicate that the majority of cetacean reactions appear to be elicited by the speed and direction of whalewatching vessels and that noise appeared to play an important role. The authors concluded that there is a body of evidence, varying by species and location, that can provide important information about cetacean reactions to whalewatching vessels and guidance for a science-based formulation of new regulations or the revision of current ones. The authors further suggested that areas where extensive whalewatching research has been conducted, in particular those where long-term studies exist, can provide research models for locations looking to develop a whalewatching research programme.

SC/57/WW3 summarised Goodwin and Cotton (2004). The authors suggested that guidelines incorporate speed restrictions and distances between boats and animals due to significant behavioural responses to fast-moving, planning-hulled vessels, but not other categories of boats studied.

It was noted that the majority of authors cited in SC/57/WW5 provided management advice, linking it to their research (Williams *et al.*, 2002; Constantine *et al.*, 2003; Constantine *et al.*, 2004; Lusseau, 2004a; Simmonds, 2004). The studies are summarised and discussed in Annex M, item 8.

In principle, all human activities in proximity to cetaceans will impact the animals. Therefore, it is critical to identify management objectives and then develop a management procedure that links the knowledge base to regulation. This management procedure should include an assessment of risk associated with anthropogenic disturbance in proximity to cetaceans, and describe the relation between level of disturbance and effect on the cetaceans. As a precautionary approach, whalewatching activities should be regulated well within the levels that

have no significant, detrimental effect on cetaceans. The level of whalewatching activities that will be allowed might differ between areas and countries, taking into account *inter alia*, socio-economic conditions, and will reflect the level of risk the respective managers are willing to take.

It was noted that one of the recommendations of the Workshop on Science for Sustainable Whalewatching was to conduct risk assessment analyses. The Committee **agrees** that terms of reference be developed for an intersessional Working Group to correspond on this subject and present a report at next year's meeting (see Annex P(28)).

14.5 Other topics

14.5.1 Review of risk to cetaceans of high-speed whale-watching boats

SC/57/WW8 presented a review of known collisions between whalewatching boats and whales worldwide. Thirty-two records were identified between 1984-2003. Results indicate the need for caution as whalewatching industries increase the use of larger, faster whalewatching boats. However, risks from whalewatching boats may not be substantively higher than any other transiting vessel in the same area. Details of the study are given in Annex M, item 9.1.

The Committee expressed an interest in receiving more information on this issue next year. Based on the evidence presented in SC/57/WW8, the Committee **agrees** to provide the following scientific advice for whalewatching management: whalewatching vessels, as well as other vessels, are at an increased risk of striking a whale within a set distance (2km or 4km) of the sighting of another individual and whales that are struck will often not be sighted prior to the strike. The severity of injury from a strike will increase as a function of the force of the strike. Since a key component of force is the speed at which the animal is struck, reducing speed in the vicinity of a sighted whale is likely to reduce the severity of a strike, and may have the auxiliary benefit of allowing operators increased time to avoid a strike altogether. This may be especially important in cases where relatively large whalewatching boats are used, since their size could also lead to increased force and therefore, injury if a strike were to occur.

14.5.2 Review of potential impacts of 'swim-with' programmes on populations of cetaceans

SC/57/WW3 reviewed studies on swim-with-cetacean tourism (Courbis, 2004; Samuels and Bejder, 2004; Orams, 2004; Scheer *et al.*, 2004). The studies are summarised in Annex M, item 9.2.

SC/57/WW6 presented an update to Rose *et al.* (2003) on the occurrence of swim-with-whale operations world-wide. Fifty-one specific commercial operations were identified, an increase of 43% from 2003. Humpback and dwarf minke whales remained the main species targeted, although swims were also offered with sperm, bowhead and blue whales. There was a decrease from 2003 in the number of web sites that mentioned conservation, human safety and research. The results reported are still only an imprecise estimate for the frequency of this activity as web searches were only conducted in English. The Committee **concurs** with steps recommended by the authors for presentation at the 2007 meeting, with an update next year, including: revising the world-wide review of swim-with-whale programmes; using additional methods; reviewing published and ongoing studies of swim-with-whale programmes; and identifying data gaps that would be necessary to fill in order to allow an assessment of the effects of such programmes on target individuals and/or populations.

The Committee **agrees** that this work be addressed by an intersessional Working Group (see Annex P(29)).

14.5.3 Other

Mayr and Ritter (2005) reviewed photo-identification research and behavioural observations of rough-toothed dolphins (*Steno bredanensis*) conducted from 2000 to 2003 on board whalewatching vessels off La Gomera (Canary Islands). The dolphins were found to have several distinct features suitable for individual identification. Identification and resighting data indicate a resident population and higher vulnerability towards anthropogenic activities. The study highlights the importance of longitudinal data collection and the value of platforms of opportunity for this type of research.

Published studies, based on data collected on whalewatching vessels, have addressed a wide range of management-relevant topics, including: distribution; stock identity; reproduction and survival rates; abundance; population composition; migratory destinations; behaviour and anthropogenic impacts (Robbins, 2000a). Some of these studies have contributed to the work of the Scientific Committee, such as in the 2001 Comprehensive Assessment of North Atlantic humpback whales. However, logistical and financial limitations can slow the pace at which whalewatching-based research emerges in the published literature (Robbins, 2000b). There also may be areas where useful data could be collected from opportunistic platforms, but no programme is underway.

It was proposed that the sub-committee on whalewatching make a dedicated effort to identify opportunistic sources of cetacean data of potential value to the work of the Scientific Committee. Committee members have detailed knowledge of the locations of whalewatching operations worldwide and so can identify areas, operations and/or data that are potentially relevant to upcoming Scientific Committee needs. Furthermore, members have expertise in the scientific use of opportunistic data sets, which have their own limitations and biases (Robbins, 2000b). The Committee could therefore provide a valuable service by scrutinising existing data collection programmes and archives, providing guidance to data collectors, seeking access to data that might address its scientific needs, and encouraging new data collection in key areas. It was noted that the ultimate value of this work within the whalewatching sub-committee would depend upon close co-ordination with other sub-committees.

The formation of an intersessional Working Group with membership from other relevant sub-committees to examine overlap between whalewatching activities, existing data collection programmes and upcoming Scientific Committee priorities was proposed and a request was made that the sub-committee solicit and review scientific information derived from opportunistic data sources and analytical techniques appropriate to such data. The Committee **agrees** that this would be of value to its work and should be a priority item for next year. It further **establishes** an intersessional Working Group to forward this work (Annex P(27)).

14.6 Work plan

The discussion of the work plan is given in Annex M, item 10. This is taken into account under Item 19.

15. DNA TESTING (SEE ANNEX N)

15.1 Progress on genetic methods for species, stock and individual identification

SC/57/SD3 presented an update on improved methods for DNA extraction and Polymerase Chain Reaction (PCR) amplification from small, old, and degraded tissue samples (including bone and dried soft tissue). Discussion of this can be found in Annex N, item 5.

SC/57/SD4 presented the results of a validation exercise for cetacean species identification using the curated reference dataset of mtDNA control region and cytochrome *b* sequences implemented in the Web-based species identification program, *DNA Surveillance* (Ross *et al.*, 2003) and the non-curated sequences available in the international repository GenBank. The purpose of the exercise was two-fold:

(1) to evaluate the potential for taxonomic mis-identification of sequences in the non-curated collection in GenBank; and
(2) to evaluate the reliability of *DNA Surveillance* to identify cetacean sequences and to recognise non-cetacean sequences.

Overall agreement between GenBank and *DNA Surveillance* in the attribution of species identity was high and there was little evidence that non-cetacean sequences in GenBank have been mislabeled as cetaceans. Discussion of this can be found in Annex N (item 5).

The Committee **agrees** that validation such as that described in SC/57/SD4 should be carried out routinely for cetacean sequences in GenBank and other such repositories and the Committee established an intersessional Working Group to develop and implement a protocol for routine validation for cetacean sequences in GenBank and other repositories. The question arose of what action could be taken when an identification is found to be erroneous, in view of the fact that the database entries are the responsibility of the original submitter. One possible solution suggested was that a new field could be added to the database where a challenge to the identification could be noted.

Kanda summarised a recent paper on the use of single nucleotide polymorphisms (SNPs) as markers in population genetics (Morin *et al.*, 2004). SNPs are genetic variation resulting from single-point mutations that produce single base-pair differences among DNA sequences.

A lengthy discussion on the advantages and disadvantages of SNPs took place in the Working Group and details can be found in Annex N (item 5). It was noted that the relevant issue for DNA registers is the potentiality of this marker for individual identification. The Committee **agrees** that SNPs offer considerable promise for application in the genetics of whale management, in particular because of the ease of standardisation of data across laboratories.

15.2 Collection and archiving of samples from catches and bycatch

A total of 638 and 537 common minke whales were landed in Norway in 2003 and 2004, respectively. Genetic analysis of these samples is in progress.

SC/57/O14 reported that samples of skin and muscle have been collected for 36 common minke whales taken in 2003 and 25 in 2004 in the Icelandic scientific whaling operations.

Regarding collection of samples in Japan, the Committee was informed that for the scientific whaling for the Antarctic (JARPA) programme, samples stored as of April 2005 were: Antarctic minke whale since 1987/88, *n*=6,794; common minke whale, *n*=16. For the western North Pacific (JARPN II) programme, samples stored as of December 2004 were: common minke whale since 1994, *n*=1,097; Bryde's whale since 2000, *n*=243; sei whale since 2002, *n*=189, and sperm whale since 2000, *n*=31. The samples from bycatch stored as of December 2004 were: North Pacific common minke whale, *n*=403; North Pacific Bryde's whales, *n*=3; North Pacific right whale, *n*=1, and North Pacific humpback whale, *n*=9. Genetic samples were stored for the following stranded whales as of l December 2004: North Pacific humpback whale, *n*=1; North Pacific common minke whale, *n*=1 and North Pacific fin whale, *n*=1.

15.3 Reference databases and standards for a diagnostic register of DNA profiles

Skaug reported on the status of the Norwegian register. Genetic analyses on samples of common minke whales landed in 2003 and 2004 have not yet been completed.

Annex N (Appendix 3) provided information on procedures, standards and status for the Japanese register for large whales. All whales taken under special permit in the western North Pacific (up to 2003) and most of those taken in the Antarctic (up to 2003/04) have been incorporated into the register. All bycaught and stranded whales (up to 2004) have been incorporated into the register.

As in the case of Norway, the Japanese register uses three kinds of genetic markers: mtDNA control region sequences for species identification; a set of nuclear DNA markers (microsatellites) for individual identification, and Y chromosome DNA for gender determination. A total of 17 microsatellite loci are used in the case of North Pacific common, Bryde's and sei whales. In the cases of the Antarctic minke whale and North Pacific humpback whales, six loci are used. Since the sex of the animals is determined by experienced researchers, molecular sexing is not conducted for samples taken under JARPA and JARPN II. In the case of bycatches, sex is determined molecularly.

The Committee **agrees** that it is important that a uniform procedure for estimating error rates be used by the several nations with DNA registers and **recommends** that this be done.

The Committee expresses its gratitude to the three nations (Japan, Norway and Iceland) for supplying information on their collections and registers.

15.4 Work plan

The terms of reference for the Working Group for the next year will remain the same as for this year, unless the Commission requests other information in the interim (and see Item 19).

16. SCIENTIFIC PERMITS (SEE ANNEX O)

16.1 Review of results from existing permits

16.1.1 Japan-Antarctic minke whales

SC/57/O5 presented the results of the eighteenth and final year of the JARPA programme. Research was conducted in the western part of the Area VI and Area V over a 92-day period between 7 December 2004 and 8 March 2005. Furthermore, the first co-operative survey with the RV *Kaiyo Maru* was conducted in the Eastern part of Area V. This was a meso-scale survey for the elucidation of the Antarctic marine ecosystem based on recommendations from the JARPA mid-term review meeting in 1997. Details of this cruise were reported in SC/57/O16.

One sighting vessel, three sighting and sampling[14] vessels and one research base ship were engaged in the research. A total of about 4,120 n.miles was covered in the western part of Area VI, and 14,460 n.miles in Area V. The total searching distance of the four research vessels was about 18,700 n.miles, which was similar to the totals in previous JARPA cruises.

Eight large whale species were seen during this cruise. Antarctic minke whales were the most numerous species in the research area overall and were also widely distributed throughout most of the area except for the West-North stratum of Area V. There were numerous sightings of four other species (in decreasing order of occurrence, humpback whales, sperm whales, fin whales and southern bottlenose whales (*Hyperoodon planifrons*)) in the whole research Area except for the East-South stratum in Area V.

The total number of sightings of Antarctic minke whales by the four research vessels was 4,400 individuals in 1,711 schools. Primary sightings of Antarctic minke whales made by the three sighting and sampling vessels amounted to 3,045 individuals in 1,049 schools. A total of 467 schools (consisting of 1,167 animals) was targeted for sampling of one whale from each school. On some occasions the chase was interrupted, e.g. by adverse chasing conditions or animal movements. One whale was struck and lost. A total of 440 individuals were sampled. The rate of success in sampling targeted individuals was therefore 94%.

Mature females dominated the samples in the East-South stratum, whereas mature males dominated the samples in the North strata in Area V and Area VI-W. Pregnant females were most numerous in the East-South stratum where a few immature individuals of both sexes were also sampled. There were 182 individual pregnant females with 182 foetuses in the whole research area.

Two Discovery tags were collected from a mature female that was 8.87m in length. This animal was captured at 72°59'S, 172°12'E on 5 February 2005. The Discovery tags had been attached at 66°16'S, 140°57'E on 4 January 1981 by the IDCR cruise and the visually estimated body length at that time had been 29ft (8.84m).

Particular features of this research cruise were:

(1) the East-South stratum in Area V (Ross Sea) was more extensive than in previous research cruises;
(2) relatively warm SST (1-4°C) was widely distributed in the western part of Area V; and
(3) a cooperative survey with RV *Kaiyo Maru* was conducted in the Eastern part of Area V for the elucidation of structure and function of the Antarctic marine ecosystem.

The survey indicated that the feeding migrations and segregation pattern of cetaceans were strongly influenced by yearly changes in oceanic environmental conditions such as SST and ice-pack distribution. It was stated that this indicated that long-term monitoring is therefore necessary to elucidate the structure and function of the Antarctic marine ecosystem.

The sampling regime has remained unchanged and the Committee did not enter into any detailed discussion of the results of this survey as the opinions of proponents and critics of this work within the Committee as expressed in previous years' meetings (e.g. see IWC, 2005c, pp.45-6) have remained unchanged.

16.1.2 Japan-North Pacific common minke, Bryde's, sei and sperm whales

SC/57/O3 outlined the offshore component of the 2004 full-scale survey under JARPN II. The objectives of the full-scale research were:

(1) to investigate the feeding ecology of common minke and other whales and to further ecosystem studies, involving studies of prey consumption by cetaceans, prey preferences of cetaceans and ecosystem modelling;
(2) to monitor environmental pollutants; and
(3) to study stock structure, particularly for common minke whales.

Target species were the common minke whale, Bryde's whale, sei whale and sperm whale. The research area covered sub-areas 7, 8 and 9 in the western North Pacific. The survey covered the four whale species as well as their prey. A total of six research vessels were used: one dedicated sighting vessel, three sighting and sampling vessels, one research base vessel and one trawl survey vessel equipped with a scientific echo sounder. A total of 10,695 n.miles was surveyed over a period of 96 days. During that period, 119 common minke, 180 Bryde's, 385 sei and 523 sperm whales were sighted by the sighting and sampling vessels. A total of 100 common minke, 50 Bryde's, 100 sei and 3 sperm whales were sampled. The co-operative survey on ecosystem research was conducted in a part of sub-area 9, 15-17 September. All whales sampled were examined on board the research base vessel. Stomach contents of the common minke whales consisted mainly of Pacific saury (*Cololabis saira*), minimal armhook squid (*Berryteuthis anonychus*) and Japanese anchovy (*Engraulis japonicus*). Bryde's whale stomachs contained mainly Japanese anchovy and Chub mackerel (*Scomber japonicus*). Sei whale stomachs contained mainly Japanese anchovy, copepods and Pacific saury. Dominant prey items in the stomach of three sperm whales were various kinds of mid- and deep-water squid.

The coastal component of the ongoing JARPN II work was described in SC/57/O4. Based on the results of the two-year feasibility study conducted in 2002 and 2003, the coastal component has been revised to be conducted twice a year, with 60 common minke whales being sampled in the spring and autumn seasons respectively. The first of the JARPN II revised coastal surveys was conducted 13 September-31 October 2004, off Kushiro, northeast Japan (i.e. the northern part of sub-area 7), using four small-type

[14] Under Special Permit research, sampling implies lethal sampling of whales unless otherwise specified.

whale catcher boats, one echo-sounder trawl survey vessel and one dedicated sighting survey vessel. An additional dedicated sighting survey using one small-type whale catcher boat was also attempted. The sampling was conducted in coastal waters within 50 n.miles of the port of Kushiro and all whales sampled were landed at the land station at the port of Kushiro.

During the survey, the total search effort for whale sampling was about 6,920 n.miles (635 hours), 151 schools and 156 individual common minke whales were sighted and 59 whales were sampled. The average body length of the sampled whales was 6.87m (SD=0.80, *n*=47) for males and 6.00m (SD=1.09, *n*=12) for females. Dominant prey species found in the forestomach were Japanese anchovy (62.1%) and Pacific saury (31%). The concurrent prey survey revealed the distribution of those prey species in the research area, and the dedicated sighting survey sighted 17 schools (18 individuals) of common minke whales within some 810 n.miles searched. Compared with the results of the 2002 survey off Kushiro, the length frequency of the whales inclined towards larger males, while the species composition of the prey species found in the forestomach was similar.

These results revealed yearly changes in the migration and feeding habits of common minke whales in the coastal waters off Kushiro in the autumn season, and it was suggested that those changes might be related to yearly variation in environmental factors such as the oceanographic conditions or the distribution of prey species. To evaluate the potential for long-term competition between whales and fisheries in the local area and to clarify the role of whales in the marine ecosystem, the proponents stated that further surveys should be conducted on a yearly basis.

The relevance of the reported collection of oocytes from female common minke whales for *in vitro* fertilisation (SC/57/O5) was questioned. The Committee was referred to the work of Prof. Y. Fukui, of the Obihiro University of Agriculture and Veterinary Medicine, who has published several papers in international journals on his work on oocyte development and whale reproduction, some of which are detailed in SC/57/O15.

There remained divided views on the validity of the JARPN II research programme and its results, as expressed in previous years (e.g. see IWC, 2005c, p.46; IWC, 2004d, p.364).

16.1.3 Iceland-North Atlantic common minke whales

The Icelandic Research Programme on common minke whales was reviewed in SC/57/O14. The original plan had called for a sample of 200 common minke whales in the two years after the review by the Committee in June 2003. The programme began in August 2003, with takes of 36 whales that season, followed by 25 in the 2004 season. Progress has therefore been much slower than anticipated. The reasons for this were political rather than scientific, with the Icelandic Ministry of Fisheries deciding the rate of sampling. This should not present a problem in scientific terms, so long as the total expected take of 200 is achieved and the original seasonal and geographical distribution is retained. The present expectation is that 39 whales will be taken in 2005 and the remaining 100 in 2006.

The 2004 season was 3 June-6 July. Three catching boats had been employed with search effort distributed all around Iceland. The 2004 season had taken more females than males (15 out of 25) than in the previous year (13 out of 36). This year seven animals were taken ashore for a full veterinary post mortem examination. Aerial surveys were also conducted during the period April to September 2004 and the resulting maps of survey effort and sightings were shown in SC/57/O14 and SC/57/O8.

Satellite telemetry was attempted on seven animals and data were received from one of these for several months, until 5 December 2004, at which time the animal was off the coast of West Africa (SC/57/O9). A summary of other projects within the overall programme was also given in SC/57/O14. Some members commended the work on satellite telemetry.

In response to questions about the criteria used to select animals for toxicological studies, it was stated that from the animals taken under the Special Permit, five animals had been selected under domestic legislation for marketing purposes. Another 25 animals had been selected over the two years for toxicological studies in order to obtain a representative sample from both sexes and different age classes from the whales taken under Special Permit. Some of these samples needed to be sent abroad for full analysis, and there had been some delays in obtaining the relevant permits.

In order to address the question of how effectively faecal samples collected at sea might be used to study diet, faecal matter was also being collected from the posterior end of the rectum of some common minke whales in order to make comparisons with stomach contents. This might then be compared with results from an International Fund for Animal Welfare (IFAW) project that had collected faeces under a research permit issued by the Icelandic authorities in 2004. The project will shed light on the feasibility of collecting common minke whale faecal samples at sea to study their feeding habits.

Childerhouse welcomed the increase in attention to non-lethal methods. Víkingsson welcomed a proposal from Hatanaka for collaboration with Japanese scientists.

The Committee noted the lower than expected sampling rate. As for the preceding programmes, opinions were divided on other aspects of the work, and reference was made to earlier statements on this programme by proponents and opponents respectively (IWC, 2005c, pp.46-7).

16.1.4 Review report from non-IWC meeting on JARPA results

A JARPA Review Meeting called by the Government of Japan was held at the Institute of Cetacean Research, Tokyo, on 18-20 January 2005, and is summarised in SC/57/O6. The JARPA research objectives and its work tasks were first reviewed. The JARPA survey procedure, the data collected and the results were also reviewed in the light of the JARPA objectives. The meeting agreed that:

(1) JARPA has collected a very large and consistent database over a 16-year period, which provides a basis for time series analyses relating whales to the Antarctic environment and the beginning of an ecosystem approach to the management of whale resources in the region;
(2) JARPA has contributed to the elucidation of biological parameters of Antarctic minke whales, and improved the understanding of the Antarctic marine ecosystem; and
(3) JARPA has revealed the changes that have occurred in the ecosystem since the 1970s suggesting competition among Antarctic minke and other large whales and data

obtained through this monitoring will contribute to the development of ecosystem models, which are necessary for ecosystem-based management of whales.

The review meeting considered that JARPA had made good progress in addressing its objectives, and also agreed that tasks identified in the IWC mid-term review meeting in 1997 (see section 5 of SC/57/O6) had been appropriately addressed.

Some members of the Committee noted that the meeting to review JARPA hosted by Japan had been attended largely by representatives of nations that supported whaling, and thus they questioned the objectivity of this non-IWC review. In response it was noted that the review meeting had been widely made known, and that all members of the Scientific Committee had been invited, although it had been agreed that this review meeting would not be considered an IWC sponsored meeting (IWC, 2005c, p.46).

16.1.5 Preparations for JARPA review

The JARPA Review Planning Steering Group worked intersessionally to prepare for a full review of the JARPA programme by the Scientific Committee when the complete set of results of the 18 year programme is available. It had been agreed that the review would not be limited simply to results relating to Antarctic minke whales, but that research areas not covered in the original plan, and later adopted by JARPA, such as the work on blue and humpback whales, would also be considered. Abundance estimates and sightings survey work are also part of JARPA and need to be considered in full. The Group agreed that this review should be carried out by an Intersessional Working Group to Review Data and Results from Special Permit Research on Minke Whales in the Antarctic. This would be done during an intersessional meeting, most likely in Tokyo in late 2006. Progress in planning for this review was summarised, and a draft Terms of Reference and a draft Agenda were provided as appendices to the progress report (given as Annex O2 to this report).

The Steering Group had agreed on most aspects of the proposed review except for the draft Terms of Reference numbers 3 and 4, and proposed agenda item 9. There was some disagreement over how to address Resolutions made by the Commission with respect to the review, including issues surrounding the utility of lethal or non-lethal methods (proposed agenda items 9.1 and 9.2). It was **agreed** that a group led by Zeh (Annex P(30)) would reconsider this issue by re-examining the Commission's Resolutions in detail.

Noting the differences of opinion between members over interpretation of the Commission's Resolutions, the Committee nevertheless **agrees** that only scientific and not ethical issues should be considered by the review. However, a discussion of the scientific aspects of the respective merits of lethal and non-lethal methodologies was important. In view of the fact that some experts from outside the Scientific Committee would be invited to the review meeting, the Committee **agrees** that some discussion of the respective merits of lethal and non-lethal methodology (proposed agenda items 9.1 and 9.2, and Proposed Terms of Reference 3 and 4) is necessary to allow the Invited Participants to the Review to contribute to this debate. However, the main focus of the review would be on the remaining agenda items, and these more contentious issues would mainly be discussed at the subsequent Scientific Committee meeting by the full Committee. The Committee **accepts** the proposed terms of reference and proposed agenda with this qualification.

16.1.6 Responses to previous Scientific Committee reviews

Childerhouse asked what changes had been made to each of the research programmes as a result of extensive comments received from the Scientific Committee in previous years. In response it was noted that the meso-scale surveys had been added to the JARPA research programme as a direct result of recommendations made at the mid-term review of JARPA in 1997. It was noted, however, that no modifications to the JARPN II work plan had been implemented as a result of any comments or suggestions made by the Committee in previous years. In reply it was stated that all comments on JARPN II research plans had been studied and considered but that few if any were constructive while others were difficult to accommodate.

With regard to Icelandic common minke whale research, it was noted that SC/57/O14 states that no major changes had been made to the original proposal, but that some new non-lethal components had been added in response to Scientific Committee comments made on the original proposal. Specifically, the Committee was informed that additional prey sampling was being conducted by taking samples from the posterior end of the rectum of sampled animals to compare with stomach contents and potentially with faecal samples collected at sea.

Although there is no formal requirement for Special Permit holders to report on what changes have been made to their research plans as a result of any comments or suggestions received from the Scientific Committee, the Committee **agrees** that it would be good practice to do so. This would help to speed up future reviews and would constitute an act of good faith.

16.2 Review of new or continuing proposals

16.2.1 JARPA II

The Plan for the Second Phase of the Japanese Whale Research Programme under Special Permit in the Antarctic (JARPA II) was presented in SC/57/O1.

JARPA was conducted between the 1987/88 and 2004/05 austral summer seasons, under Article VIII of the International Convention for the Regulation of Whaling. The IWC Scientific Committee conducted an interim review of JARPA results in 1997. In January 2005, a non-IWC JARPA review meeting called by the Government of Japan was held.

Based on its stated desire to take into account species-interaction (ecosystem) effects in understanding the dynamics of the baleen whale species in the Antarctic ecosystem, and predicting future trends in their abundance and population structure, the Government of Japan will launch a new comprehensive study under the Second Phase of the Japanese Whale Research Programme under Special Permit in the Antarctic (JARPA II), combining lethal and non-lethal methods, starting from the 2005/06 austral summer season. The first two seasons (2005/06 and 2006/07) will be dedicated to feasibility studies. The practicability and appropriateness of sighting methods in the enlarged area and sampling procedures given the increased sample size and number of species to be sampled, will be examined. Methods for catching, flensing and taking biological measurements of the larger species will be tested. The full-scale JARPA II will start from the 2007/08 season.

It will be a long-term research programme with the following objectives:

(1) monitoring of the Antarctic ecosystem;
(2) modelling competition among whale species and developing future management objectives;
(3) elucidation of temporal and spatial changes in stock structure; and
(4) improving the management procedure for the Antarctic minke whale stocks.

JARPA II will focus on Antarctic minke, humpback and fin whales and possibly other species in the Antarctic ecosystem that are major predators of Antarctic krill. Annual sample sizes for the full-scale research (lethal sampling) are 850 (with 10% allowance) Antarctic minke whales (eastern Indian Ocean and western South Pacific stocks), 50 humpback whales (D and E stocks) and 50 fin whales (Indian Ocean and the western South Pacific stocks). During the feasibility study, a maximum sample of 850±10% Antarctic minke whales and ten fin whales will be sampled in each season. Humpback whales will not be taken during the feasibility study.

The research methods for the JARPA II are basically the same as the previous JARPA with some modifications. The programme also includes non-lethal research techniques such as sighting surveys, biopsy sampling, acoustic surveys for prey species and the collection of oceanographic data.

The research proposal for JARPA II as described in SC/57/O1 was elaborated upon in an audio-visual presentation. In response to subsequent questions of clarification from members of the Committee, it was made clear that there will be six vessels involved in the JARPA II survey. Two of these will be dedicated sighting vessels and these will cover the entire area independently of the sighting and sampling vessels, but their tracklines have not yet been determined. Three of the vessels will be sighting and sampling vessels (the sixth vessel being the research base vessel). In response to a query as to how the same vessels could double the catch rate achieved under JARPA within the same seasonal sampling period, the Committee was informed that in previous seasons about 1,000 schools had been encountered, but that not all schools had been sampled and that whereas previously one animals per school had been taken, the plan for JARPA II was to take two animals per school. It was stated that sampling just one animal might lead to bias, and that sampling two animals per school would therefore be less biased. It was also stated that a larger area would be covered by JARPA II. The objective in JARPA II was to sample sufficient animals to achieve statistically significant results, and this required more animals to be taken.

There are as yet no plans to use trawls to validate acoustic estimates of krill abundance, although the independent meso-scale surveys of the area using another vessel may employ trawls to monitor krill at a later date. None of the vessels used in the JARPA II survey will be ice-breakers, so pack ice areas will be avoided, but some sightings survey work may occur in the marginal ice areas, so long as ice conditions permit the vessels to maintain speeds of 11 knots. This condition will define the ice-edge for these surveys. It is also intended to include sightings data from other expeditions involving ice-breakers working in the pack-ice if these are available. The issue of collaboration with CCAMLR was also brought up, as the removal of 850 Antarctic minke whales might impact ongoing CCAMLR studies of the Antarctic ecosystem, so it was questioned whether or not collaboration with CCAMLR had been sought. It was stated in response that under JARPA, meso-scale surveys had included the participation of a Japanese CCAMLR scientist, and that collaboration with CCAMLR was therefore already happening.

In answer to the question of whether or not an ethical review process had been implemented it was stated that Japanese domestic legislation on animal welfare had recently been updated, and that although there was no formal process in terms of inter-agency consultation, the Fisheries Agency of Japan had considered the JARPA II plan in relation to the revised legislation and no conflict had been found between the planned research and the revised legislation. In response to a question on the issue of humane killing, it was stated that in previous JARPA surveys the time-to-death had been recorded, and that this practice would be continued.

Regarding the rationale for having an allowable error of 10% of the sample size of 850 animals, it was stated that tracklines are set according to previously observed densities, taking account of catchability by area, but it was not always possible to guarantee that the target would be attained.

Following these points of clarification, the proposal was reviewed by the Committee in accordance with the relevant guidelines for reviewing proposals for scientific permits. However a group of 63 members objected to a review of the JARPA II proposal because the Committee has had no opportunity to conduct a formal review of the results of the original JARPA programme; these members submitted a statement to this effect (SC/57/O22). This statement is included in Annex O, Appendix 2. These members further stated that they had substantial concerns about all aspects of the JARPA II proposal, but that it would be inappropriate to provide a detailed critique until after a JARPA review had been conducted by the IWC.

Accordingly, they stated that the lack of comments and criticisms of JARPA II in the Scientific Committee report should in no way be construed as consensus within the Committee regarding the objectives and methodology proposed by the JARPA II programme.

In response to this, the proponents tabled a working paper (Annex O, Appendix 3) that rebutted the assertions of SC/57/O22. Specifically these members stressed that the Scientific Committee was obliged to review the JARPA II proposal, according to paragraph 30 of the Schedule. These members also asserted that Japan was not trying to abandon the RMP, but rather was trying to strengthen it by addressing a multi-species approach. Concerning the lack of peer-reviewed results in international journals, it was stated that there has been a number of publications but that many western journals refuse to publish results from JARPA for ethical reasons. It was also asserted that the proposed sample sizes would not have an adverse impact on the recovery or status of any whale populations.

Following this exchange of views, the Committee continued to review the research plan in accordance with the relevant guidelines, but without the participation of the authors of SC/57/O22.

A. The Proposal

The current relevant guidelines for review are as follows:

1. A statement as to whether the permit proposal adequately specifies the four sets of information required under paragraph 30 of the Schedule (IWC, 1986, p.133).
2. Objective of the research (Schedule Paragraph 30).
3. Number, sex, size and stock of the animals to be taken (Schedule Paragraph 30).

Summary of proposal
The proposal provides the information required under Paragraph 30 of the Schedule.

Comments and discussion
Some members expressed the opinion that the JARPA research programme had made a major contribution to the knowledge of the biology of Antarctic minke whales, and that in the face of changing environmental conditions the value of this work would increase. They stressed the importance of preserving the continuity of the research programme, provided the research does not hamper the development of the stocks. Some other members stressed the importance of JARPA II as an approach towards ecosystem management of the Antarctic.

One member also expressed the view that many of the important results of JARPA have been presented to the Scientific Committee during the past few meetings, and that large parts of the proposed JARPA II have objectives that are virtually independent of the JARPA objectives and results. For these reasons he felt that the Committee has more than sufficient information to conduct a review of the JARPA II research plan. He also stated that it was reasonable to expect a continuation of scientific whaling in Antarctica, because of the need to keep ships and personnel employed with the task, and also the need to maintain markets for the whale meat, which helped to fund the entire programme. In reply it was noted that these logistical and economic considerations should be outside the purview of the Scientific Committee, and that the validity and necessity of such research programmes should be considered on their scientific merits alone.

B. Objectives
The current relevant guidelines for review are as follows:

1. comments on the objectives of the research to be carried out under the proposed scientific permit, including in particular how they might relate to research needs identified by the Scientific Committee (IWC, 1986, p.133);
2. the proposed research is intended and structured accordingly to contribute information essential for rational management of the stock (IWC, 1987, p.25);
3. is required for the purposes of management of the species or stock being researched (IWC, 2000a);
4. the research addresses a question or questions that should be answered in order to conduct the comprehensive assessment or to meet other critically important research needs (IWC, 1988, pp.27-8); and
5. the number, age and sex of whales to be taken are necessary to complete the research and will facilitate the conduct of the comprehensive assessment (IWC, 1987, p.25).

Summary of proposal
The proponents stated that JARPA has revealed evidence that the Antarctic ecosystem is changing and therefore, it is necessary to understand the dynamics of interactions between whale species in order to achieve rational management and sustainable use of whale resources. Based on the results of JARPA, JARPA II was planned with the following four objectives:

(a) monitoring of the Antarctic ecosystem;
(b) modeling competition among whale species and future management objectives;
(c) elucidation of temporal and spatial changes in stock structure; and
(d) improving the management procedure for Antarctic minke whale stocks.

JARPA II will provide information on abundance trends, biological parameters and stock structure, which will contribute to comprehensive/in-depth assessments of Antarctic whale stocks. An ecosystem model will be developed based on data collected under JARPA II, which will contribute to the testing of hypotheses concerning changes in the Antarctic ecosystem as well as the establishment of an ecosystem-based management scheme for whale resources.

Comments and discussion
Responses from the Committee to the listed objectives were limited in view of the opinions expressed in SC/57/O22. Some members stressed the importance of continued monitoring of biological parameters of Antarctic minke whales, not least in the light of global environmental changes, but also to supplement other ongoing research into Antarctic ecosystem dynamics. The failure of several baleen whale stocks to recover was also a matter that required an ecosystem level analysis, and while JARPA represented a significant step in addressing this question, JARPA II would provide a framework for multi-species modelling of the Antarctic marine environment. Other members also stressed the need to develop an ecosystem-based approach to managing the Antarctic marine environment and commended the objectives of JARPA II in this respect.

One member questioned the assumption expressed in SC/57/O1 that the population of Antarctic minke whales had increased after the cessation of whaling on the larger baleen whale species and in response to the depletion of these whale populations, noting that there had been no assessments of Antarctic minke whale stocks in the early 20th century.

C. Methodology
The current relevant guidelines are as follows:

1. 'comments on the methodology of the proposed research and an evaluation of the likelihood that the methodology will lead to achievement of the scientific objectives. These comments may also include evaluation of the methodology in terms of current scientific knowledge' (IWC, 1986, p.133);
2. 'the objectives of the research are not practically and scientifically feasible through non-lethal research techniques' (IWC, 1987, p.25);
3. '. . .whether the information sought could be obtained by non-lethal means' (IWC, 2000a, p.51);
4. 'the research addresses a question or questions that can not be answered by analysis of existing data and/or use of non-lethal research techniques' (IWC, 1988, pp.27-8);
5. 'whales will be killed in a manner consistent with the provisions of Section III of the Schedule, due regard being had to whether there are compelling scientific reasons to the contrary' (IWC, 1987, p.25); and
6. 'the research is likely to yield results leading to reliable answers to the questions being addressed' (IWC, 1988, pp.27-8).

Summary of proposal
The proponents stated that JARPA II will involve both lethal and non-lethal sampling. In general the research methods established by JARPA will be used in JARPA II. Monitoring of food consumption, blubber thickness, and age at maturity are important because these parameters are indicators of food availability and competition for a major food species in the Antarctic, krill. These data cannot be obtained through non-lethal sampling. Age, which can only be obtained by lethal sampling, is essential for detecting

recruitment trends by VPA and for studies of pollution on whales. All whales are taken using explosive grenades. If instantaneous death is not achieved, a suitable secondary method is applied.

Comments and discussion

Again, responses from the Committee were limited. Some members agreed that lethal sampling was the only way to collect the necessary data to achieve the stated research objectives and suggested furthermore that in order to elucidate ecosystem interactions sampling should be expanded to include other krill predators such as penguins and seals. Other members also noted the two-year feasibility phase and suggested that this would be valuable in refining the methodology. They agreed that while some biological data could be collected using non-lethal methods, the overall objectives would require lethal sampling.

Polacheck noted, in relation to guideline C1, and not withstanding the concerns raised in SC/57/O22 concerning the difficulty and validity of reviewing the JARPA II proposal prior to the completion of the review of JARPA, three additional general concerns with methodological aspects of the proposal, as listed below.

(1) The level of details in the proposed survey and sampling designs is insufficient to adequately review the proposal – particularly with respect to the consideration of sample size, the relative effort devoted to sighting activities and the representativeness of coverage and sampling.

(2) Monitoring of the Antarctic ecosystem and testing of hypotheses for changes in whale abundance through ecosystem modelling are two of the stated primary objectives of JARPA II. As noted in the proposal, krill play a central role in the Antarctic ecosystem and is a critical hypothesis underlying the proposal is that 'the carrying capacity of the whale species depends on available biomass of krill'. The abundance of krill is seen as the dominant factor controlling changes in whale abundance. As such, estimation of the abundance of krill, monitoring trends in their abundance and understanding krill dynamics are critical for achieving the above two primary objectives of the proposal and would have been expected to have been a central component in the proposal. However, the proposal appears to recognise this but contains no commitment or specific survey plans for such work.

(3) Monitoring of Antarctic minke whale abundance and biological parameters are a central focus of the proposed research programme. Substantial numbers of Antarctic minke whales appear to occur within the pack ice and the pack-ice is a potentially important habitat for this species. The current Scientific Committee review of Antarctic minke whale abundance and trends has found that lack of information on the abundance of Antarctic minke whales within the pack-ice, possible differential distributions with age and/or sex is an important uncertainty that confounds the interpretation of past research efforts (including those of JARPA). In designing a future research programme, it is critical to learn from the past results. JARPA II contains no plans to survey within the pack-ice, but will simply repeat this past deficiency of previous research. Similarly, as in (2), addressing the question of Antarctic minke whales in the pack-ice through direct monitoring would have been expected to be a central component of the research if the proposal were serious about achieving its objective. The lack of this will likely compromise the interpretation of the Antarctic minke whale results and the likelihood of the programme achieving its stated objectives.

In response to these criticisms, the proponents of JARPA II stated firstly that the sampling design is still not finalised, but that the same approach as was used in JARPA will be used to lay down the specific tracklines that will be used in JARPA II. Secondly, and with respect to the issue of krill sampling, acoustic survey methods will be used to determine krill abundance, as was the case in JARPA, whilst simultaneously surveying cetacean distribution. Data collected in this way will promote the development of an ecosystem-modelling framework for the Antarctic marine environment. Finally, and with respect to Antarctic minke whales in the pack-ice, data on Antarctic minke whale distribution in the pack-ice have been collected gradually using ice-breakers, and this data collection will continue. Previous pack-ice work under JARPA has shown, for example, that there was a high proportion of mature females in the pack-ice and if enough time is spent collecting such data in future years, then these issues will be investigated.

Polacheck responded that he would still expect both krill sampling and Antarctic minke whale sampling in the pack-ice to be central components of any research projects with the stated objectives of JARPA II, rather than the adjunct exercises they appeared to be from both the proposal and the explanation given. Hatanaka replied that krill abundance estimates would certainly be carried out routinely every year.

D. Effects on stocks

The current relevant guidelines are:

1. a review of the most recent information on the stock or stocks concerned, including information on any exploitation, stock analysis and recommendations by the Scientific Committee to date (including, where appropriate, alternative analyses and conclusions and points of controversy) (IWC, 1986, p.133);
2. an evaluation of the specification in the permit proposal of 'possible effect on conservation of the stock'. As appropriate, the Scientific Committee may carry out its own analysis of the possible effects (IWC, 1986, p.133); and
3. the research can be conducted without adversely affecting the overall status and trends of the stock in question or the success of the comprehensive assessment of such stocks (IWC, 1988, pp.27-8).

Summary of proposal

Based on the most recent information on stock structure and abundance in the Antarctic minke and humpback whale as well historical information in the case of the fin whale, the effect of JARPA II catches on the stocks has been evaluated by the proponents. They reported that the FITTER methodology used for Antarctic minke whales showed no negative effect on the stocks. In the case of humpback whales, they had applied the population dynamics model developed by Johnston and Butterworth (SC/57/SH16). The results showed that the proposed take of 50 animals per year would probably not delay the recovery of stocks to pristine level. The abundance estimate of fin whales does not cover their entire range and therefore is greatly underestimated. The planned sample size of fin whale is less than 1% of the underestimated abundance, and therefore the planned catch was considered by the proponents to have no adverse effect on the stocks.

Comments and discussion

Some members believed that the takes of Antarctic minke whales would not pose any threat to the population. They also asserted that sample sizes of the larger whale species were also small and unlikely to affect the stocks involved. The proposed takes of humpback whales in particular, are well below recruitment levels judging from recent evidence of a population growth of at least 10%. Abundance of fin whales has also increased so that the proposed catches should not have a negative effect on these stocks.

Leaper reminded the Committee that when the effect of research programme time-scales on catch quotas had been addressed at the 2000 meeting, the Scientific Committee had expressed concerns that open-ended special permit programmes initially proposed as feasibility studies had become ongoing programmes. Consequently the Committee **agreed** that when addressing the effects of special permit catches on stocks it would examine such effects as if the takes were ongoing. The continued increase in special permit takes since that time would seem to make that agreement in 2000 (IWC, 2001d, pp.57-8) even more pertinent for the present discussions.

In response, Hakamada pointed out that in Appendix 9 of SC/57/O1, simulation trials had been run in which continued catches at the levels proposed in JARPA II had little effect on the populations of Antarctic minke or humpback whales even when extended for as long as 30 years. However, the duration of the research programme is independent from the period of the research assumed in the trial.

E. Research co-operation

The current relevant guideline is:

1. comments on the adequacy and implications of specific arrangements for participation by scientists of other nations (IWC, 1986, p.133).

The proponents offered the usual invitation for suitably qualified foreign scientists to join the cruises.

16.2.2 JARPN II

Last year a revised JARPN II plan had been submitted, and the research in 2004 had been conducted according to those plans. There were no changes to the current research plans, on which the Committee had divided views. The Committee therefore refers back to previous statements made by proponents and critics of this research programme (IWC, 2003a, pp.66-77; IWC, 2005c, pp.47-9).

16.2.3 Iceland

The initial Icelandic proposal has been changed with respect to the rate of sampling, and this year's sample size has yet to be determined, although the Marine Research Institute's proposal was for 39 common minke whales. Once again, in the absence of any significant change to the planned research, the Committee refers back to previous statements by members (IWC, 2004b, pp.40-7; IWC, 2005c, p.49).

16.3 Proposals to facilitate the review process of scientific permits

Last year, (IWC, 2005c, pp.44-5; Bjørge and DeMaster, 2004) efforts were made to prepare a proposal to the Commission on restructuring the guidelines for scientific permits but no agreement was reached on any proposal for changes. This included a proposal to use independent reviewers, as had been done for the Southern Ocean Sanctuary review. Therefore, the Committee agreed at last year's meeting that, lacking further guidance from the Commission, the Committee would not be able to agree any recommended changes and that this item should be removed from the agenda. Following a short discussion of several aspects of scientific permit whaling the Committee agreed that little had changed regarding the two disparate positions described in last year's Committee Report and the disparate positions described in Annex O (SC/57O22 and Appendix 2). For example, some members again questioned whether the scientific content of the proposal was sufficient to justify taking whales, while others believed it was. When reviewing scientific permit proposals, the Committee recognises the chronic difficulties it faces in separating purely scientific issues from those issues that are more appropriate for discussion in other fora and notably the Commission. However, **it draws to the Commission's attention** the fact that the integral nature of the scientific and non-scientific issues surrounding expanding scientific permit programmes makes it extremely difficult for the review process within the Committee to function effectively, since it wishes to limit its discussions to purely scientific aspects of the proposals.

Nonetheless, two specific proposals were raised concerning the review process.

Holders of special permits provide annual progress reports on the activities conducted under the special permit during the previous year. The Scientific Committee is required to review these reports and provide advice to the Commission. This year, the Committee was required to review reports from two Japanese permits (JARPA and JARPN II), the Icelandic permit and a new permit proposal by Japan (JARPA II). In all cases the scientific merit and value of the programs are highly controversial with entirely polarised views being expressed.

Some members believe that a major problem with the review process in the Scientific Committee is its lack of independence. They pointed at the proponents defending their own reports and proposals, participating in the review of these and in the drafting of the resulting reports. This is in contrast to a process that leads to the review being undertaken by scientists without conflict of interest, and they felt that this has created a scientific deadlock and an ineffective review process within the Committee. They suggested that an external, transparent review of these progress/mid-term/final reports and proposals should take place by submitting these for review to an international body representing independent scientists with marine mammal expertise e.g. the Society of Marine Mammalogy (SMM). The Journal of this Society publishes peer-reviewed scientific reports irrespective of lethal or non-lethal sampling protocols. They believed that by submitting the reports to the board of SMM, the IWC can expect an external independent review of the science of the work conducted under special permits.

Other members doubted that any independent and objective review of such proposals would be possible, as the issue of scientific whaling has polarised opinions in the wider scientific community as well as in the Scientific Committee. It was also noted by some members that a review of scientific permits is a mandated responsibility of the Committee under the Convention, the Schedule, and the Rules of Procedure. Therefore, it did not seem appropriate for the Committee to abrogate this responsibility to another organisation.

A second proposal for an alternate approach to how the Committee reviews scientific permits was to require the

country responsible for the proposal to subsequently submit a revised proposal that incorporates comments received from the Committee. It was also suggested that under this alternative approach, delegates from the country preparing the proposal would not participate in the review. There is no consensus within the Committee for this proposal.

As noted above, some members did not believe it was reasonable to expect a meaningful review by independent experts, given the controversy that exists over lethal sampling in general in the scientific community, and lethal sampling of large whales in particular.

Polacheck suggested in any case, review of the methodological aspects of proposals relative to evaluation of whether the methodology would likely lead to achievement of the scientific objectives (including survey design, lethal and non-lethal sampling methods and sampling sizes) was one component of the review process that should be feasible and for which it would be useful to seek independent review. Walløe commented that in his experience it is impossible to separate validation of methodology from other aspects of the research plan, such as costs, logistics and questions such as lethal versus non-lethal sampling.

The Committee **concludes** that there is no agreement on any of the suggestions raised during the meeting. It **notes** two issues that emerged that might be given further consideration at next year's meeting:

(1) the possibility of an independent and objective review panel; and
(2) the debate over whether or not the proponents of a proposal should participate in a review of their own proposal.

It further **concludes** that any new review process must be consistent with the Convention and with established Rules of Procedure.

17. WHALE SANCTUARIES

The only agenda item related to whale sanctuaries this year was in response to a request from Palazzo and the Government of Brazil to review a proposal to establish a South Atlantic Whale Sanctuary (SAWS) (IWC/57/4).

Palazzo summarised the proposal. It was noted that this document was not prepared *only* for the Scientific Committee. It was written to be discussed in several fora, including *inter alia* the Scientific Committee, the Conservation Committee, and the Commission Plenary. In the author's opinion, the proposal for a South Atlantic Sanctuary has not received proper time or consideration by the Scientific Committee. The Committee's previous reviews are summarised under Item 17.1.

The author stressed that the proposal for a SAWS presented jointly by Argentina, Brazil and South Africa has a very clear stated goal: that of promoting and consolidating a non-lethal management regime for cetacean resources in the area it encompasses. The author pointed out that the most relevant parts of the proposal for review by the Scientific Committee were contained in parts 6 and 7 of the proposal.

The author also noted that the proposed Sanctuary is to serve the stated goal of promoting non-lethal use of whales. The author pointed out that in this context, the proposed Sanctuary should not be judged in relation to the RMP, nor should its establishment be constrained by the possible future existence of RMP-based management regimes in other areas. It was noted that in the author's opinion, the management decisions concerning the best way of appropriating whale resources are not to be dictated globally only on the basis of lethal harvests.

Finally, it was recognised by the author that the Committee was deeply divided about the issue of sanctuaries and its role in cetacean management. Nevertheless, Palazzo noted that this discussion would be a valuable exercise for the Commission as it attempts to craft a way out of the current deadlock in whale management alternatives.

The issue was raised whether coastal range states had been contacted, as it was desirable for their consent before going forward with this proposal. Palazzo stated that they had and noted that while the Convention applies to 'all waters in which whaling is prosecuted' (Article I (2)), the authors of the proposal understand that nothing in the proposal was intended to imply any restrictions to the sovereign rights of coastal States.

17.1 Background information regarding reviews of sanctuary proposals

Proposals similar to IWC/57/4 have been reviewed in the past by the Scientific Committee. A summary of the most recent comprehensive review was published in IWC (2002c, pp. 65-67; 2002e, pp. 404-7). During its annual meeting in 2001, the Committee 'was unable to reach a consensus view'.

At the 2001 meeting of the Commission, the Scientific Committee received further instructions from the Commission regarding reviews of sanctuaries (IWC, 2002c, p.65). The general guidance was that the Committee 'should give primary attention to considering the scientific feasibility of meeting the scientific aspects of the stated objectives, and, if necessary, recommend amendments to the objectives, or changes to the proposal to better meet its objectives.' Specific guidance included *inter alia*:

(1) assess whether the sanctuary distinguishes between species and stocks that are depleted and apparently slow to recover, those that are increasing rapidly, and those that are abundant and not threatened and assess the present and potential threats to whale stocks and their habitats in the area of the proposed sanctuary and how the proposed sanctuary addresses these;
(2) assess the anticipated effects of the proposed sanctuary in terms of:
    (i) improving protection of whales, in breeding areas, feeding grounds, or migratory routes;
    (ii) improving the conservation of breeding sites, migratory routes or feeding grounds; and
    (iii) complementing existing or potential protection;
(3) provide advice on whether the proposed boundaries of the sanctuary are ecologically appropriate;
(4) provide advice on whether the sanctuary addresses the issue of critical habitat and non-critical whale habitat;
(5) evaluate whether the sanctuary may contribute to or impede the conduct of scientific research useful for meeting IWC objectives and facilitate coordinated and integrated research and monitoring programmes; and
(6) provide advice on whether the sanctuary is consistent with the precautionary approach.

At the 2002 meeting of the Scientific Committee 'it was noted that a proposal for a South Atlantic Sanctuary would

be submitted to the Commission this year and that its supporting document remains the same as that presented to the Committee in 2001' (IWC, 2003a, p.81). There was therefore, no substantive discussion of this proposal during the 2002 meeting.

In 2003, the Scientific Committee discussed an evaluation of the SAWS Proposal based on the instructions from the Commission and the review criteria. As in previous years, there was no consensus regarding recommendations to the Commission (IWC, 2004b, p.50). A summary of the perspectives both for and against the proposal to establish a SAWS is reported in Appendices 2 and 3 of Annex P (IWC, 2004e, pp.372-4).

At the 2004 meeting of the Scientific Committee, no review of the SAWS was undertaken. However, the Committee endorsed the recommendations listed below that were to be implemented generically to the review of sanctuary proposals (IWC, 2005c, p.50).

(1) The purpose(s) of the SOS [Southern Ocean Sanctuary] (and other IWC Sanctuaries) should be better articulated through a set of refined overall objectives (e.g. preserving species biodiversity; promoting recovery of depleted stocks; increasing whaling yield). In particular, the relationships between the RMP and the Sanctuary programme should be articulated.
(2) Appropriate performance measures both for Sanctuaries in general, and the SOS in particular, should be developed. These performance measures should link the refined objectives of the SOS with monitoring programmes in the field.
(3) Systematic inventory and research programmes should be established or further developed so as to build the required information base for a Sanctuary management plan and subsequent monitoring programmes.
(4) A Sanctuary management plan should clearly outline the broad strategies and specific actions needed to achieve Sanctuary objectives (e.g. how to protect x% of a given feeding area for stock y).
(5) A monitoring strategy that measures progress toward achieving the Sanctuary objectives should be developed and subsequently implemented. A key component of this monitoring strategy would be the development of tangible indicators to monitor progress.
(6) Review criteria that reflect the goals and objectives of the Sanctuary (as described above) should be established.
(7) The Sanctuary management plan should be refined periodically to account for ecological, oceanographic and possible other changes in an adaptive fashion.

17.2 Instructions from the Commission to the Scientific Committee for reviews of sanctuaries

As noted above, the Scientific Committee undertook a review of the SAWS proposal at its 2003 meeting following the instructions received from the Commission at their 2001 annual meeting (IWC, 2002b, pp.18-9). After some discussion, there was general agreement that the information presented in IWC (2004e, pp.367-374) remained a reasonable summary of the two primary viewpoints of the Scientific Committee regarding this proposal relative to the most recent guidance from the Commission. However, both proponents and opponents agreed to provide additional comments to update the material provided in Borsani *et al.* (2004) and Hatanaka *et al.* (2004). Their summaries are provided below under Items 17.2.1 and 17.2.2.

17.2.1 Proponents section

Committee members supporting the SAWS proposal noted that the issues presented in Borsani *et al.* (2004) are relevant to the current review. In addition to those, it was further noted by these members that the proposal:

(a) addresses threats to cetacean populations other than whaling in the region encompassed by the SAWS, and considers ways of dealing with these in light of current international law and the sovereign rights of coastal States as expressed in The United Nations Convention on the Law of the Sea (UNCLOS) (pp. 11-15 and 23-24 of IWC/57/4);
(b) fully complies with the list of anticipated effects provided in (2) of the Commission instructions in terms of providing adequate protection of whales in breeding areas, feeding grounds and/or migratory routes, as well as the conservation of vital habitats through international coordination and cooperation, and complements effectively the Commission's current management regimes by proposing non-lethal management in the ocean basin level;
(c) is ecologically justifiable as regards the SAWS proposed boundaries (IWC/57/4, pp.6-8; 18-21);
(d) will contribute to the co-ordination and promotion of research as outlined in IWC/57/4 (pp.22-9), by providing for further involvement of the IWC in fostering cooperation; and
(e) is consistent with Principle 15 of the United Nations Conference on Environment and Development (UNCED) 1992 Declaration, the Precautionary Principle, as it strives for attaining the natural carrying capacity levels and promoting use through exclusively non-lethal means (IWC/57/4, p.30).

17.2.2 Opponents section

Committee members opposing the SAWS proposal noted that the evaluation based on the instructions provided by the Commission presented in Hatanaka *et al.* (2004) also applies to the current review. In addition to that evaluation, these members also noted the points listed below.

In the context of the conservation and management of a living resource, a sanctuary means a limited land or sea area where harvesting activities of the resource is prohibited in order to achieve sustainable utilisation of the resource outside the area. This area is expected to provide a 'refuge' for a certain part of the migration, distribution, and/or life stage of the resource so that the resource is not over-harvested. Conservation measures that are totally prohibitive over a large area when the status of stocks allows for sustainable utilisation or when a management regime in effect is sufficiently precautionary can not be scientifically justified and negate the principle of sustainable utilisation.

A whale sanctuary in the South Atlantic is unnecessary for whale conservation given the application of the moratorium on commercial whaling to that area. Further, the proposal undermines almost a decade of work by the Scientific Committee to develop the risk-averse RMP. Once the RMP is implemented, it will only provide safe quotas for abundant stocks meaning that a sanctuary would be unnecessary and contrary to the purpose of the Convention even after the moratorium is no longer in place. The proposal is also contrary to Article V (2) of the International Convention for the Regulation of Whaling (ICRW) since it ignores the fact that the stock status of some of the large whale species is well above exploitable level.

Table 2
Proposed Workshops and pre-meeting meetings for the intersessional period. Financial implications are dealt with under Item 21.

Subject	Agenda item	Venue	Dates	Steering group
Finalise Soviet catch data	3.3.2	Cambridge	Before January 2006	P1
SOWER cruise: planning meeting and future	10.5	Tokyo	Mid-September (5 days)	P12
Bryde's whale *Implementation* workshop	6.1	Tokyo	25-29 October 2005 (5 days)	P15
SH humpback whale assessment workshop	10.3.1	Hobart	Spring 2006 (5 days)	P25
Fin whale stock structure and catch history	6.2	Reykjavík	Spring 2006	n/a
POLLUTION 2000+ workshop	12.3.1	?Boston	Spring 2006	P20
Bowhead *Implementation Review* workshop	8.4	La Jolla or Seattle	March 2006	P2
TOSSM workshop	11.1	Potsdam	March 2006 (5 days)	P9
Seismic pre-meeting	12.4	St Kitts and Nevis	May 2006 (2 days)	P18
Pre-meeting AWMP (early start)	8.1	St Kitts and Nevis	2 days prior to start of meeting	P2
Pre-meeting RMP (early start)	6.3	St Kitts and Nevis	May 2006	n/a

The opponents of the SAWS proposal noted that the conclusions of the external reviewers which highlight major flaws in the IWC's approach to sanctuaries are also applicable to the proposed sanctuary for the South Atlantic. A summary of these conclusions (IWC, 2005c, pp. 49-51; IWC, 2004a; Zacharias *et al.*, 2004) follows:

(1) the SOS and IWC sanctuaries in general are not ecologically justified;
(2) the SOS is based on vague goals and objectives that are difficult to measure;
(3) the SOS lacks a rigorous approach to its design and operation and does not have an effective monitoring framework to determine whether its objectives are being met;
(4) the SOS represents a 'shotgun' approach to conservation, whereby a large area is protected with little apparent rationale for boundary selection and management prescriptions within the sanctuary; and
(5) the SOS is more prohibitive than precautionary.

17.2.3 Recommendations from the Commission for reviews of sanctuaries
In discussion, with respect to the instructions from the Commission to the Committee, there was no agreement within the Committee regarding the proposal to establish a SAWS.

17.3 Recommendations from the 2004 Scientific Committee meeting for reviews of sanctuaries
Regarding the recommended approach for reviewing sanctuary proposals, the Committee agreed to use the seven topics reported in IWC (2005c, p.50) in evaluating the SAWS proposal under this Agenda Item. Summaries of the positions against and for the proposal are provided in Annexes R1 and R2.

18. RESEARCH AND WORKSHOP PROPOSALS AND RESULTS

Table 2 lists the proposed intersessional meetings and Workshops.

18.1 Review results from previously funded research proposals
Results from IWC funded projects are dealt with under the relevant agenda items.

18.2 Review proposals for 2005/2006
No unsolicited research proposals were received.

19. COMMITTEE PRIORITIES AND INITIAL AGENDA FOR THE 2006 MEETING

19.1 Committee priorities for SC/57 (2005)
At this year's Scientific Committee meeting, 13 sub-committees (including standing Working Groups and *ad hoc* Working Groups) were established. As was the case last year, the annual meeting of the Committee was conducted over a 12-day period of which two days were allocated to Plenary. The number of sessions for sub-committee deliberations was therefore limited to 90. This is based on three concurrent sub-committee meetings for each of five work sessions per day, starting at approximately 08:30 and ending typically at 21:30, for a period of six days. At this year's meeting, because of our inability to schedule certain sub-committees opposite other sub-committees we were only able to schedule 85 meetings of sub-committees and Working Groups.

Some members were disappointed that insufficient time in sub-committee meetings was available to adequately discuss certain agenda items or issues, as reflected in some sub-committee reports. However, it was recognised by all members of the Committee that there was insufficient time to fully address all of the issues of relevance to the Commission. Therefore, difficult choices had to be made about which issues to assign priority during the 2005 meeting.

Table 3
Number of sessions by subgroups in 2005.

Sub-committee	Sessions	Sub-committee	Sessions
RMP	6	SM	8
AWMP	5*	SD	4
BRG	7**	SH	8
IA (+SOWER/NPM)	18**	Sanctuaries	2
BC	6*	Scientific Permits	5
E	10**	DNA	2
WW	4	**Total**	**85**

*Had pre-meeting; **had joint pre-meeting.

19.2 Committee priorities for SC/58 (2006)
As in recent years and with the Committee's agreement, the Convenors met after the close of the Committee meeting and drew up the following as the basis of an initial agenda for the 2006 meeting. The same criteria as previous years were taken into account (IWC, 2004b, p.51). The Committee recognises that priorities may have to be reviewed in light of decisions made by the Commission at IWC/57.

As last year, the Convenors agreed a provisional number of sessions per sub-committee. It was agreed that the

number of sessions allocated to each sub-committee will have to be strictly followed, as with only six days for sub-committee meetings there will be a maximum of 90 sessions available. The provisional number of sessions per sub-committee is indicated in Table 3. Items of lower priority on sub-committee agendas will only be discussed as time allows. The Committee **stresses** that papers considering anything other than priority topics will probably not be addressed at next year's meeting.

Based on comments received during Plenary, the Convenors agreed to form an *ad hoc* Working Group under IA to handle discussions related to North Pacific common minke whales. In addition, an *ad hoc* Working Group under Environmental concerns will be formed to handle discussions related to ecosystem modelling (e.g. interspecific competition). At this stage, the Convenors were not aware of the need to create a Working Group to evaluate the scientific merits of any sanctuary proposals at next year's meeting.

In addition, it was agreed that three pre-meeting meetings will be proposed to the Commission for:

(1) AWMP;
(2) RMP; and
(3) E (Seismic Noise Workshop).

The proposal is that AWMP and RMP will share 2 days.

Table 4
Proposed allocation of sessions for 2006.

Sub-committee	Sessions	Sub-committee	Sessions
RMP	11*	SM	9
AWMP	8*	SD	5
BRG	8	SH	7
IA	10	Scientific Permits	3
BC	7	DNA	2
E	6**	North Pacific common minke (NP)	5
WW	6	Ecosystem modeling	3
		Total	**90**

*Plus pre-meeting; **plus workshop.

Revised Management Procedure (RMP)
As last year, this Committee will concentrate on general issues as well as preparations for *Implementation*. The Committee **agrees** on the following priority items (in order).

General issues
Evaluation of the criteria developed to determine whether the conservation performance of a RMP variant is 'acceptable', 'borderline' or 'unacceptable' (Item 5.1.1).

Implementation *process*

(1) 'First Intersessional Workshop' for western North Pacific Bryde's whales; and
(2) finalise the issues related to completing the *pre-Implementation assessment* for North Atlantic fin whales.

Aboriginal Whaling Management Procedure (AWMP)
The Committee **agrees** that the items below should be given priority:

(1) review progress on the Greenlandic research programme (especially with respect to abundance, stock structure and the use of sex data in assessments) and attempt to provide management advice;
(2) review progress on and refine design of trial specifications and coding for B-C-B bowhead whales (will include joint sessions with BRG on stock structure); and
(3) review information on the St. Vincent and The Grenadines fishery and provide management advice.

Bowhead, right and gray whales (BRG)
The Committee **agrees** that the following item will be given highest priority:

(1) review of new information on the stock structure of the B-C-B Seas stock of bowhead whales and on the progress of on-going research (joint meetings with the SWG on the AWMP).

It will also:

(2) perform the annual review of catch information and new scientific information for the B-C-B Seas stock of bowhead and ENP gray whales; and
(3) review new information on the western North Pacific stock of gray whales, right whales and the small stocks of bowhead whales.

In-depth assessment (IA)
The Committee **agrees** that the following item will be given highest priority:

(1) produce agreed abundance estimates of Antarctic minke whales;

followed by (in priority order):

(2) continue development of the catch-at-age analyses of the Antarctic minke whales;
(3) develop recommendations for future SOWER cruises, both for the short- and long-term; and
(4) continue to examine and then attempt to agree on reasons for differences between Antarctic minke abundance estimates from CPII and CPIII.

A separate Working Group will continue preparation for an in-depth assessment of western North Pacific common minke whales, with a focus on J stock.

Estimation of bycatch and other human-induced mortality (BC)
The Committee **agrees** on the following priority items:

(1) further review of information and methods to estimate bycatch based on fisheries data and observer programmes:
  (a) continue collaboration with FAO on collation of relevant fisheries data;
  (b) progress on joining the FIRMS partnership;
  (c) report back on EU bycatch monitoring schemes; and
  (d) review modeling to determine observer coverage needed in a fishery to estimate bycatch; and
(2) further consideration of methods to estimate bycatch based on genetic data;
  (a) review progress on intersessional work related to market sampling; and
  (b) report from Steering Group for follow-up Workshop on the use of market sampling to estimate bycatch.

In addition, the following items may be discussed if time allows (in priority order):

(3) further review information and methods to estimate mortality from ship strikes;
   (a) review results of data collected on vessels relevant to ship strikes;
   (b) review report from planned ACCOBAMS workshop on ship strikes; and
(4) consider methods for estimating additional human induced mortalities (e.g. from acoustic sources and marine debris).

Other Southern Hemisphere whales (SH)
The Committee **agrees** that the following item will be given highest priority:

(1) completion of the Comprehensive Assessment of Southern Hemisphere humpback whales;
   (a) completion of a final catch series; and
   (b) an intersessional Workshop.

It will also:

(2) initiate the Comprehensive Assessment of blue whales to the extent that time allows.

Environmental concerns (E)
The Committee **agrees** that the following items will be given high priority:

(1) two day pre-meeting Workshop to assess the potential for seismic surveys to impact cetaceans; and
(2) Working Group on ecosystem modelling.

The SWG will also receive progress reports on:

   (a) POLLUTION 2000+ (review of final report from Phase 1);
   (b) Southern Ocean Collaboration;
   (c) SOCER: focus on the Indian Ocean;
   (d) Sea ice: Arctic and Antarctic; and
   (e) Diseases: developing plans for a future workshop.

Stock definition (SD)
The Committee **agrees** that the following items will be given priority:

(1) review statistical and genetic issues relating to stock definition; and
(2) review progress on TOSSM (including the intersessional Workshop report).

The following items will be discussed if time allows (in priority order):

(3) unit-to-conserve; and
(4) genetic quality issues and implications for population structure analyses.

Whalewatching (WW)
The Committee agrees that the two priority items will be:

(1) assessing the biological impacts of whalewatching on cetaceans; and
(2) identifying data sources from platforms of opportunity of potential value to the Scientific Committee.

In addition, the following items will be discussed if time allows:

(3) reports from Intersessional Working Groups;
(4) review of potential impacts of 'swim-with-whales' programmes on populations of cetaceans;
(5) review of whalewatching guidelines and regulations; and
(6) review of risks to cetaceans from whalewatching vessel collisions.

Small cetaceans (SM)
The Committee **agrees** that the following item will be given highest priority:

(1) review of small cetaceans of the Caribbean and western tropical Atlantic.

The following items will also be discussed:

(2) progress on previous recommendations; and
(3) takes of small cetaceans.

Scientific permits (SP)
The Committee **agrees** that the following items will be given priority:

(1) review proposals for other procedures for reviewing scientific permits;
(2) review results from existing permits (including plans for the JARPA review); and
(3) review of new or continuing proposals.

DNA
The Committee agrees that the following items (as directed by the Commission) will be given priority:

(1) review genetic methods for species, stock and individual identification;
(2) collect and archive tissue samples from catches and bycatches; and
(3) reference databases and standards for diagnostic DNA registries.

20. DATA PROCESSING AND COMPUTING NEEDS FOR 2005/2006

The Committee identified and agreed the requests for intersessional work by the Secretariat given in Table 5.

Two items (WNP Bryde's whale trials and bowhead whale trials) cannot be specified in any detail until after the two intersessional Workshops (in late October 2006 and March 2006, respectively) so the time listed for these tasks is an estimated maximum. The work in coding the final bowhead trials is not scheduled to be completed until the 2nd intersessional Workshop in October 2006, whereas work resulting from the intersessional workshop for WNP Bryde's whales is required to be completed by the 2006 annual meeting, in order to comply with the agreed timetable for an *Implementation*. It is not expected that there will be conflict, but if there is any, higher priority will be accorded to the Bryde's whale work (which is required first) and urgent consideration should be given to determining ways to ensure that both tasks are completed on time.

Progress will be reviewed by Donovan, Bannister, Punt, Bjørge and Palka.

Table 5
Computing tasks/needs for 2005/6.

Task	Est. time
RMP – General issues	
Work with Punt to evaluate the criteria developed to determine whether the conservation performance of a RMP variant is 'acceptable', 'borderline' or 'unacceptable' (see Item 5.1.1).	<1 month
RMP – Preparations for *Implementation*	
Finish preparation of catch data for western North Pacific Bryde's whales.	<1 month
Work resulting from intersessional workshop for western North Pacific Bryde's whales: write code to implement the *IST*s and do conditioning.	4-6 months[1]
Preparation of catch data for a North Atlantic fin whale *Implementation* (including collaboration with Dorete Bloch).	1 month
Encoding of Faroese data from 1902 on (as supplied by Dorete Bloch).	>6 months
AWMP	
Work resulting from intersessional workshop for the Bowhead *Implementation Review*: write code to implement the final stock structure hypotheses.	Up to 8 months[2]
In-depth assessment	
Validation of the 2004/05 SOWER cruise data and incorporation into the sightings database.	6 months
Southern Hemisphere whale stocks	
Validation of basic individual records from the revised Soviet catch data and documentation of inconsistencies in the data.	6 months
Preparation of summaries of the revised Soviet Southern Hemisphere catch data and work towards creation of an interpolated dataset of missing data (including collaboration with former Soviet scientists at a workshop in Cambridge).	1 month
Finalise the Southern Hemisphere humpback whale catch series (by January 2006).	1 month
Investigate whether the historic blue whale catch data can be amended to distinguish between blue and pygmy blue whales.	1 month
Stock definition	
Development of interface between *CLA* and TOSSM programs (with Punt).	<1 month

[1]This item will not be specified until the intersessional workshop in October 2005 and so a guessed maximum time has been entered. [2]This item will not be specified until the intersessional workshop in March 2006 and so a guessed maximum time has been entered; the work is not scheduled to be completed until the 2nd intersessional workshop scheduled for October 2006.

All other tasks required for the Scientific Committee meeting in 2006 should be completed in timely fashion.

The Scientific Committee will be notified by e-mail when the Southern Hemisphere whale catch series has been finalised.

A Russian minority statement is presented in Annex S.

21. FUNDING REQUIREMENTS FOR 2005/2006

Table 6 summarises the complete list of recommendations for funding made by the Committee. The total required to meet its preferred budget is £409,400. The Committee **recommends** all of these proposed expenditures to the Commission.

However, it understands that the projected amount available for funding is £265,000. It therefore carefully reviewed the full list, taking into account its work plan, priorities and the possibility that some of the work requiring funding could be postponed to a future year or years. Such considerations are difficult and the Committee **stresses** that projects for which it has had to suggest reduced or no funding are still considered important and valuable. Should the Commission be unable to fund the full list of items in Table 6, the Committee **agrees** that the final column given in the table represents a budget that will allow progress to be made by its sub-committees and Working Groups in its priority topics. Progress will not be possible in some important areas, as outlined below and the Committee **requests** that the Commission or individual member governments provide additional funding in these areas. The Committee **strongly recommends** that at a minimum, the Commission accepts its reduced budget of £266,000, noting that this is only £1,000 more than the projected budget.

A summary of each of the items is given below, by sub-committee or standing Working Group. Full details can be found under the relevant Agenda Items and Annexes as given in the table.

(a) Items recommended for funding under the reduced budget

Revised Management Procedure

(1) NORTH PACIFIC BRYDE'S WHALE - INTERSESSIONAL WORKSHOP

The Commission has endorsed the process recommended last year by the Committee with respect to the time schedule if an *Implementation* begins (IWC, 2005e, pp.84-92); this requires two intersessional Workshops and thus another will be required after the 2006 annual meeting. The funding is required to cover the costs of invited participants; Japan has kindly offered to host the Workshop.

(2) NORTH ATLANTIC FIN WHALES - STOCK STRUCTURE

The Committee has outlined a programme to complete the *pre-Implementation* process for fin whales. This was agreed by the Commission last year. The money is required to allow two IWC scientists to participate in a joint workshop with NAMMCO in Reykjavík. The Workshop will not deal with management issues but will focus on the scientific aspects of stock structure and the development of an agreed catch series for North Atlantic fin whales.

Aboriginal Whaling Management Procedure

(3) AWMP DEVELOPERS FUND

The developers fund has been invaluable in the work of the AWMP trials and other essential tasks of the Standing Working Group. It has been agreed as a standing fund by the Commission. The two primary developing tasks facing the SWG are the bowhead whale *Implementation Review* (a requirement of the Committee and Commission) and issues relating to the Greenlandic fisheries. The task facing the SWG with respect to the Greenlandic fisheries is a major one and of high priority to the Committee which has expressed its great concern at its inability to provide management advice on safe catch limits (see Item 8.3, 8.4 and 8.5). The fund is essential to allow progress to be made.

(4) GREENLAND COMMON MINKE WHALES – GENETIC DATA AND ABUNDANCE

The Committee is unable to provide advice on the effects of aboriginal subsistence whaling on the common minke whale stocks off West Greenland. A major problem in terms of its ability to give management advice is that the total geographical area occupied by common minke whales potentially available to be harvested off West Greenland during summer is largely unknown and thus surveys consequently cover an unknown fraction of the range of the stock. Genetic methods may be able to provide a lower bound for the size of the total stock. This study will assess the statistical power of various genetic approaches to estimate abundance. It will be conducted intersessionally and if found to be appropriate, it will develop estimates of sample size and costs for an appropriate study. This would be seen as of very high priority by both the national authorities and the Commission.

In-depth assessments

(5) SOWER CIRCUMPOLAR CRUISE

The Committee and the Commission have both given high priority to obtaining agreed abundance estimates for Antarctic minke whales and for explaining the differences between CPII and CPIII. The proposed plans for this year's survey are directed at experiments to address these problems as well as to conduct a pilot study to determine the best method to collect abundance data for fin whales (north of 60°S, acoustic survey, biopsying), and to continue research on blue whales and particularly humpback whales which are the subject of a comprehensive assessment. The funding is for equipment and participation by international scientists. The vessels are generously provided by the Government of Japan.

(6) FURTHERING ESTIMATION OF ANTARCTIC MINKE WHALE ABUNDANCE

As noted above, the Commission and the Committee have given high priority to obtaining agreed abundance estimates and trends for Antarctic minke whales and for explaining the differences between CPII and CPIII. To maintain the progress expected by the Commission requires that projects (i)-(iv) below are funded. The Committee notes that a considerable amount of in-kind support is included in these projects. Next year the Committee expects to receive abundance estimates from at least the standard method

Table 6

Summary of budget requests for the coming year. The number in parentheses after the short title refers to the number in the discussion below.

		Budget	
	Reference	Requested	Reduced
RMP (Annex D)			
North Pacific Bryde's whales *Implementation*. 1st intersessional workshop (a1).	Item 6.1.1.2	£10,500	£10,000
North Atlantic fin whales. Participate at workshop (a2).	Item 6.2.2	£2,500	£2,000
AWMP (Annex E)			
AWMP developers fund (a3).	Item 8.	£10,000	£8,500
West Greenland common minke whales. Abundance estimation from genetic data (a4).	Item 8.2	£3,500	£3,500
Bowhead whale. Intersessional workshop to prepare for *Implementation Review* (b1).	Item 8.4	£7,700	£0
IA (Annex G)			
Furthering estimation and interpretation of abundance estimates			
SOWER cruise 2005/6 (a5).	Item 10.1.5	£95,900	£80,000
DESS maintenance (a6i).	Item 10.1	£7,500	£7,500
DESS standard analysis method (a6ii).	Item 10.2.3	£6,000	£4,000
Integrated model analysis (a6iii).	Item 10.2.3	£2,000	£2,000
CPII and CPIII explanation: VPA analysis (a6iii).	Item 10.1.2	£6,000	£5,000
CPII and CPIII explanation: catch-at-age analysis (a6iv).	Item 10.1.2	£20,000	£20,000
E (Annex K) – some with IA and BRG			
ICCED science planning and analysis/SO-collaboration. Cruise coordination (a7).	Item 12.3.2	£40,000	£13,000
German SO-GLOBEC, Weddell Sea. IWC participation (a8).	Item 12.3.2	£22,000	£17,500
Deakin University SOC database completion (a9).	Item 12.3	£30,000	£10,000
Whales and shelf break krill distribution (a10).	Item 12.3.2	£2,000	£1,000
Arctic sea ice – population dynamics (a11).	Item 12.1	£30,000	£14,500
Impact on cetaceans from seismic surveys. Workshop (a12).	Item 12.3.5	£6,000	£4,000
Arctic sea ice – body condition and health (b2).	Item 12.1	£20,000	£0
SOCER. Coordination, literature search and editing (b3).	Item 12.3.3	£3,000	£0
SH (Annex H)			
Southern Hemisphere humpback whale. Workshop (a13).	Item 10.3.3	£12,000	£8,000
Southern Hemisphere humpback whale. Code and run population dynamics model (a14).	Item 10.3.1.4	£1,000	£1,000
Southern Hemisphere humpback whale. Finalise catch series (a15).	Item 10.3.1.2	£2,000	£1,000
Cataloguing of Antarctic humpback whales for online access (a16).	Item 10.3.1.5	£5,300	£5,300
Southern Hemisphere blue whales. Initiate Comprehensive Assessment (a17).	Item 10.3.2	£6,000	£3,000
SD (Annex I)			
TOSSM intersessional workshop with non-SC developer of genetic methods (a18).	Item 11.1	£9,000	£8,000
BC (Annex J)			
Co-ordination with FAO (a19).	Item 7.1.1	£2,500	£1,200
Estimation of bycatch. Simulation modelling (a20).	Item 7.2.1	£7,000	£1,000
Estimation of bycatch. Data collection and market pathways (a20).	Item 7.2.1	£5,000	£5,000
Scientific Committee			
Invited participants (a21).		£35,000	£30,000
Total		**£409,400**	**£266,000**

(Branch), the integrated model (Cooke) and the hazard probability method (Okamura). The IWC's DESS is vital to the Committee's work on abundance estimation, both with respect to providing estimates of abundance for past cruises and for future work on the abundance of Antarctic minke whales.

(i) DESS maintenance
(ii) DESS-standard analysis and integrated methods
(iii) and (iv)VPA analysis and catch-at-age analysis
This work has been recommended by the Committee and is essential in furthering the work on exploring the reasons for differences in Antarctic minke whale abundance from CPII and CPIII and working towards an in-depth assessment. The data have been generously been made available by the Institute of Cetacean Research (Tokyo) under the Data Availability Agreement.

Environment (some with IA and BRG)

(7) ICCED SCIENCE PLANNING AND ANALYSIS/SO-GLOBEC COLLABORATION

This work will contribute to high priority analysis outlined in the sea ice Symposium (and see Annex K) and to ongoing collaboration with SO-GLOBEC. Research on Southern Ocean whales and their ecosystem is recommended by IWC Resolutions 1998-3 and 1998-6. Support for this activity complements the considerable in-kind support the IWC receives for the SO collaborative cruises. The Committee recognises that the funds available are less than those requested and **agrees** that allocation of the available funds should be the responsibility of the SOC Steering Group who must inform the Secretariat of their final decision on a spending plan.

(8) ANTARCTIC: GERMAN SO-GLOBEC. IWC PARTICIPATION

This is part of the field work programme previously funded in collaboration with SO-GLOBEC. The money is to fund a team of two observers on two cruises. The work will provide data to further elaborate the relationship between ice and cetaceans. It is the final year of a German Weddell Sea research programme. This work was given high priority at the Committee's recent sea-ice Workshop (SC/57/Rep5).

(9) DEAKIN UNIVERSITY – SOC DATABASE COMPLETION

The SOC database comprises data for all IWC/SO-GLOBEC/CCAMLR and other multidisciplinary survey data and sea-ice data under international collaborative programmes. This work will contribute to high priority analyses, outlined in SC/57/Rep5. The Committee has reluctantly recommended, as necessary, to reduce the funding for this proposal and thus priority should be given to coding data directly relevant to examining the questions related to the proportion of Antarctic minke whales in the pack ice. It is hoped that if external funding cannot be found this year, the remainder of the work can be completed next year.

(10) WHALES AND SHELF BREAK KRILL DISTRIBUTION

This work relates to possible differences between CPII and CPIII of the SOWER cruises. The funds will be used to pay for the travel and subsistence costs of Ensor (SOWER cruise leader) to attend a collaborative meeting to discuss spatial analysis and sea ice conditions on surveys.

(11) SEA ICE – POPULATION DYNAMICS

This work represents partial funding for one of the high priority Arctic projects identified in the sea ice Workshop. (SC/57/Rep5 and Annex K). It relates to a number of issues potentially affecting the management and conservation of B-C-B Seas bowhead whales and eastern gray whales. The funds are for a student to work with a sea ice specialist to derive regional (meso-scale) analysis of changes in sea ice since 1979 and undertake projections into the future. This will feed into the project to be undertaken *gratis* by Wade, Punt, Breiwick and Brandon, to incorporate sea ice analyses into the population dynamics record of those two whale populations.

(12) IMPACT ON CETACEANS FROM SEISMIC SURVEYS WORKSHOP

Last year, the SWG on environmental concerns had recommended the holding of a Workshop on seismic exploration (including both industrial and academic activities) at the 2006 meeting. This proposal was developed further this year (Annex K, Appendix 3). It is timely as the hydrocarbon industry is expanding. Accelerating studies to assess potential impacts on cetaceans and examine ways to mitigate known and potential effects is thus particularly important. The funds are required to pay for IPs.

Southern Hemisphere whales (other than Antarctic minke whales)

(13) SH HUMPBACK COMPREHENSIVE ASSESSMENT - WORKSHOP

The Committee has been undertaking a comprehensive assessment of Southern Hemisphere humpback whales for several years and has given priority to its completion. The best way to finalise this work is to hold an intersessional Workshop. The Government of Australia have kindly offered to host this Workshop in Hobart, Australia. The funds are required for IPs (see Annex H, Appendix 7).

(14) SH HUMPBACK WHALE – POPULATION DYNAMICS MODEL

This project involves the coding and use of population dynamics models needed to finalise the Comprehensive Assessment referred to above. This work is essential for the success of the Workshop. The funds are to enable Johnston to complete this work.

(15) SH HUMPBACK WHALE - FINALISE CATCH SERIES

Similarly, the success of the Workshop referred to in (13) above depends on having a final catch series available. The funds will allow a scientist to travel to Cambridge to work with Allison, former Soviet scientists and others, to complete the historical catch data series and extract catches of humpback whales for the Comprehensive Assessment.

(16) ANTARCTIC HUMPBACK WHALE CATALOGUE

The Committee is already committed to funding this project, which represents only a partial cost of running the catalogue and is of great benefit to its in-depth assessment of Southern Hemisphere humpback whales. The work required to *inter alia* make the IWC/SOWER photographs more accessible is being carried out. The funds are mainly required for database management.

Stock definition

(18) TOSSM WORKSHOP

The Committee has noted the importance of stock structure issues to most of its Working Groups and sub-committees. For that reason it funded the first TOSSM workshop. Progress on the first stage of the process, developing simulated populations, has been excellent but for this to be of maximum value to the IWC, the next stage, i.e. the

incorporation of management related issues and the testing of methods to determine boundaries, must be undertaken. It was agreed that the only way to achieve this efficiently and appropriately is to hold another workshop. This will enable progress to be made at the 2006 Annual Meeting. The University of Potsdam has kindly agreed to host the Workshop. The funds are required for Invited Participants (IPs).

Bycatch

(19) CO-ORDINATION WITH FAO

The Committee has recommended that co-operation with FAO be continued with respect to information on fisheries, fishing gear and effort, as part of its work to try and estimate bycatch levels in terms of assessment and RMP related work to determine total removals. As a result of contacts made last year it is clear that increased cooperation can be of great mutual benefit. The collaboration will allow the IWC to become a partner agency in to FIRMS.

(20) ESTIMATION OF BYCATCH

In 2004, the Committee agreed to hold a Workshop to determine whether market sampling based methods can be used to provide adequate estimates of the number of bycaught animals. The initial Workshop was held this year and before deciding when the final Workshop should be held, the Committee identified work that needed to be completed. It was agreed that this year the following should be undertaken: (i) initial work to develop a modelling framework for sensitivity analysis and for testing market sampling design; and (ii) the collection of additional data on markets and market pathways. The initial modelling work will cost £1,000 and the data collection £5,000. After discussion of the results at the next Annual Meeting (2006), guidance on completing the development of a full simulation modelling framework can be given (the costs of completing this development is provisionally estimated at about £6,000 but this will be discussed next year).

Scientific Committee

(21) INVITED PARTICIPANTS FUND

The Committee **draws attention** to the essential contribution made to its work by the funded IPs. The IWC-funded IPs play an essential role in the Committee's work. They represent excellent value as they receive only travel and subsistence costs and thus donate their time, which is considerable. As was the case for previous meetings, where possible effort will be made to accommodate scientists from developing countries.

(b) Recommended items not included under the reduced budget (but still supported by the Scientific Committee)

(1) BOWHEAD *IMPLEMENTATION REVIEW* - INTERSESSIONAL WORKSHOP

This is a high priority item. The Commission has noted that we will have a bowhead *Implementation Review* in 2007. Due to the oddly named if not oddly derived 'Oslo bump', a major research programme has been initiated on bowhead whale stock identity. This has the potential to initiate a complex modelling exercise to test the performance of the *Bowhead SLA* with alternative stock hypotheses. The purpose of this Workshop is to specify the basic structure and types of simulation trials required. It is integral to the SWG workplan on this agenda item and will form an important contribution to its work at the next annual meeting and beyond. The USA has kindly agreed to host this meeting and it has been allocated no funding because the USA has also indicated that it will make a donation to the research fund to cover the costs of the necessary IPs. Venue and dates will be determined when more information on progress becomes available but it will probably be in March 2006.

(2) SEA ICE – BOWHEAD WHALE BODY CONDITION AND HEALTH

This was identified as one of the priority items from the Sea Ice Workshop and was endorsed in Annex K. The Committee recognise the value of the work outlined in SC/57/Rep5 and hopes that this project will obtain outside funding.

(3) PREPARATION OF SOCER

The Commission (IWC, 2001a) has encouraged work in this area. A Working Group within the SWG again produced a SOCER this year that forms Appendix 2 of Annex K of the Committee's report. It is aimed at providing a non-technical report of some events and developments in the marine environment relevant to cetaceans to the Commission. The Committee hopes that this work will receive outside funding.

22. WORKING METHODS OF THE COMMITTEE

There was no substantive discussion under this Agenda Item. It was agreed to keep it on the agenda for next year.

23. ELECTION OF OFFICERS

The three-year terms of DeMaster as Chair and Bjørge as Vice-Chair end at the completion of IWC/57. The heads of delegations therefore met according to the new Rules agreed last year (IWC, 2005c, p.59). The Committee was delighted to welcome Bjørge as Chair and Palka as Vice-Chair by consensus.

24. PUBLICATIONS

2004 was another productive year with respect to the IWC's scientific publications and the Journal continues to attract increasing numbers of submissions. This year, in addition to the 500 page supplement, Volume 6 was completed. Volume 6 contained a total of 34 papers involving some 120 authors from 24 countries. Papers have been published on the full variety of subjects considered by the Committee. Donovan thanked the Publications staff for their hard work. In particular, he thanked Clare Last, who was Assistant Editor from the first issue, for her great contribution both to the Journal and to the work of the Scientific Committee. She left the IWC for pastures new in September 2004. The Committee members send her their best wishes for the future. He also welcomed the new Assistant Editor, Jemma Miller, who replaced Clare in January 2005.

Donovan reported that he and Hammond will finalise the third special issue (on development of the Revised Management Procedure) this autumn. With respect to ISI listing, he has been informed that the ISI listing is now complete.

Following discussions last year, the Guide for Authors has been modified as follows:

> **Welfare and legal policy**
> When submitting a manuscript for publication, the author(s) must state that all work conforms to the legal requirements of the country in which it was carried out, including those relating to conservation and animal welfare.

Sequence data
Authors submitting papers containing nucleic acid data must provide full primary sequences as Appendices for reviewing purposes. In addition it is expected that new DNA sequences are submitted to GenBank, and accession numbers cross-referenced throughout the text.

Finally, Donovan reiterated the importance of Committee members urging their respective institutes and colleagues to subscribe to the Journal and to submit high quality papers to it. The success of the Journal will be greatly increased as it becomes established in more institutional libraries.

The Committee welcomes this report and **stresses** the vital contribution the Journal makes to the work of the Committee and to the wider issues of the management and conservation of whales.

25. OTHER BUSINESS

On behalf of the Committee, the outgoing Chair expressed deep appreciation to the Government of Korea and the Mayor and people of Ulsan for the exceptional level of support and hospitality extended to the Committee during the meeting. The Committee also thanked the Secretariat for its major contribution to the smooth running of the meeting, as always carried out with great diligence and cheerfulness. The Committee gave DeMaster a standing ovation for his outstanding work as Chair of the Committee. In particular, he was praised for his unflinching efforts to reach consensus on as many issues as possible, his fairness and his great good humour. In reply he noted that he was handing over to an outstanding team in Bjørge and Palka. He also wryly noted that he was the only person to have faced competition in elections for both Chair and Vice-Chair – he hoped this was an 'honour' he alone would always retain!

26. ADOPTION OF REPORT

The report was adopted at 16:47hrs on 10 June 2005. As usual, final editing was carried out by the Convenors after the meeting.

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Report of the Scientific Committee

Panama City, Panama, 11-23 June 2012

International Whaling Commission, Panama City, 2012

Scientific Committee Report

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The meeting was held at El Panama Hotel and Conference Centre, Panama from 11 June to 23June 2012 and was chaired by Debra Palka. A list of participants is given as Annex A

1. INTRODUCTORY ITEMS

1.1 Chair's welcome and opening remarks

The Chair welcomed the participants to the 2012 IWC Scientific Committee meeting noting that the Committee faced a long and complex Agenda this year. In particular, she thanked the Government of Panama for providing the facilities for this year's meeting and the IWC Commissioner for Panama, Tomas Guardia for his assistance. The Committee paused in silence for Alexandre de Lichtervelde, the previous Commissioner from Belgium who had been deeply involved in the issue of ship strikes, and Frank Hester, a long time Committee member, who had both sadly passed away since the last meeting. They both will be greatly missed.

Simon Brockington, the Secretary to the IWC, addressed the meeting on behalf of the Commission to convey a message of gratitude. He noted that the Scientific Committee is rightly regarded as one of the foremost international fora dedicated to cetaceans, and that this reputation stemmed from the quality of research conducted by the participants. He hoped that the meeting would be productive both in terms of providing advice to the Commission, but also in allowing knowledge to be gained and shared between participants so as to allow improved research in the future. He wished all participants a successful meeting.

On behalf of the Government of Panama Giovanni Lauri, the Administrator General of the Aquatic Resources Authority of Panama (ARAP) addressed the Committee and welcomed the participants to Panama. He hoped that everyone would enjoy their time in Panama City and wished the meeting every success.

1.2 Appointment of rapporteurs

Donovan was appointed rapporteur with assistance from various members of the Committee as appropriate. Chairs of sub-committees and Working Groups appointed rapporteurs for their individual meetings.

1.3 Meeting procedures and time schedule

Brockington summarised the meeting arrangements and information for participants. The Committee agreed to follow the work schedule prepared by the Chair.

1.4 Establishment of sub-committees and working groups

As intimated last year, (IWC, 2012f, p.59) and included in the draft agenda, a pre-meeting of the Standing Working Group on Environmental Concerns met from 9-10 June 2012 in Panama City to consider interactions between marine renewable energy developments and cetaceans. Its report is given as SC/64/Rep6.

A number of sub-committees and working groups were established. Their reports were either made annexes (see below) or subsumed into this report (see items 17 and 19).

Annex D – Sub-Committee on the Revised Management Procedure (RMP);
Annex D1 – Working Group on the *Implementation Review* of Western North Pacific common minke whales (NPM);
Annex E – Standing Working Group on an Aboriginal Whaling Management Procedure (AWMP);
Annex F – Sub-Committee on Bowhead, Right and Gray Whales (BRG);
Annex G – Sub-Committee on In-Depth Assessments (IA);
Annex H – Sub-Committee on Other Southern Hemisphere Whale Stocks (SH);
Annex I – Working Group on Stock Definition (SD);
Annex J – Working Group on Estimation of Bycatch and other Human-Induced Mortality (BC);
Annex K – Standing Working Group on Environmental Concerns (E);
Annex K1– Working Group to Address Multi-species and Ecosystem Modelling Approaches (EM);
Annex L – Standing Sub-Committee on Small Cetaceans (SC);
Annex M – Sub-Committee on Whalewatching (WW);
Annex N – Working Group on DNA (DNA).

1.5 Computing arrangements

Allison outlined the computing and printing facilities available for delegate use**.**

2. ADOPTION OF AGENDA

The Adopted Agenda is given as Annex B1. Statements on the Agenda are given as Annex R. The Agenda took into account the priority items agreed last year and approved by the Commission (IWC, 2012a, pp.27-29). Annex B2 links the Committee's Agenda with that of the Commission.

3. REVIEW DATA, DOCUMENTS AND REPORTS

3.1 Documents submitted

Donovan noted that the pre-registration procedure, coupled with the availability of electronic papers, had again been successful. With such a large number of documents, pre-specifying papers had reduced the amount of photocopying and unnecessary paper dramatically. He was pleased to note that this year the percentage of people opting to receive their papers entirely electronically had continued to grow. As last year, the Secretariat provided participants with a memory stick with all of the papers

that had been received by the official deadline. Revised or new papers and reports were uploaded onto the IWC website. The list of documents is given as Annex C. The issue of electronic papers is discussed further under item 24.

3.2 National Progress Reports on research

The Committee is in the transition phase from receiving paper progress reports to online submission into a database (Skaug, 2012, pp.2). A working group was established to facilitate this process and its report is given as Annex O. The Committee **reaffirms** its view of the importance of national Progress Reports and **recommends** that the Commission continues to urge member nations to submit them following the new online system. It thanks the Secretariat and especially Tandy and Miller for their development work on the portal.

3.3 Data collection, storage and manipulation

3.1.1 Catch data and other statistical material

Table 1 lists data received by the Secretariat since the 2011 meeting. As requested last year, the Secretariat had contacted both Canada and Indonesia to request information on recent catches. The information received from Canada is included in Table 1, but no response has been received to date from Indonesia. The Committee requests that the Secretariat try again to obtain data on catches off Indonesia.

3.1.2 Progress of data coding projects and computing tasks

Allison reported that Version 5.2 of the catch databases was released in November 2011 and a new release was due shortly. Work has continued on the entry of catch data into both the IWC individual and summary catch databases, including data received from the 2010 season. Sightings data from the 2010 POWER cruise (see item 10.8) has been validated.

Programming work during the past year has focussed on amending the control program and datasets for use in the North Pacific common minke whale *Implementation* trials and is discussed further under Item 6.3.

4. COOPERATION WITH OTHER ORGANISATIONS

The Committee noted the value of co-operation with other international organisations to its work. The observers' reports below briefly summarise relevant meetings of other organisations but the contributions of several collaborative efforts are dealt with in the relevant sub-committees.

4.1 Convention on the Conservation of Migratory Species (CMS)

4.1.1 Scientific Council

The report of the IWC observer at the CMS Scientific Council meeting held in Bergen, Norway from 17-18 September 2011 is given as IWC/62/4E. With relation to cetaceans, their agenda included items on critical sites and ecological networks for migratory species, impacts of marine debris on migratory species and presentation of the report of the Working Group on Aquatic Mammals. It was agreed that the narwhal and the North Pacific killer whale populations be considered for cooperative action. A draft resolution on a programme of work for cetaceans (to implement the previous CoP resolution 'Adverse human-induced impacts on cetaceans') was endorsed. Note was taken of the recent split of the finless porpoise into two species, *Neophocaena brevirostris* and *N. asiaeorietalis* and both were recommended for inclusion in Appendix II of the Convention.

The Committee thanked Perrin for his report and **agrees** that he should represent the Committee as an observer at the next CMS Scientific Council meeting. Further information can be found at *http://www.cms.int*.

4.1.2 Conference of Parties

The report of the IWC observer at the 10th Conference of Parties for CMS held in Bergen 20-25 September 2011 is given as IWC/62/4E. The Convention now has 117 Parties. Three Resolutions related primarily to cetaceans:

Resolution 10.14 *Bycatch of CMS-listed species in gillnet fisheries* called on Parties to *inter alia* assess the risk of bycatch arising from their gillnet fisheries and conduct research to identify and improve mitigation measures (including use of alternative fishing gear and methods) and instructed the Scientific Council to develop terms of reference for studies identifying the degree of interaction between gillnet fisheries and CMS-listed species;

(1) Resolution 10.15 *Global programme of work for cetaceans* laid out tasks for the Scientific Council, Secretariat and Parties to advance the conservation of CMS-listed cetaceans, organised primarily on a regional basis; and

Resolution 10.24 *Further steps to abate underwater noise pollution for the protection of cetaceans and other migratory species* among other recommendations strongly urged the Parties to prevent adverse effects on cetaceans and other marine species by restricting the emission of underwater noise, understood as keeping it to the lowest necessary level with particular priority given to situations where the impacts on cetaceans are known to be heavy.

Table 1

List of data and programs received by the IWC Secretariat since the 2011 meeting.

Date	From	IWC ref.	Details
Catch data from the previous season:			
08-07-11	St Vincent: R. Ryan	E103 Cat2011	Information on the St Vincent and the Grenadines humpback harvest 2011 season
01-03-12	Canada: A. McMaster	E103 Cat2011	Information on the Canadian bowhead harvest 2011 season
30-03-12	Iceland: E. Thordarson	E103 Cat2011	Individual catch records from the Icelandic commercial catch 2011
22-05-12	Russia: R.G. Borodin	E103 Cat2011	Individual catch records from the aboriginal harvest in the Russian Federation in 2011
24-05-12	Norway: N. Øien	E103 Cat2011	Individual minke records from the Norwegian 2011 commercial catch. Access restricted (specified 14-11-00).
11-06-12	Japan: S. Hiruma	E103 Cat2011	Individual data for Japan special permit catch 2011 N.Pacific (JARPN II) & 2011/12 Antarctic (JARPA II).
Other catch data:			
10-4-12	Canada: J. Ford	E105	Comparison of N. Pacific catch data held by Canada with the IWC database, including 1,471 new individual records.
Sightings data:			
01-12-11	K. Matsuoka	E102	2011 POWER cruise sightings data
22-12-11	K. Matsuoka	E102	Data from the JARPN II sighting survey in the North Pacific 2011 (SC/63/RMP12); inc. sightings, weather, effort and distance and angle experiment data.
Other:			
30-11-11	USA: D. Palka	E101	List of data for the NP gray Implementation Review in June 2012
23-03-12	A. Punt	E104	Programs and data used in AWMP gray whale trials up to March 2012 workshop
23-06-12	A. Punt	E104	Programs and data used in AWMP gray whale trials at SC 2012

The resolutions can be seen in full on the CMS website (*www.cms.int.)*.

The Committee thanked Perrin for his report and **agrees** that he should represent the Committee as an observer at the next CMS Scientific Council meeting.

4.1.3 Agreement on Small Cetaceans of the Baltic and North Seas (ASCOBANS)

There was not a meeting of parties in the intersessional period. The next meeting of parties will take place 22-24th October 2012, Brighton, UK. The report of the observer at the 19th meeting of the Advisory Committee to ASCOBANS held in Galway, Ireland 20-22 March 2012 is given as IWC/64/4F. Topics covered included:

(1) *Baltic Sea harbour porpoises*. Those in the Western Baltic, Belt Seas and the Kategat form a different population to those of the Baltic proper and North Sea and since 2005 there has been a 60% decline in the population size of the former. A separate conservation plan for this area should be established.
(2) *Working Group on a Conservation Plan for Harbour Porpoises in the North Sea*. A follow-up SCANS II survey was recommended, as was bringing smaller and recreational fisheries under the reformed Common Fisheries Policy.
(3) *Working Group on Bycatch*. A review of the 1.7% removal rate was recommended.
(4) *Dogger Bank surveys*. Independent surveys, both aerial and vessel-based, indicate that the harbour porpoise is the most common cetacean in the area, with most records on the slopes of the bank.
(5) *Small cetacean hunt outside agreement area*. Tagging data indicates the pilot whale population subject to the Faroese hunt also occurs in the ACOBANS agreement area. Because of considerable uncertainties regarding the population ASCOBANS welcomes future studies (e.g. SCANS, CODA, T-NASS).

A working group on marine debris was established and in collaboration with ACCOBAMS, the ASCOBANS Secretariat is working to acquire satellite based data on shipping density to identify high risk areas and trends. A joint ECS/ASCOBANS/ACCOBAMS workshop on management of Marine Protected Areas for cetaceans will be held at the 2013 ECS conference.

The Committee thanked Scheidat for her report and **agrees** that she should represent the Committee as an observer at the next ASCOBANS Advisory Committee meeting and Meeting of Parties. Further information can be found at *http://www.ascobans.org*.

4.1.4 Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS)

No meetings of ACCOBAMS occurred intersessionally, but a Scientific Committee meeting is scheduled for November 2012. The Committee **agrees** that Donovan should represent the IWC at this meeting.

4.1.5 Memorandum of Understanding (MoU) on the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia

There was no report related to the MoU on the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia. Perrin will represent the Committee at future activities.

4.1.6 Memorandum of Understanding (MoU) for the Conservation of Cetaceans and Their Habitats in the

Pacific Islands Region (MoU for Pacific Islands Cetaceans)

There was no report related to the *MoU for Pacific Islands Cetaceans*. Donohue will represent the Committee at future activities. Further information can be found at http://www.pacificcetaceans.org.

4.2 International Council for the Exploration of the Sea (ICES)

The report of the IWC observer documenting the 2012 activities of ICES is given as IWC/64/4A. The ICES Working Group on Marine Mammal Ecology (WGMME) met in February 2011. It conducted a review of the effects of tidal turbines on marine mammals and provided recommendations on research, monitoring and mitigation schemes. The working group recommended identification of sites of low risk for turbine deployments before consenting to further devices or upscaling in more sensitive sites. It also recommended extreme care when extrapolating environmental impacts between species and device types and caution when scaling up environmental lessons learned from studies of single turbines.

Marine spatial planning practices were considered by the working group. It recommended that data on cetacean presence and occurrence be incorporated at a very early stage of planning and it emphasised the importance of including information on seasonal changes in distribution. Due to the wide-ranging nature of cetaceans the relevance of 'important areas' outside MPAs should be assessed within marine spatial plans.

The working group discussed designation of MPAs. It recommended that the boundaries should be decided based on long-term data series (of at least five years). Creation of MPAs in response to public opinion without scientific evidence to support their selection risks providing false assurances and could reduce the pressure for targeted action on the most significant threats.

The Working Group on Bycatch of protected species (WGBYC) met in February 2011. It reviewed the status of information on recent bycatch estimates and assessed the extent of the implementation of bycatch mitigation measures. Reports from 15 member states indicated extrapolated estimates of bycatch for 2009 of 879 striped dolphins, 1,500 common dolphins, 11,000 harbour porpoises and at least 10 bottlenose dolphins in a variety of fisheries. Estimates are patchy and monitoring obligations not being met by several member states. Implementation of bycatch mitigation measures was also found to be poor, with few countries able to confirm that obligations for pinger deployment were being met.

The 2011 ICES Annual Science Conference (ASC) was held in Gdansk, Poland, 19-23 September 2011. Some sessions were designed with marine mammals included as an integral part. A number of sessions were of relevance to the Committee, including those describing:

(1) integration of top predators into ecosystem management;
(2) integration of multi-disciplinary knowledge in the Baltic Sea to support science-based management; and
(3) Extraction of energy from waves and tides – consequences for ecosystems.

Butterworth advised that a World Conference on Stock Assessment Methods for sustainable fisheries will be held from 16-18 July 2013, in Boston, USA with Steve Cadrin, Mark Dickey-Collas and Rick Methot as Conveners, as part of the ICES SISAM initiative. A Scientific Steering Group (including Butterworth of the Scientific Committee), linked to SISAM, has been set up to assist the Conveners in planning the Symposium.

The symposium will be structured with presentation sessions, participatory workshops and open floor discussion groups. Further information can be found at *http://ices.dk/iceswork/symposia/wcsam.asp.*

The Committee thanked Haug for the report and **agrees** that he should represent the Committee as an observer at the next ICES meeting.

4.3 Inter-American Tropical Tuna Commission (IATTC)

The report of the observer at the 82nd meeting of the IATTC held La Jolla, USA 4-8 July 2011 is given as IWC/64/4C. The Antigua Convention came into force on 27 August 2010 and under this the IATTC is expected to give greater consideration to non-target and associated species, including cetaceans, in taking management decisions. A summary of ongoing work describing what is known about the direct impact of the fisheries on other species in the ecosystem and the environment. This ongoing work will shape future directions of AIDCP (see 4.4) and IATTC measures aimed at managing fisheries and conserving dolphins.

The Committee thanked Rusin for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next AIDCP meeting.

4.4 Agreement on the International Dolphin Conservation Program (AIDCP)

The report of the observer at the 24th Meeting of Parties to the AIDCP held in La Jolla, USA on 21 October 2011 is given as IWC/64/4C. The AIDCP mandates 100% coverage by observers of fishing trips by purse seiners of carrying capacity greater than 363t in the agreement area and in 2011 all trips by such vessels were sampled by independent observers.

The overall dolphin mortality limit (DML) for the international fleet in 2011 was 5,000 animals and the

unreserved portion of 4,900 was allocated to 86 qualified vessels that requested DMLs. In 2010 no vessel exceeded its DML. The number of sets on dolphin associated schools of tuna made by vessels over 363t has been increasing in recent years, from 9,246 in 2008 to 10,910 in 2009 to 11,645 in 2010, however fewer were made in 2011 – 9,604. This type of set accounted for 44% of the total number of purse-seine sets made in the ETP in 2011. While fewer dolphin sets were made in 2011, this remains a frequent practice and the predominant method for catching yellowfin tuna by purse-seine in the ETP. Assessment surveys scheduled for 2009 and 2010 have been delayed so it is unclear when abundance estimates for cetaceans in the ETP will be available to update the 2006 survey data.

The Committee thanked Rusin for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next AIDCP meeting.

4.5 International Commission for the Conservation of Atlantic Tunas (ICCAT)

No observer for the IWC attended the 2011 meeting of ICCAT.

4.6 Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)

The report of the IWC observer at the 30th Meeting of the CCAMLR Scientific Committee (CCAMLR-SC), held in Hobart, Australia from 23-27 October 2011 is given as IWC/64/4J. The main items considered at the CCAMLR meeting of relevance to the IWC included: (1) fishery status and trends of Antarctic fish stocks, krill, squid and stone crabs; (2) incidental mortality of seabirds and marine mammals in fisheries in the CCAMLR Convention Area; (3) harvested species; (4) ecosystem monitoring and management; (5) management under conditions of uncertainty about stock size and sustainable yield; (6) scientific research exemption; (7) CCAMLR Scheme of International Scientific Observation; (8) new and exploratory fisheries; (9) joint CCAMLR-IWC workshop with respect to ecosystem modelling in the Southern Ocean; and (10) the CCAMLR performance review.

The publication status of documents from the 2008 joint CCAMLR-IWC workshop on ecosystem modelling was discussed. Almost all expert groups have completed their review papers. The review process for the papers, which will be published in either *CCAMLR Science* or the *Journal of Cetacean Research and Management*, will begin soon.

Marine Protected Areas were discussed in detail. The area of the southern South Orkney shelf and the Seasonal Pack-ice Zone and part of the Fast Ice Zone south of the Shelf was the first MPA designated by CCAMLR. The following milestones were previously agreed: (1) by 2010, collate relevant data for as many of the 11 priority regions as possible;

(2) by early 2011, convene a workshop to review progress, share experience and determine a work programme for the identification of MPAs; (3) by 2011 identify candidate areas for protection in as many priority regions as possible;

(4) by 2011, submit proposals for areas for protection to the CCAMLR-SC; and (5) by 2012 submit proposals on a representative system of MPAs to the CCAMLR Commission.

The Committee thanked Kock for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next CCAMLR-SC meeting. In addition, Butterworth will act as an observer at meetings of the WG-EMM.

4.7 Southern Ocean GLOBEC (SO-GLOBEC)

The synthesis and analysis process under SO-GLOBEC has continued and has produced a number of papers relating cetacean distribution to prey and other environmental variables. There is no active work with respect to SO-GLOBEC at this time.

4.8 North Atlantic Marine Mammal Commission (NAMMCO)

4.8.1 Scientific Committee

The report of the IWC observer at the 18th meeting of the NAMMCO Scientific Committee (NAMMCO SC) held in Gjógv, Faroe Islands from 2-5 May 2011 is given as IWC/64/4I. The ICES-NAMMCO workshop on bycatch monitoring reviewed indirect and direct bycatch monitoring, data collection and fleet data needed for raising estimates to fleet level. It was noted that bycatch numbers could be high both in Norway and Iceland. The NAMMCO SC strongly encouraged Norway, Iceland and the Faroes to proceed with the implementation of their bycatch monitoring systems. The NAMMCO SC reiterated its recommendation to Greenland to investigate the degree to which bycatch is reported as catch.

Extensive biological sampling was conducted by Iceland from all fin whales landed in 2010. Analysis of all samples is complete and a DNA registry has been initiated.

The 2007 abundance estimates for humpback whales for all areas have now been provided to, reviewed and endorsed by the NAMMCO SC. For the first time since 1986 there was a quota for humpback whales in West Greenland and all nine whales were caught. The NAMMCO SC recommended eye sampling of the whales for age determinations, as well as tail photographs.

Corrected estimates for minke whales for the 2007 and 2009 Icelandic aerial surveys were endorsed. The best available estimate of abundance for 2007 was 48% of that

for 2001. Abundance in 2009 remains the lowest yet seen in all areas. The NAMMCO SC agreed that the new evidence presented strengthened the conclusion that the observed decline in abundance was not a result of error in measuring or analyses.

A conventional distance sampling abundance estimate of pilot whales for the Iceland-Faroes shipboard area was endorsed by the NAMMCO SC. They noted the difficulties in providing abundance estimates appropriate for management of this species given the absence of adequate data.

Observations of bowhead whales around Svalbard, Norway from 1940-2009 show an increase in abundance in the last decade. This could be due to an increase in the numbers of whales or increased tourism and a dedicated reporting system. An acoustic study that will continue through 2012 has shown that bowhead whales are present in the Fram Strait throughout the winter and generally during most of the year. A satellite tracked whale from the Spitsbergen stock moved from the so-called northern whaling ground to the southern whaling ground during summer and then back north again during winter. This is opposite of the general seasonal movement patterns for other bowhead whale stocks, but in accordance with reports from whalers in previous centuries.

An aerial survey in West Greenland was scheduled for spring 2012. The primary targets were planned to be narwhals and white whales, with bowhead whales and walruses secondary targets.

The Committee thanked Walløe for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next NAMMCO SC meeting.

4.8.2 Council

The report of the IWC observer at the 20th annual meeting of NAMMCO held in Oslo, Norway in September 2011 is given as IWC/64/4B. All requested stock assessments for large whale species in the North Atlantic have now been finalised based on sightings data from the Trans North Atlantic Cetacean Sightings Surveys (T-NASS) in 2007 and additionally in 2009. Management procedures applied have been derived from those already developed by the Scientific Committee of the IWC using the Revised Management Procedure (RMP) approach. An RMP-like approach has been recommended by the Scientific Committee of NAMMCO for some large whale stocks in their discussions on general models to be adopted by NAMMCO. These stock assessments by the constitute the main basis for catch limits set for some baleen whale stocks (fin and minke whales) in the North Atlantic.

Based on T-NASS data, an updated abundance estimate for pilot whales has been made in the areas surveyed in 2007. Although the combined area represented is small and not directly comparable with previous surveys, the available information gives no reason to amend previous conclusions on the sustainability of the Faroese catch. The next regular NASS is scheduled to take place between 2013 and 2015 and planning is already under way.

The working group on marine mammal-fisheries interactions continued its work on development of a large international ecosystem modelling project. A network has been established between several leading scientists in this field aimed at securing funding for the project which includes applying four different modelling approaches to two data rich areas, the Barents Sea and Icelandic coastal waters.

A training course for observers appointed under the NAMMCO joint control scheme for the hunting of marine mammals is to be organised this year.

The Committee thanked Katsuyama for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next NAMMCO Council meeting. Further information on NAMMCO can be found on their website.[1]

4.9 International Union for the Conservation of Nature (IUCN)

Cooke and Reeves, the IWC observers, reported on the considerable cooperation with IUCN that had occurred during the past year and this is given as IWC/64/4K.

Western gray whales

The mandate of the IUCN Western Gray Whale Advisory Panel (WGWAP) has been renewed for a further five years, under the aegis of the IUCN Global Marine and Polar Programme. The Panel has expressed concerns about plans to install a third offshore platform for oil and gas extraction just offshore of the gray whale feeding ground, but this project has now been postponed. Analyses of the data collected during a 2010 seismic survey with respect of the effects on gray whales and the effectiveness of mitigation measures are still in progress. Similar mitigation and data collection arrangements are in place for a smaller seismic survey that is currently underway and further information is given in Annex F Appendix 9. The work of WGWAP is discussed further underwritten 10.4.2.

Red List updates

A current list of all cetacean species and populations that have been assessed for the Red List, and their current Red List classification, is maintained on the Cetacean Specialist Group site[2] with links to the assessments which are held on the Red List site *www.redlist.org*. Updates since the last Annual Meeting include separate assessments for the two recently recognied species of finless porpoises (*Neophocaena asiaeorientalis* and *N.*

[1] *http://www.nammco.no*

[2] *www.iucn-csg.org/index.php/status-of-the-worlds-cetaceans*

phocaenoides), both listed as Vulnerable. New assessments are underway for the dolphins in the genus *Inia*, which were recently split into two species, *Inia geoffrensis*, the Amazon River dolphin, and *I. boliviensis*, the Bolivian bufeo.

Cetacean Specialist Group
The website of the IUCN Cetacean Specialist Group (*www.iucn-csg.org*), contains regular updates of IUCN's cetacean-related activities and other work in which group members are involved. New items since last year relate to vaquita conservation efforts, Mekong River dolphins in Cambodia, Indus dolphins in Pakistan, new cetacean protected areas in Bangladesh.

World Conservation Congress
The IUCN 4-yearly World Conservation Congress will be held 6-15 September 2012 in Jeju, Korea with the theme 'Nature+'. The programme includes three cetacean-related events: a workshop on lessons learned from the IUCN western gray whale conservation initiative, a presentation on a local population of Indo-Pacific bottlenose dolphins found around Jeju Island, and a workshop on cetacean conservation and whale-watching in Africa[3].

The Committee thanked Cooke and Reeves for their report. It thanks Larsen for his contributions in the past and has left IUCN and agrees that Cooke should continue to act as observers to IUCN for the IWC.

4.10 Food and Agriculture Organisation (FAO) related meetings – Committee on Fisheries (COFI)
No observer for the IWC attended the 2011 meeting of COFI.

4.11 Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES)
No observer for the IWC attended the 2011 meeting of CITES.

4.12 North Pacific Marine Science Organisation (PICES)[4]
The report of the IWC observer at the 20th annual meeting of PICES held 14-23 October 2011 in Khabarovsk, Russia is given as IWC/64/4H. The Marine Birds and Mammals Advisory Group (AP-MBM) recommended that PICES request the IWC Scientific Committee includes a seabird observer on the IWC POWER cruise survey vessel in the future.

Spatial ecology and conservation was selected as the basis of the new activity plan for the AP-MBM. The objectives are:

(1) synthesise distribution data on marine birds and mammals and its temporal change in the North Pacific;
(2) examine the physical and biological factors that correspond to the distribution and abundance of marine birds and mammals and their economic/ecological hot spots; and
(3) provide information on ecological areas in the PICES regions to aid understanding and sustainable use of marine resources.

Two sessions at the 2012 AP-MBM workshop were of relevance to the IWC, these were: (1) environmental contaminants in marine ecosystems: seabirds and marine mammals as sentinels of ecosystem health; and (2) the feasibility of updating prey consumption by marine birds, marine mammals and large predatory fish in PICES regions.

The Committee thanked Kato for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next PICES meeting.

4.13 Eastern Caribbean Cetacean Commission (ECCO)
No information on the activities of ECCO was provided.

4.14 Protocol on Specially Protected Areas and Wildlife (SPAW) of the Cartagena Convention for the Wider Caribbean[5]
The report of the IWC observer to SPAW is given as IWC/64/4D. The MSP LifeWeb Project was launched in October 2010, which aims to assist with the implementation of decisions from the Convention on Biological Diversity, as well as those of the Cartagena Convention and its SPAW protocol. Recent activities under this project include:

(1) a workshop on integration, mapping and GIS analysis of marine mammal migration routes, critical habitats and human threats in the wider Caribbean region (May 2011);
(2) assisting in the coordination of a conference on Marine Mammal Protected Areas (November 2011);
(3) identifying marine mammal data sources within the wider Caribbean Region and collating information in an online database;
(4) a workshop on broad-scale marine spatial planning (March 2012);
(5) analysis of identified marine mammal data in order to develop data layers and maps on the critical habitats for marine mammals in the wider Caribbean; and
(6) a workshop on broad-scale marine spatial planning and transboundary marine mammal management (May 2012).

[3] *www.worldconservationcongress.org*
[4] *http://www.pices.int.*
[5] *http://www.cep.unep.org/cartagena-convention.*

In 2011 a project focusing on marine mammal watching was implemented. It aims to improve and centralise the level of information and knowledge on the status, distribution and threats of marine mammals in the region. A related workshop was held in October 2011. The Committee thanked Carlson for attending on its behalf and agrees that she should represent the Committee as an observer at the next SPAW meeting.

4.15 Indian Ocean Commission (IOC)[6]

No information on the activities of IOC was provided.

4.16 Permanent Commission for the South Pacific (CPPS)[7]

No information on the activities of CPPS was provided.

4.17 International Maritime Organisation (IMO)[8]

The report of the IWC observer to the IMO is given as IWC/64/4G. The IWC has contributed to IMO discussions on addressing ship strikes and the impacts of underwater noise from shipping. The IMO has established a correspondence group to develop non-mandatory draft guidelines for reducing underwater noise from commercial ships (Donovan is a member of this group). This group will report to the IMO's 57th session of the sub-committee on Ship Design and Equipment in early 2013.

The IMO is also working to develop a mandatory Polar Code to control the expected increase in ship traffic in polar waters (the Arctic and the Antarctic) that results from climate and other changes. The Polar Code is intended to function alongside existing IMO conventions and to augment existing measures to reduce the environmental impacts of shipping taking into account the greater environmental sensitivity of polar waters. An IMO Workshop on Environmental Aspects of the Polar Code was held in Cambridge in September 2011 where there was considerable discussion of ship strikes and underwater noise impacts on whales. The Polar Code work is also co-ordinated by the IMO Design Sub-committee on Ship Design and Equipment.

The Committee thanked Leaper for his report and **agrees** that the IWC Secretariat should represent the Committee at the next IMO meeting.

4.18 Conservation in the SE Pacific under the framework for the Lima Convention

No information on Conservation in the SE Pacific under the framework for the Lima Convention was provided.

4.19 International Committee on Marine Protected Areas (ICMMPA)[9]

At its 60th annual meeting in Santiago, Chile, the Committee endorsed support for the first International Conference on Marine Mammal Protected Areas, which was subsequently held in Hawaii, in 2009. The committee that formed to organize that conference has remained intact and is now a task force of the IUCN. It hopes to continue its constructive relationship with the IWC- SC/64/O1 is the summary report of the second International Conference on Marine Mammal Protected Areas (ICMMPA) meeting. Some 150 marine mammal protected area (MMPA) researchers and managers as well as government and conservation group representatives from 42 countries and overseas territories convened in Martinique in the French Caribbean from 7-11 November 2011 for the Second International Conference on Marine Mammal Protected Areas (ICMMPA 2). The goal: to seek solutions to shared problems related to marine mammal conservation and to MMPA network and site design, creation and management. A secondary goal was to orient those working in MMPAs to set those protected areas in the broader context of marine management. The conference was co-hosted by the French MPA Agency (*Agence des aires marines protégées*) and the US National Oceanic and Atmospheric Administration (NOAA). Fifteen other international and regional sponsors, as well as a dozen supporting organizations, were actively involved.

The conference theme of 'Endangered Spaces, Endangered Species' was explored in keynote talks, panels and workshops focusing on monk seals, sirenians, river dolphins and other small and large cetaceans. In several workshops and plenary talks, special attention was given to the *vaquita*, the most endangered, space-restricted marine mammal in the world. Plenary sessions were divided into panels, followed by discussions, focusing on:

(1) special considerations for particularly endangered marine mammals and whether MPAs are the right tool;
(2) refining our understanding of marine mammal critical habitat and hotspots to inform MMPA designation;
(3) using marine spatial planning and ecosystem-based management to address broad threats to marine mammals;
(4) managing MMPAs for localized threats and mitigation by spatial protection and other means;
(5) development of MMPAs in the wider Caribbean region; and
(6) regional cooperation for MMPA scientific and technical networking.

[6] *http://www.coi-ioc.org*.
[7] *http://www.cpps-int.org*.
[8] *http://www.imo.org.*
[9] *www.icmmpa.org.*

The workshops focused on marine mammals and oil spills, decision-making with limited data, best practices for whale watching in MMPAs, integrating marine mammal data in marine spatial planning, forging agreements to establish effective MMPA networks, and the widespread mortality attributed to fisheries bycatch.

Proceedings of this second ICMMPA meeting will be available and released briefly and a third ICMMPA meeting is planned to be held in about two years' time. A proposal was received from Australian scientists and decisions on exact location an date are yet to be taken.

5. REVISED MANAGEMENT PROCEDURE (RMP) – GENERAL ISSUES (SEE ALSO ANNEX D)

5.1 Complete the MSY rates review

Since 2007, the Committee has been discussing maximum sustainable yield rate (MSYR) in the context of a general reconsideration of the plausible range to be used in population models used for testing the *Catch Limit Algorithm* (*CLA*) of the RMP (IWC, 2008c; 2009b; 2010b; 2010h; 2011j). The current range is 1% to 7%, in terms of the mature component of the population. As part of its review, the Committee has been considering observed population growth rates at low population sizes. An important issue raised (Cooke, 2007) was that should variability and/or temporal autocorrelation in the effects of environmental variability on population growth rates be high, simple use of such observed population growth rates could lead to incorrect inferences being drawn over the lower end of the range of plausible values. In 2010, the Committee agreed a Bayesian approach (Punt, 2010) for calculating a probability distribution for the rate of increase for an 'unknown' stock in the limit of zero population size, once the inputs needed to apply it become available (IWC, 2011e).

Last year, the Committee had agreed that the review would be completed at this meeting (IWC, 2012f). However, given effectively no intersessional progress, the issue was furthered but not completed during the present meeting (Annex D, Appendix 2) as follows:

(1) values of demographic parameters to be used for the calculation of the CV and autocorrelation of the rate of increase were agreed for the 15 populations for which estimates of growth rate at low population size were available if it is assumed that only fecundity is stochastic;
(2) calculations were undertaken for the case where there is no variability in survival rate;
(3) progress was made on the implementation of two approaches for specifying variability in survival rate; one which results in the same CV for the rate of increase for variability in survival rate as the CV implied by the variability in fecundity, and another which is based on an approach involving optimal allocation of energy between reproduction and survival.

The Committee expressed serious concern that once again the process has not been completed and it carefully examined whether it was worth continuing the process. However, given the good progress during the meeting, and the workplan developed (Annex D, Item 2.1), the Committee **agrees** that no more than one further year would be allowed for this process. If the MSYR review cannot be completed at next year's meeting, the current range of MSYR rates (1% - 7% in terms of the mature component of the population) will be retained.

To ensure completion of these tasks, a three-day intersessional meeting is required, with at least five participants, ideally back-to-back with another intersessional meeting. An intersessional steering group (under Butterworth Annex R1) was appointed to co-ordinate the meeting and associated preparation. Any models related to variability in survival rate to be considered must be fully specified to the Steering Group at least one month before the intersessional meeting. The financial considerations are given under Item 23.

5.2 Finalise the approach for evaluating proposed amendments to the *CLA*

The Committee last discussed this issue in 2006 (IWC, 2007c) noting that it was originally intended that this work would occur in conjunction with the completion of the MSYR review (see Item 5.1 above). The Committee re-established a working group under Allison (Annex R1) to develop trials to examine the effects of possible environmental degradation in terms of trials in which *K*, and perhaps MSYR, varies over time. The Committee **stresses** that this work must be completed by the next Annual Meeting irrespective of the progress made under Item 5.1.

5.3 Evaluate the Norwegian proposal for amending the *CLA*

The Committee was unable to complete its evaluation of the Norwegian proposal given the discussions under Items 5.1 and 5.2 above. The Committee **agrees** that this task will be completed at the next Annual Meeting either using the revised values from the MSYR review or the existing values if the review is not completed.

5.4 Modify the 'CatchLimit' program to allow variance-covariance matrices

The 'CatchLimit' program implements the *Catch Limit Algorithm* and now allows variance-covariance matrices for the abundance estimates to be specified (IWC, 2012f). Allison noted that it includes some non-standard coding statements and she will be working with the Norwegian

Computing Center during the intersessional period to develop a final version of the program.

5.5 Update requirements and guidelines for conducting surveys and *Implementations*

The Committee's Requirements and Guidelines for Conducting Surveys and Analysing Data within the Revised Management Scheme (IWC, 2012v) were written when only design-based surveys were realistic. Subsequently, spatial modelling approaches have been developed as an additional realistic approach. In addition, many [quasi] design-based surveys do not formally meet design-based criteria, and there may be a question regarding on the adequacy of resultant estimates. The Committee has frequently considered model-based and quasi-design-based estimates (e.g., IDCR/SOWER and SCANS), but without explicit criteria and not necessarily in the context of the RMP. Two linked issues therefore arise: under what circumstances might approval from the Scientific Committee reasonably be given to surveys that are not design-based, and should the Guidelines should be amended to give more specific advice on the considerations for evaluating model-based estimates (including extrapolations) and/or quasi-design-based estimates.

The statistical issues involved are complex, both theoretically and in practice. A number of detailed starting points for discussion are noted in Annex D, Item 2.5, and sufficient experience with model-based methods has now accumulated to warrant a review. The Committee, also recognising the importance of this work for all sub-committees that consider abundance estimates in a conservation and management context, therefore **recommends** that such a review (covering model-based abundance estimation in theory and practice, and its relation to the design-based approach), be conducted. The review (Annex D, Appendix 4) will also provide draft text for inclusion in the Committee's Requirements and Guidelines for Conducting Surveys document. The financial considerations are given under Item 23.

5.6 Evaluate the optimisation method used when conditioning trials

Punt and Elvarsson (2011) developed and compared a number of ways to improve the performance of the optimisation algorithm underlying the conditioning process, as discussed in Annex D, Item 2.6. The Committee noted that the optimisation scheme used for conditioning the trials for the western North Pacific minke whales had been modified accordingly.

5.7 List of abundance estimates and their recommended uses

The list of accepted abundance estimates for those stocks that have been subject to RMP *Implementations* (and Reviews) are provided in Annex D, Appendix 2 along with references to discussions as to whether they are acceptable for use in conditioning; acceptable for use in trials, and/or acceptable for use in applications of the *CLA*. The only exception was for western North Pacific common minke whales where evaluation is ongoing (see Item 6.3).

5.8 Work plan

The Committee's views on the workplan developed by the sub-committee on the RMP are given under Item 21 and financial matters are considered under Item 23.

6. RMP – PREPARATIONS FOR *IMPLEMENTATION*

6.1 Western North Pacific Bryde's whales

6.1.1 Prepare for 2013 Implementation Review

The Committee was informed that Japan wished to postpone the 2013 *Implementation Review* for North Pacific Bryde's whales until 2016 because:

(1) Dedicated sighting surveys have been conducted in the western North Pacific since 2010 and additional surveys targeted towards Bryde's whales were planned for 2012 and beyond.
(2) Lower latitudinal waters in the eastern North Pacific will be covered during the IWC/POWER research program during 2013- 2015.
(3) There are currently no genetic samples for sub-area 2 (east of 180°). It is expected that biopsy samples will be collected from Bryde's whales during the IWC/POWER research programme.
(4) New genetic samples have been obtained for sub-area 1 (west of 180°) during JAPRN II as well as other sources, but the data have yet to be analysed.

6.1.2 Recommendations

Implementation Reviews should normally be scheduled not later than six years after the completion of the previous *Implementation* (or *Review*) (IWC, 2012w). The western North Pacific Bryde's whale *Implementation* was completed in 2007 (IWC, 2008). However, the Committee **recommends** that the *Implementation Review* for western North Pacific Bryde's whales be delayed until 2016 given: (a) the *Implementation* completed in 2007 considered a range of hypotheses related to stock structure and productivity; (b) three more years of catches are unlikely to lead to conservation concerns given the results of the *Implementation*; (c) that it cannot conduct more than one *Implementation Review* at a time (see Items 6.2 and 6.3 below); and (d) allow additional sightings and genetics data to be available.

6.2 North Atlantic fin whales

In 2009, the Committee agreed (IWC, 2010d) that if the RMP is implemented for North Atlantic fin whales,

certain variants (see table 4 of IWC, 2010d, pp.122) could be implemented without a research programme. It also agreed that another variant would be acceptable only with an agreed research programme for the reasons given in IWC (2010d). A primary aspect of this related to whether or not a particular stock hypothesis, 'hypothesis IV', was appropriate.

SC/64/RMP3 responded to a recommendation from the Committee last year that further analysis of the Discovery Marking data should be carried out within the framework of the *Implementation Simulation Trials* as detailed in Annex D, Item 3.2. The Committee noted that SC/64/RMP3 provided evidence suggesting that stock structure hypothesis IV is inconsistent with existing data but recognised that making a final decision on its acceptability could also involve additional trials. This can best be achieved within the context of an *Implementation Review*.

Annex D, Table 1 summarises new information available for an *Implementation Review*. The Committee **agrees** that the available information is sufficient to warrant an *Implementation Review* in 2013. It noted that while the *Implementation Review* would be focused on providing advice for the Icelandic hunt, the discussions of stock structure would also be valuable in the context of the SWG's work to develop an *SLA* for the aboriginal hunt off West Greenland (Annex E).

6.2.1 Recommendations

The Committee **recommends** that the *Implementation Review* for the North Atlantic fin whales be brought forward to 2013. The *Review* should start during a pre-meeting immediately before the 2013 Annual Meeting to ensure that it is completed in one year. An intersessional email Steering Group (Víkingsson, Gunnlaugsson, Donovan (chair), Butterworth, Allison) was established to coordinate the work prior to the 2013 meeting.

6.3 North Pacific common minke whales (continue *Implementation*)

The Committee is conducting an *Implementation Review* for western North Pacific common minke whales and is following the schedule set out in its Requirements and Guidelines (IWC, 2012a). At last year's meeting, the Committee had been unable to complete the tasks required for the First Annual Meeting, primarily because it had not been possible to complete conditioning of the *Implementation Simulation Trials*a major task given their complexity. This meant that the 2 year schedule for the *Implementation Review* had been disrupted.

This year's meeting was effectively a repeat of the First Annual Meeting with the same list of tasks that had been initiated last year. There had been another Intersessional Workshop in December 2011 to facilitate the work necessary to ensure that all relevant tasks could be completed at this year's meeting as described under item 6.3.1.1.

6.3.1 Report of the December 2012 Intersessional Workshop

Donovan presented a summary of the report of the Intersessional Workshop held 12-16 December 2012, kindly hosted by the Government of Japan (SC/64/Rep2). The primary objective of the Workshop was to ensure completion of the conditioning of trials in time for the 2012 Annual Meeting, although a number of other topics were addressed to assist the Committee in its work to complete the *Implementation Review*. Conditioning is the process of selecting the values for the parameters of the operating models that implement the trials such that the predictions from these models are consistent with the available data.

The Intersessional Workshop covered issues relating to: stock structure and mixing matrices; conditioning; abundance estimates for use in trials; specification of these trials; plausibility of stock structure hypotheses; and data/analyses to reduce the number of stock structure hypotheses in future *Implementations*. Considerable progress was made and details are given in Annex D1, Item 3 and SC/64/Rep2.

6.3.2 Conditioning

Following the Intersessional Workshop, a number of problems with the fits of the operating model to the data had been identified. Suggested changes to the trial specifications were developed, details of which are given in Annex D1, Item 4.1, which the Committee **endorses**.

The Committee reviewed the results for the six baseline trials (stock structure hypotheses A, B and C with MSY rates of 1% and 4%) given in Annex D1, Appendix 2 and **agrees** that the conditioning for these trials had been acceptably achieved. There was insufficient time to evaluate the results of the conditioning of all the sensitivity tests. However the Committee **agrees** that the results for trials for which 100 simulations were available suggested that it is possible to determine whether conditioning has been achieved successfully based on the fit of the operating model to the actual data.

The Committee received a summary report from a small group appointed to review the results of trials run to date. Allison reported that all trials for stock structure hypotheses A and C with MSYR = 1% had now been run with the actual data. Conditioning had been achieved for all these trials except two, for which the mixing matrices needed adjustment. Based on these results and on extensive past experience with reviewing the results of such trials, the Committee **agrees** that conditioning of the *Implementation Simulation Trials* of western North Pacific common minke whales had been acceptably achieved.

6.3.3 Update to standard datasets - abundance estimates

Abundance estimates play three roles in the *Implementation* process: (a) for use in conditioning trials; (b) for use when applying the *CLA* during *Implementation Simulation Trials*; and (c) for actual application of the *CLA*. The abundance estimates for use during conditioning were selected during the First Intersessional Workshop in December 2010 (IWC, 2012d). At this meeting, the Committee needed to select which abundance estimates to use when applying the *CLA* during *Implementation Simulation Trials*. The abundance estimates for use in actual application of the *CLA* will be finalised next year.

The Committee received a cruise report of a sightings survey in the Yellow Sea in May 2011 (SC/64/NPM6) and an estimate of abundance for minke whales from this survey (SC/64/NPM7); details are given in Annex D1, Item 5.1.1. The Committee expressed its appreciation to the Government of Korea for its continued commitment to surveys for minke whales in Korean waters, and to An for his role of oversight on behalf of the Committee. In discussion, the Committee raised a number of issues with the analysis that requires further work. Therefore this estimate was not accepted for use in implementation of the RMP at this meeting but the Committee looks forward to the presentation of a revised estimate in the future.

The Committee received SC/64/NPM2, an updated summary of the information on survey procedures for the Japanese dedicated sighting surveys conducted by the Institute of Cetacean Research (ICR) and the National Research Institute of Far Seas Fisheries (NRIFSF), in response to a recommendation from the December 2011 Intersessional Workshop (SC/64/Rep2). The authors concluded that sighting procedures for the ICR surveys follow the RMP requirements and guidelines for surveys, except that the surveys were not subject to Committee oversight, and that the survey procedures for the NRIFSF surveys met all these requirements and guidelines. The Committee also received SC/64/NPM3, which presented abundance estimates from JARPN II (see item 17) sightings data for minke whales in sub-areas 7CS, 7CN, 7WR, 7E, 8 and 9 collected during 2008 and 2009. Details are given in Annex D1, Item 5.1.2.

A number of issues were raised and discussed relating to survey design, survey direction relative to migration, survey protocol for responding to bad weather and achieved coverage; details are given in Annex D1, Item 5.1.2. One specific point was that the estimates of abundance for 2008 and 2009 use information from other years. The Committee therefore **recommends** that variance-covariance matrices be computed for the entire time-series of abundance estimates for sub-areas 7CS, 7CN, 8, and 9.

Whether and how to use estimates with low coverage or design concerns and the treatment of JARPN and JARPN II surveys (i.e. surveys that had not originally been intended to produce estimates for use in the RMP) that did not have Committee oversight raised issues beyond the specifics of the *Implementation Review* of western North Pacific minke whales. Accordingly, the Committee had a general discussion of these issues, the report of which is given under Item 5.8.

In light of that discussion, a small group reviewed all of the available abundance estimates to determine whether or not they were acceptable for use when applying the *CLA* during *Implementation Simulation Trials*. Each available estimate was categorized as 'Yes', 'No', 'No agreement', and 'Yes*' (see Annex D1, Appendix 3). The category Yes* indicates that they can be used in the trials but that further analysis needs to be considered for the estimate to become acceptable for application of the RMP. Surveys which had been accepted for use in the trials during the 2003 *Implementation* were automatically deemed acceptable. The Committee **endorses** the categorisations given in Annex D1, Appendix 3.

Regarding those estimates for which no agreement had been reached on whether or not they were acceptable for use in trials, the Committee **agrees** that the baseline trials should be conducted for the least and most aggressive RMP variants both using and not using the 'No agreement' estimates when applying the *CLA*. If the results of the trials are sensitive to the inclusion of the 'No agreement' estimates, the proponents would be requested to justify how the 'No agreement' estimates could become acceptable with further analysis. The final decision on whether further analysis is likely to allow 'No agreement' estimates to be acceptable will be made by the Intersessional Steering Group established under Butterworth (Annex R).

Annotation 21A to the RMP specifications (IWC, 2012w) states that 'A part of an *Area* which is unsurveyed in a single year may count as surveyed when the data from several years are combined, provided that an appropriate multi-year regression analysis is used, and additional variance is taken into account'. In response to a recommendation in SC/64/Rep2, the Committee received SC/64/NPM5, which extrapolated abundance estimates to parts of sub-areas 8, 11, and 12NE which were not covered during some past surveys, to eliminate the bias in estimated abundance trend which arises due to variable coverage. Details are given in Annex D1, Item 5.1.2.

The Committee noted that blocks B11-2 and B12NE-2 had only been surveyed once which meant that there are insufficient data to inform additional variance. The Committee **agrees** that the information for sub-area 8 satisfied the requirements for applying annotation 21A.

6.3.4 Update to standard datasets – best catch series

The Committee **agrees** with the recommendation in Annex D of SC/64/Rep2 that the 'Best' catch series was appropriate for the direct catches.

The Committee noted that a single series of bycatches would be used for all of the trials when applying the RMP, irrespective of the true values for the bycatches, which differ among trials, and simulations within trials. The Committee **agrees** that the bycatches would be set to the averages of the predicted bycatches based on the fit to the actual data of the operating model for the six baseline trials (see Annex D1, Appendix 4).

Regarding the specification of future bycatches in the trials, the Committee **agrees** that this should be achieved by assuming that the bycatch rate in the future equals the bycatch rate estimated for the trial in question averaged over the previous five years (Annex D1, Appendix 9).

6.3.5 Final consideration of plausibility

A key step in the Committee's Requirements and Guidelines for *Implementations* (IWC, 2012w) is assigning plausibility to hypotheses and, by extension, to all of the *Implementation Simulation Trials*. Trials are assigned 'low', 'medium' or 'high' weights, or are categorised as 'no agreement', which are treated as 'medium' weighted trials. Trials with 'low' weights are not considered further in the *Implementation*.

When the results of the trials are examined, for each management variant (see Item 6.3.1.5), 'acceptable' conservation performance is required for all 'high' weight trials but 'borderline' or 'unacceptable' conservation performance for a number of 'medium' weight trials, leads to further consideration of a possible 'with research' option, as detailed in IWC (2012w). Unacceptable performance of a management variant in any 'high' weight trial leads to that variant being eliminated from further consideration, including with respect to the 'with research' option.

The schedule for *Implementations* in the Committee's Requirements and Guidelines for *Implementations* (IWC, 2012w) required final decisions on the plausibility of hypotheses to be made at this year's meeting.

SC/64/Rep2 noted that the present meeting would decide whether analyses of CPUE data (or sighting per unit effort data, SPUE) could be used qualitatively to inform assignment of plausibility weights to the hypotheses (stock structure and MSYR) on which the trials are based (see Annex D1, Item 3.6). The Workshop had noted that a document outlining relevant operational factors needed to be developed for the Committee to make a decision in this regard, and it had made a number of recommendations regarding such a document.

SC/64/NPM4 summarised information pertaining to catch, sightings and effort data from Japanese small-type whaling during 1977–87 in relation to minke whales. The authors concluded that CPUE or SPUE data can be useful as an index of population trend if standardised.

The Committee thanked the authors of SC/64/NPM4, which covered most of the factors identified. It noted that there was considerable variation in where individual vessels operated during the year, and that if vessel movement reflects availability of whales, CPUE or SPUE may be biased as an index of relative abundance. It was suggested that focussing on April-May only may provide more consistency.

Following the presentation of the results of additional analyses, the Committee considered that further analysis and model diagnostics would need to be provided before the resultant SPUE trends could be used to assist the assignment of plausibility to hypotheses related to stock structure and MSYR. Given the time available, this was not feasible this year. It was noted that these data could be re-analysed and presented to the next *Implementation Review*, although some members considered that use of whaling SPUE data was inherently problematic and that no analyses of these data would lead to information which could inform plausibility.

6.3.5.1 STOCK STRUCTURE

In response to a request made intersessionally, the Committee received papers from the proponents of Hypotheses A/B (SC/64/NPM1) and of Hypothesis C (SC/64/NPM11) summarising their main features and supporting evidence. Details of these papers are given in Annex D1, Item 6.2. a graphical representation of these stock structure hypotheses is given in fig.1 of (IWC, 2012h, pp.103).

Two papers containing new genetic analyses were presented. SC/64/NPM9 used computer simulations to examine the effect of different sample sizes on the distributions of the correlations between θ and F_{IS}, following an analysis presented last year (SC/63/RMP7) in which it was proposed that, in a sample that contains individuals only from two distinct stocks, the largest departures from equilibrium (quantified as F_{IS}) should be seen at the loci that show the largest allele frequency differences between the two stocks (quantified as θ). Details are given in Annex D1, Item 6.2. given the considerable variability seen in the simulated data, the authors of SC/64/NPM9 suggested that further evaluation is required before the results of SC/63/RMP7 could be used as evidence against Hypotheses A and B.

In discussion, it was suggested that it would be useful to extend these analyses to the two-locus (linkage disequilibrium - LD) correlations that were also reported

in SC/63/RMP7. Additional discussion is given in Annex D1, Item 6.2.

SC64/NPM10 responded to a request from last year's meeting for follow-up analyses comparing the performance of two Bayesian clustering programs (STRUCTURE and HWLER) for detecting the number of gene pools represented in a sample. Details are given in Annex D1, Item 6.2. Both programs only detected one population when true panmixia was modelled, but both also failed to detect a second population at the weakest level of differentiation (F_{ST} = 0.007). STRUCTURE reliably detected two populations at F_{ST} = 0.02 but HWLER did not, but HWLER was more consistent in resolving mixtures for F_{ST} > 0.03.

In discussion, the Committee noted that the results provide additional confirmation that these Bayesian clustering methods cannot detect the weakest levels of population structure, at least using currently available numbers of genetic markers. Details of additional discussion are given in Annex D1, Item 6.2. Several more technical aspects of the performance of STRUCTURE at moderate levels of population differentiation (F_{ST} = 0.045-0.06) were also discussed; details are given in Annex I.

In response to a request in SC/64/Rep2, the summary information relating to key stock structure questions developed last year (Appendix 9 of Annex D1 of last year's report - IWC, 2012h) was reformatted and presented to the Committee. It was revised following discussion and a final version is given in Annex D1, Appendix 6. This table provided a useful starting point for final considerations of plausibility of stock structure hypotheses.

The Committee also received Annex D1, Appendix 7, which synthesised information relating to the relevance of departures from Hardy-Weinberg equilibrium at one and two gene loci, to distinguish between stock-structure hypotheses. The author's overall conclusion was that evidence from Hardy-Weinberg departures for more than two O+J stocks is only weak to moderate. Details of discussion are given in Annex D1, Item 6.2.

Following these presentations and discussions, the Committee considered a concise overall summary by the 'G5 group' of geneticists of their interpretation of the relative support for and against the five hypothesised stocks (JE, JW, OE, OW, Y), based on the cumulative genetic information presented and discussed during the last several years. This summary table is given in Annex D1, Appendix 8.

During the discussion, there was some attempt to reduce the number of stock structure hypotheses for consideration in the *Implementation Simulation Trials*. It was noted that the conclusion in Annex D1, Appendix 8 regarding Y stock did not depend on data on conception date, which some consider the strongest evidence for Y stock. Some members suggested that as a consequence, Hypothesis A be assigned 'Low' plausibility. This was not agreed to by the proponents of that hypothesis, who pointed out that reliability of the conception date data has been questioned (e.g. IWC, 2012h) and who argued that the genetic data are too limited to be considered strong support for existence of Y stock. Similarly, assigning 'High' plausibility to a 4-stock version of Hypothesis C that includes two O stocks but only one J stock, and 'Medium' plausibility to Hypothesis C did not receive agreement.

In the end, it was not possible to reach agreement on any of these alternatives and, as a consequence, all three main stock structure hypotheses (A, B and C) were 'no agreement'. The Committee **agrees** that they should therefore be treated as if they had been assigned 'Medium' plausibility and that the *Implementation Review* should proceed on this basis.

Pastene commented that although several types of data had been considered during the *Implementation* process thus far, he felt that the conclusions on plausibility were too heavily weighted to the genetic data. The Committee reaffirms the importance of using data from a suite of techniques.

Some members expressed their concern that, despite an enormous investment in research, no consensus had been reached on according low plausibility to the hypothesis of two J stocks. They noted the conclusion of five geneticists who were not proponents of any of the hypotheses (Gaggiotti, Hoelzel, Palsbøll, Tiedemann and Waples) that, based on existing genetic data and analyses, the evidence for the two J stock hypothesis is low and the evidence against it is medium or high (Annex D1, Appendix 8). They questioned whether it would ever be possible to agree, on the basis of genetic analyses, that a hypothesis be given low plausibility if such a statement was not considered by the Committee to be sufficient.

Other members considered that the genetic data were insufficient to evaluate any of the three stock structure hypotheses. They noted that genetic data do not provide information on annual mixing rates between *Small Areas*, which has been shown to be an important consideration in the application of the RMP (Martien *et al.*, 2008). They also noted the discussion under Item 6.1.3.8 on the lack of samples from the breeding grounds and recommendations for further research to determine the levels of demographic mixing between breeding populations in relation to management outcomes.

6.3.5.2 MSYR AND OTHER FACTORS

The previous *Implementation* assigned 'high' plausibility to $MSYR_{mat}$=4% and 'medium' plausibility to

$MSYR_{mat}$=1% (IWC 2005). It was noted that these whales are found in a region in which there are very large fisheries which might impact the prey base. However, the size of any such an effect on MSYR cannot be quantified at this time. In addition, the review of MSY rates will not be completed during the current meeting so there is effectively no new information related to MSYR for western North Pacific minke whales. The Committee therefore **agrees** to assign 'high' plausibility to $MSYR_{mat}$=4% and 'medium' plausibility to $MSYR_{mat}$=1%, as in the previous *Implementation*.

The baseline trials are based on the hypothesis $g(0)$=0.8, based on the estimate of $g(0)$ by SC/62/NPM9 for the combination of top barrel and upper bridge. The December 2010 First Intersessional Workshop (IWC, 2012d) had noted that this estimate is conservative because the $g(0)$ value is to be applied identically to all surveys, including those by Korean vessels which have lower top barrels, and hence seem likely to miss a greater proportion of minke whales on the trackline. The Committee therefore **agrees** to assign 'high' plausibility to $g(0)$=0.8 and 'medium' plausibility to $g(0)$=1.

Regarding the full set of sensitivity trials, the Committee **agrees** to assign 'medium' plausibility to all of the trials except for the following three:

(1) Trial 24, which is based on stock structure hypothesis C, but there is a single O-stock and two J-stocks. This trial was assigned 'low' plausibility given the results of the genetics analyses (see Annex D1, Appendix 8).
(2) Trials 21 and 29, which are based on the abundance in sub-areas 5 and 6W, respectively, being set to the 'minimum' values. These trials were assigned 'low' plausibility because the Korean surveys in sub-areas 5 and 6W only cover a small fraction of the overall area of these sub-areas.

The Working Group noted that results of trials 21 and 29 might provide useful information regarding the behaviour of the trials, and **recommends** that these trials be conducted if time is available.

Annex D1, Appendix 5 lists the factors considered in the trials and the final plausibilities assigned by the Committee to each factor.

6.3.6 Specifications of operational features and management variants

In order to implement the *CLA* in trials, specifications of proposed whaling operations are required. Japan intends to conduct coastal whaling in sub-areas 7CS, 7CN and 11, and pelagic whaling in sub-areas 8 and 9. Coastal whaling will be restricted to 10 n.miles. from the coast and during August-October in sub-area 11 to minimise catches of J-stock animals. Whaling in sub-areas 8 and 9 will take place during April-October. Korea intends to conduct whaling using small-type catcher boats in sub-areas 5 and 6W from March to November. Operations will be conducted up to 60 n.miles. from the coast in sub-area 5 and up to 30 n.miles. from the coast in sub-area 6W.

It is also necessary to specify the management variants that will be implemented in the trials. A management variant defines the way the *CLA* is applied to *Management Areas*. This includes specifying *Medium Areas*, *Small Areas* and combinations of *Small Areas* (*Combination Areas*), specifying from which *Management Areas* catches are to be taken, and selecting *Catch-cascading* and/or *Catch-capping* options.

The **agreed** RMP variants and the associated *Small* and *Medium Area* definitions are given in Annex D1, Appendix 9.

The Committee noted that the trials will take longer to run than in previous *Implementations* because the *CLA* will be implemented using the Norwegian 'CatchLimit' program rather than the Cooke version of the *CLA*. The Committee **agrees** that priority should be given to running all RMP variants for the baseline trials as quickly as possible so that any of the RMP variants that are clearly likely to perform 'unacceptably' can be excluded from further consideration. The process of distributing and evaluating trials will be co-ordinated by the Intersessional Steering Group (see Annex R).

6.3.7 Specifications and classification of final trials

The final trial specifications are given in Annex D1, Appendix 9.

The Committee **agrees** that for running the trials it will be assumed that the proportional coverage of sub-areas will remain unchanged.

The planned future surveys and a proposal for how past surveys can be combined to calculate survey estimates for *Small Areas* are given in Annex D1, Appendix 9.

SC/64/NPM8 reported that a survey in the Yellow Sea will be conducted during spring 2013. Details are given in Annex D1, Item 8.2. The Committee was pleased to hear that additional surveys would continue to be conducted in the waters off Korea and appointed An to provide oversight on its behalf. In relation to survey design, the Committee had recommended some changes to the survey design, which was subsequently modified during the meeting (see Annex D1, Item 8.2).

SC/64/O9 reported on a sightings and satellite tagging survey for common minke whales in sub-area 7 in April-June 2011. Only two animals were encountered and efforts to deploy a tag were unsuccessful. SC/64/O10 reported on a sighting and biopsy sampling survey for common minke whales in the Okhotsk Sea, including the

Russian EEZ, in May-June 2011. Three schools of minke whales were targeted for biopsy sampling, but no samples were obtained because of difficulties closing on the animals. The Committee expresses its support for continued efforts to collect telemetry and biopsy data to help elucidate stock structure for minke whales in this region. More details are given in Annex D1, Item 9.

6.3.8 Consideration of data/analyses to reduce hypotheses in future

The Committee had a general discussion of the fact that, in spite of many years of concerted efforts and a great deal of genetic and non-genetic data, considerable uncertainties remain regarding stock structure of western North Pacific minke whales. This issue is particularly difficult because of the lack of any samples from breeding grounds. The Committee considered a number of types of genetic analyses that might help to reduce these uncertainties in the future. These included sensitivity analyses of recently-used methods and development and application of new analyses, details of which are given in Annex D1, Item 9. The importance of considering further work on non-genetic data was also noted. The Committee notes that plans for internation collaborative work, including a workshop, to assist the Committee prepare for an *Implementation Review* under the RMP and the development of an AWMP *SLA* for the Greenland hunt for North Atlantic minke whales (Annex D, Appendix 6) could serve as a useful model for this.

In addition to proposed analyses specifically related to North Pacific common minke whales, the Committee considered an approach that would more broadly address core stock-structure problems that recur for many species in many areas. This general approach has two parts: (1) determining what levels of demographic mixing between breeding populations do and do not make a difference in terms of conservation goals or management outcomes; and (2) using genetic and other methods to determine whether actual levels of connectivity are above or below this threshold.

The Committee **agrees** that work towards this general approach should receive high priority. Suggestions to facilitate implementation of this approach are given in Annex D1, Item 9; further discussion is given in Annex I.

It was noted that the *Implementation Review* for North Atlantic common minke whales will undertake some of this work (see Annex D, Item 3.3) and that it would be desirable to coordinate efforts in that regard. It was also noted that similar work was being undertaken by scientists at the US Southwest Fisheries Science Center. Cumulative results of these analyses should make it apparent whether general rules of thumb about 'tipping point' levels of migration can be identified, or whether the outcomes are so diverse that each situation must be evaluated on its own merits.

As noted in SC/64/Rep2, in addition to issues of stock structure, other difficulties in conducting the present *Implementation Review* centred on abundance estimates, including their unavailability in some areas and the large CVs for some of the estimates that were available. The difficulties faced by the Committee in determining the acceptability of abundance estimates for use in trials (see Annex D1, Item 5.1.2) amplify this concern.

The Committee **agrees** that, to avoid such difficulties in future *Implementation Reviews*, it should consider taking a more active and collaborative approach to this issue. Examination of trial results will assist in identifying the key temporal and geographical areas where new/improved abundance estimates would be most valuable. The Committee should consider developing, in conjunction with the appropriate range states, a short-medium term survey strategy (including design and required effort) and analytical approach that would improve the availability of satisfactory abundance estimates with reasonable CVs at the appropriate geographical and temporal scale to facilitate future *Implementation Reviews*. This could follow a similar process to that used to develop the IWC-POWER programme (Annex G, Item 6.2).

6.3.9 Inputs for actual application of the CLA

The Committee **agrees** that the best estimates of the direct catches and the average predicted bycatch from the six baseline trial would be used for applications of the *CLA*.

The Committee did not have sufficient time to select abundance estimates for use in application of the *CLA*. This issue will need to be addressed at the Second Intersessional Workshop (see Item 20).

6.4 North Atlantic common minke whales

6.4.1 Review new information

SC/64/RMP4 summarised the results of aerial surveys covering most of the continental shelf waters of the Icelandic economic zone; the off season component was part of the Icelandic Research Programme of Common Minke Whales conducted during 2003-07. The Committee noted that SC/64/RMP4 will be considered during the review of this program in 2013 (see Item 17.1.3).

SC/64/RMP5 summarised a sighting survey conducted in the eastern Norwegian Sea in the *Small Management Area EW* during the summer 2011. Details are given in Annex D, Item 3.3.1 This was the fourth year in the ongoing six-year survey program 2008-2013. The Committee **welcomes** the information provided. The data will be included in developing a future abundance estimate for North Atlantic minke whales.

6.4.2 Prepare for 2014 Implementation Review

The Committee agreed last year (IWC, 2012i) to undertake an *Implementation Review* of common minke

whales in the North Atlantic in 2014. It has agreed that this will include a full review of stock structure and other issues, recognising that there has been substantial new information collected over the period since the original hypotheses were developed during the *Implementation* itself (IWC, 1993).

The Committee recognised that it was important to begin preparations for the review in sufficient time to allow for this thorough analysis. It therefore **recommends** the workplan (including a joint intersessional workshop with AWMP in 2014) as outlined in Annex D, Appendix 6, to consider stock structure hypotheses for North Atlantic common minke whales. It appointed a Steering Group under Palsbøll (Annex R).

6.5 North Atlantic sei whales

Víkingsson *et al.* (2010) represented a proposal to initiate a *pre-implementation assessment* of sei whales in the Central North Atlantic. As required (IWC, 2005), the paper provides a broad outline of the available data relevant to an pre-implementation assessmen, including historical catches, distribution and abundance from dedicated and non-dedicated sightings surveys, stock structure (Discovery marking, genetics and satellite telemetry), biological parameters, feeding ecology and pathology. The authors concluded that the data are sufficient to warrant a pre-implementation assessment of sei whales in the North Atlantic.

The decision whether to initiate an *Implementation* is made by the Commission. The Committee **recommends** that an intersessional group convened by Vikingsson (Annex R) should be established with Terms of Reference to review the available data for North Atlantic sei whales in the context of a *pre-implementation assessment* and provide a report to the 2013 Annual Meeting. The Committee will review the report and any new information so that the Commission can be advised whether sufficient information is available to proceed with the *pre-implementation assessment*.

6.6 Work plan

The Committee's views on the workplan developed by the sub-committee on the RMP are given under Item 21.

7. ESTIMATION OF BYCATCH AND OTHER HUMAN-INDUCED MORTALITY (BC)

The report of the Working Group on Estimation of Bycatch and Other Human-induced Mortality is given as Annex J. This subject was introduced onto the Agenda in 2002 (IWC, 2003d) because under the RMP, recommended catch limits must take into account estimates of mortality due to *inter alia* bycatch, ship strikes and other human factors in accordance with Commission discussions at the 2000 Annual Meeting (IWC, 2001a), although of course such mortality can be of conservation and management importance to populations of large whales other than those to which the RMP might be applied. Subsequently, the issue of ship strikes has become of interest to the Commission's Conservation Committee (e.g. IWC, 2011b) while entanglement response is being considered by the Commission's Working Group on whale killing methods and associated animal welfare issues (e.g. see IWC/64/WKM&AWI Rep1).

7.1 Collaboration with FAO on collation of relevant fisheries data

There has been an ongoing effort by the Secretariat and Sea Mammal Research Unit to consolidate data on entanglements submitted in the National Progress Reports into a single database to be shared with FAO. All bycatch records reported to the IWC for the period 1967-2010 have now been entered. The IWC is currently an observer to the FIRMS partnership (Fisheries Resources Management System), a collaborative partnership organised by the FAO, which enables fishery management bodies to share information. It was hoped that FIRMS may hold data on fishing effort that could be useful in estimating bycatch but FIRMS appears to have changed its focus somewhat since initial discussions. The Committee **recommends** that the Secretariat contact FIRMS to establish whether the partnership is still attempting to collate data on fishing effort in such a way that could be of use to the Committee in estimating bycatch.

7.2 Estimation of bycatch mortality of large whales

A long-term data set on entanglements and disentanglements off South Africa showed two centres of entanglement involving humpback or southern right whales, one off the coast of KwaZulu-Natal involving nets set to protect bathers from sharks and the second off the coast of the Western Cape involving traps and attached lines set for rock lobster. Interventions were successful in removing gear from 81% of whales entangled in shark nets off KZN (38 humpback, 17 right whales), while 11 humpback and 2 right whales were found dead. Off the Western Cape, whales were successfully disentangled in 23% of cases (n = 90) and partially disentangled in another 12%. The trend in humpback whale entanglement since 1990 was compatible with the recorded rate of population increase. Entanglement rates of southern right whales apparently increased from 1990 and this could also be attributed to an increase in the population (Meyer *et al.*, 2011).

Entanglement data from the coasts of Newfoundland and Labrador, Canada from 1979 to 2008 included 1,209 large whale entanglements, consisting primarily of humpback whales (80%) and minke whales (15%). Reported entanglements dropped from an average of 64 prior to the

moratorium on cod fisheries in 1992 to 19 afterwards (Benjamins *et al.*, 2011).

The Committee noted the value of the extensive data sets described in these studies and that they contributed to an understanding of the impacts, rates and trends over time in entanglement mortality. Both studies had been able to identify trends over time and relate these to either population size or fishing effort. The Committee **recommends** the continuation (or initiation) of these and similar studies and encourages the presentation of results at future Committee meetings.

7.3 Estimation of risk and rates of entanglement

Recent capacity building on entanglement response, conducted by the IWC working in conjunction with both national and regional authorities in Argentina, stimulated an analysis of entangled southern right whales in the province of Chubut. Of nine confirmed cases of entanglement, five involved moorings and four involved marine debris or fishing gear. Six of these whales were successfully released. Many of the mooring systems contained heavy chain and relatively thick diameter rope, but were still found to entangle whales. Whales were often seen 'playing' with mooring and anchor lines and this behaviour is believed to be a primary mechanism for entanglement in this region.

The primary focus of the second IWC workshop on Welfare Issues Associated with the Entanglement of Large Whales held in 2011 (IWC/64/WKM&AWI Rep1) was on entanglement response and capacity building but several topics from the workshop were also relevant to estimating risk, including the mechanisms by which large whales become entangled. The Committee noted the value of data collected during entanglement responses and welcomed the efforts at the workshop to develop a data form to standardise the data now being collected around the world. The workshop participants had also proposed to form a 'global network of entanglement response teams' and seek the endorsement of the IWC as an expert panel to advise member nations on issues related to large whale entanglement including setting up response networks, methodologies for understanding scope and impact on local populations, and response capacity building. The Committee **supports** the call for the proposed group and a potential database noting that this will assist the work of the Committee. In many cases there are additional data available from entanglement incidents that could supplement the summary data currently requested in National Progress Reports. The IWC could become a repository for such data through a similar effort to the ship strike database.

7.4 Review progress on including information in National Progress Reports

Due to some delays with changing to electronic submission of Progress Reports, these were not reviewed at the meeting. It was noted that, when complete, electronic submission will facilitate linking relevant data to the ship strike database. Suitable links within the submission system could also encourage the entry of data to the ship strike database where more detailed information is available.

7.5 Ship strikes

New information on ship strikes was received for the Arabian Sea region, South Africa and Sri Lanka. A preliminary summary of strandings, lethal entanglements and ship strikes of large whales in the Arabian Sea region, revealed seven documented ship strikes and four lethal entanglements between 2000 and 2012 and included three Arabian Sea humpback whales. The Committee has noted its concern over the status of this population and the increasing shipping traffic in this region (see Item 10.7 for further discussion).

Of 71 recorded mortalities of southern right whales on the South African coast between 1999 and 2010 five bore injuries consistent with a ship strike.

The southern coast of Sri Lanka has one of the busiest shipping routes in the world and overlaps with an area of high whale sightings. Two pygmy blue whales were struck and killed in Sri Lankan waters in early 2012. In the absence of any abundance estimates for the local population, the population impacts of ship strikes are unknown. The Committee **draws attention** to the urgent need for long-term monitoring of the blue whale population in Sri Lankan waters and elsewhere in the northern Indian Ocean. The Committee **recommends** that the Secretariat send a letter to the Sri Lankan Government, drawing their attention to its discussion of this topic and ways in which the Committee may assist.

There is a need to better understand the variables that will affect whether a ship struck whale will strand and predict where death may have occurred. A deterministic model that uses wind archives and outputs of tidal models to predict the drift of floating object has been developed by MétéoFrance. The model can make forward calculations to predict a stranding location or backward calculations to estimate the likely origin of an object. This model had been used to predict whether small cetacean carcasses in the Bay of Biscay would reach the coast (Peltier *et al.*, 2012). It was noted that some carcasses may 'sail' across the wind to variable degrees and a large whale carcass may also 'swim' after death, because of the action of swell on its tail flukes. The Committee **recommends** further study of carcass drift, detection and deterioration for large whales that could be used to establish the location of death from a ship strike or other sources.

A better understanding of the relationship between vessel speed and collision risk is needed to assess risk. A recent study (Wiley *et al.*, 2011) evaluated the relative risk

reduction that might be achieved by speed restrictions. Two studies based on the locations relative to the ship at which humpback whales were observed from cruise ships inferred greater collision risks with increases in speed (Gende *et al.*, 2011; Harris *et al.*, 2012).

A workshop focusing on ship strikes in the Bay of Biscay was held in London in April 2012 (Bull and Smith, 2012). It made a series of recommendations, mainly dealing with mitigation measures but also related to assessing risk. In particular, the workshop considered ways in which a large data set of observations from vessels may be used. The Committee **welcomes** the approach taken by the workshop to engage a wide variety of stakeholders, and noted that the report could also be relevant to work in other regions. The workshop had considered what could be inferred from observations of 'near miss' incidents. The difficulties in defining a 'near miss' have been discussed before and further analyses leading to papers for next year's meeting were encouraged.

A proposal for a workshop of cetacean and shipping experts to agree on appropriate analytical and modeling techniques to assess ship strike risks arose out of the IWC-ACCOBAMS ship strike workshop in 2010 (IWC, 2011c). At the time there was some uncertainty about the availability and content of data on shipping density. Analysis approaches are likely to be most effective on a case by case basis and there are now commercial sources of raw data from Automatic Identification Systems (AIS). The Committee **agrees** that a dedicated workshop is not needed at this stage but **encourages** presentation of papers examining ship strike risks based on overlap of shipping and whale density.

7.6 Continue to develop global database of ship strike incidents

The IWC has been developing a global database of incidents involving collisions between vessels and whales since 2007[*]. A web based data entry system has now been in place for two years but there have been few new reports submitted. Most of the interessional database related efforts were to promote awareness, including work by Mattila who has been seconded to the Secretariat to assist with work on mitigating conflicts between whales and marine resource users. As last year, the Committee **agrees** that a more pro-active approach is needed to encourage data to be entered and it **repeats its recommendation** for the appointment of a dedicated IWC ship strike data coordinator with the tasks described in Annex J Appendix II (and see Item 23). The Committee also **recommends** that the Guide for Authors for the IWC journal should encourage authors of papers containing data on ship strike incidents to report these to the database.

Some members noted concern that ship strikes may increase in the Arctic as shipping begins to utilise increases in navigable waters resulting from reduced sea ice coverage. The Committee **welcomes** the offer to present new information on this issue at its next meeting.

7.7 Other issues

A number of papers concerning impacts of marine debris were considered under Item 12 (and see Annex K). The Committee **encourages** further activities that could help to quantify mortality related to marine debris, noting the difficulty in determining debris from actively fished gear.

7.8 Work plan

The Committees discussions on the sub-committee's workplan (Annex J) are incorporated under Item 21.

8. ABORIGINAL SUBSISTENCE WHALING MANAGEMENT PROCEDURE (AWMP)

This item continues to be discussed as a result of Resolution 1994-4 of the Commission (IWC, 1995a). The report of the SWG on the development of an aboriginal whaling management procedure (AWMP) is given as Annex E. The Committee's deliberations, as reported below, are largely a summary of that Annex, and the interested reader is referred to it for a more detailed discussion. The primary issues at this year's meeting comprised: (1) Implementation Review of eastern gray whales with special emphasis on the PCFG (the Pacific Coast Feeding Group); (2) undertaking an Implementation Review for BCB (Bering-Chukchi-Beaufort Seas) bowhead whales; (3) developing SLAs and providing management advice for Greenlandic hunts; and (4) review of management advice for the humpback whale fishery of St. Vincent and The Grenadines. This represented a significant workload.

8.1 Complete *Implementation Review* of eastern North Pacific gray whales with an emphasis on the PCFG

At the 2010 Annual meeting (IWC, 2011f), the Committee agreed that the information on stock structure and hunting presented, although some of it had not met the Data Availability Guideline requirements (IWC, 2004) for the 2010 review, warranted the development of trials as part of an immediate new *Implementation Review* to evaluate the performance of *SLA*s for hunting in the Pacific Northwest, with a primary focus on the PCFG. It had also agreed that the 2010 *Implementation Review* had shown that the population as a whole was in a healthy state, but that over the next few years, further work should be undertaken to investigate the possibility of structure on the northern feeding grounds, especially in the region of the Chukotkan hunts.

The Committee started the process of the new *Implementation Review* at an intersessional workshop in

[*] www.iwcoffice.org/sci_com/shipstrikes.htm

2011 (IWC, 2012c) and followed that with work at the 2011 Annual Meeting (IWC, 2012g). A second workshop was held in March 2012 kindly hosted by the SWFSC in La Jolla California (SC/64/Rep3). At that Workshop, most of the effort centred on finalising the operating model and trial structure and completing conditioning. The present meeting reviewed progress made at and since the workshop and focussed on finalising the *Implementation Review*. This summary here incorporates work from the intersessional workshops and the present meeting.

8.1.1 Stock structure

The *Implementation Review* considers three geographic regions:

(1) the 'north' area (north of 52°N i.e. roughly northern Vancouver Island);
(2) the PCFG area (between 41°N and 52°N); and
(3) the 'south' area (south of 41°N).

The trials consider two stocks ('PCFG' and 'north'). PCFG whales, which are treated as a separate management unit, are defined as gray whales observed (i.e. photographed) in multiple years between 1 June and 30 November in the PCFG area (IWC, 2011e, p.22). Not all whales seen within the PCFG area at this time will be PCFG whales and some PCFG whales will be found outside the PCFG area at various times during the year. However, this is not problematic since the historical catches north of 52°N occurred well north of 52°N and future catches will either occur in the Bering Sea or in the Makah U&A (Makah Usual and Accustomed Fishing Grounds). The remaining animals ('north') represent the large eastern North Pacific stock (the stock to which the whales taken during the Chukotkan hunt belong).

Several papers addressed stock structure and related issues (e.g. levels of immigration) at both the intersessional workshop (see SC/64/Rep3, item 2.4.2.2) and the present meeting (see Annex E, item 2.2.2). Notwithstanding the difficulties arising out of the complexities of the issue, the Committee was particularly pleased to see efforts to use the IWC's TOSSM framework (IWC, 2007) in SC/M12/AWMP4 and SC/64/AWMP4 (and see Item 11.3). In that context, it was recommended that future TOSSM analyses consider a broader range of parameter choices to explore the robustness of the conclusions to uncertainty. In concluding discussions on this issue, it was agreed that the trials (Table 3) covered a suitably broad range of immigration rates.

8.1.2 Abundance

The Committee reviewed the mark-recapture abundance estimates provided in SC/64/Rep3 and a new paper (SC/64/AWMP10). The agreed abundance estimates from a modified Jolly-Seber approach (**Laake, 2012**) are provided in Table 2 for the OR-SVI region (Oregon to southern Vancouver Island ~42-49ºN) and the NCA-NBC region (northern California to northern British Columbia ~41-52ºN). Given the large bias in the first (1998) estimate, the estimates for this year out of conditioning.

Table 2

Abundance estimates (N) and standard errors in OR-SVI and NCA-NBC after exclusion of known calves from the year in which they were identified as calves.

Region	Year	N	SE(N)	Region	Year	N	SE(N)
OR-SVI	1998	63	4.1	NCA-NBC	1998	101	6.2
	1999	78	8.4		1999	135	12
	2000	89	11.9		2000	141	13.2
	2001	117	8.9		2001	172	12.6
	2002	133	15		2002	189	9.2
	2003	151	13.7		2003	200	16.4
	2004	157	15.5		2004	206	14.9
	2005	162	15.7		2005	206	22.6
	2006	154	15.3		2006	190	18.8
	2007	152	14.5		2007	183	23.1
	2008	150	12.5		2008	191	16.1
	2009	146	14.9		2009	185	23.2
	2010	143	16.8		2010	186	18.7

Abundance estimates for the total eastern North Pacific are those provided by Laake *et al.* (2012); they are given in Annex E, Appendix 2,Table 4a.

8.1.3 Catch data (direct and incidental)

The agreed catch series for the period of the trials (i.e. 1930 onwards) are given in Annex E, Appendix 2, Table 1. Following work at the intersessional workshop and further review by an intersessional group established in SC/64/Rep3, it was agreed that the average annual kills during 2000-09 were 2 for the PCFG (December-May), 1.4 for the PCFG (June- November) and 3.4 for the 'south' (December-May) and this information was used to forecast future incidental catches.

8.1.4 Mixing

Mixing relates to (1) mixing of stocks in the three areas and (2) the relative probability of whaling in the Makah U&A taking a PCFG whale given the number of PCFG and 'north' whales. The latter can be estimated as the proportion of PCFG whales to total whales in photographs during December - May from the outer coast of northern Washington (0.3; SC/64/Rep3). However, there are a number of uncertainties and assumptions surrounding such an analysis resulting in the need for sensitivity tests (i.e. alternative trials spanning a range of values).

8.1.5 Biological parameters and MSYR

Biological parameter values were agreed last year (IWC, 2012j). The priors, based on the 2004 *Implementation,* are given in the trial specifications (Annex E, Appendix 2).

The most likely value for $MSYR_{1+}$ for the north stock was agreed to be 4.5% i.e. the posterior median from the most recent assessment of this stock (Punt and Wade, 2012). The *Evaluation Trials* also consider a value for $MSYR_{1+}$ for the north stock of 2% (rounded lower 90% posterior bound from the Punt-Wade assessment). There are insufficient data to estimate MSYR for the PCFG and so two scenarios are considered for the *Trials* as discussed last year (IWC, 2012j): (a) $MSYR_{1+}$ for the PCFG stock is the same as that for the north stock and there is no immigration (this is unlikely given the data but provides a conservative lower bound), and (b) three values of $MSYR_{1+}$ but with some immigration and emigration.

Table 3
SLA variants suggested by the Makah tribe used in the *Trials*.

Variant Number	PCFG Limit	Struck and Lost Count Toward APL
1	APL Formula	No
2	APL Formula	Yes
3	APL Formula	Yes
4	1	No
5	1	Yes
6	1	Yes
7	2	No
8	2	Yes
9	2	Yes
10	No limit	N/A
11	No limit	N/A

8.1.6 Variants

The management plan proposed by the Makah Tribe is given in Annex D of SC/64/Rep3 and a number of alternative *SLA*s were proposed for analysis in SC/64/Rep3 as given in Table 3. These variants explore:

(1) how the allowable bycatch of PCFG whales level[10] (APL) of PCFG whales is calculated (three options);
(2) the time of year in which the hunt is modelled to occur and hence whether struck and lost animals are counted against the APL (two options); and
(3) the effectiveness of the *SLA* if only PCFG whales are available for harvest (i.e. in effect a summer hunt).

Variants 1-3 use the APL[11] formula presented in the proposed plan, variants 4-9 have fixed bycatch limits, and variants 10 and 11 explore the impact of not having a limit on bycatch of PCFG whales (i.e. the hunt is only stopped if the total *Strike Limit* is reached, or the number of struck-and-lost animals reaches its limit, or the landing limit is reached).

Table 4
Details of factors considered in trials

Factors	Other Levels (Reference levels shown bold)
$MSYR_{1+}$ (north)	**2%**, **4.5%**
$MSYR_{1+}$ (PCFG)	**1%**, **2%**, **4.5%**
Immigration rate (annual)	**0, 1, 2**, 4, 6
Pulse immigration (1999/2000)	**0**, 10, **20**, 30
Proportion of PCFG whales in PCFG area, ϕ_{fut}	0, **0.3**, 0.6, 1
Struck and lost rate (PCFG area)	0, **50%,** 75%
Northern need in final year (linear change from 150 in 2010)	**340**, 530
Historic survey bias	**None,** Increasing between 1967 to 2002 from 0.5→1 (North only), 50% (PCFG only)
Future episodic events	**None,** 3 events occur between yrs 1-75 (at least 2 in yrs 1-50) in which 20% of the animals die, Events occur every 5 years in which 10% of the animals die
Time dependence in *K*	**Constant**, Halve linearly over 100yr, Double linear over 100yr
Time dependence in natural mortality, *M* *	**Constant,** Double linearly over 100yr
Parameter correlations	Yes, **No**
Probability of mismatching north whales, p_2	0, **0.01**, 0.01-0.05
Probability of mismatching PCFG whales, p_1	**0**, 0.5
Frequency of PCFG surveys	**Annual**, 6-year
Incidental catch	**Reference**, double reference, half reference
Future sex ratio	**0.5:0.5**, 0.2:0.8 (M:F)
Episodic events with future pulse events	**None,** 3 events occur between yrs 1-75 (with at least 2 in yrs 1-50) in which 20% of the north stock die and a pulse of 20 animals is added to the PCFG stock

8.1.7 Final trials and conditioning

The final trial structure was agreed in SC/64/Rep3. A summary of the factors considered in the trials is given as Table 4. The *Evaluation Trials* agreed are shown in Table 5 and the *Robustness Trials* are shown in Table 6. These trials were finalised at the March 2012 workshop (SC/64/Rep3). Conditioning the trials[12] began at the workshop and was evaluated after the meeting by an intersessional steering group (SC/64/AWMP11). Only three trials, B02C, I02C and P05A were eliminated after considering the conditioning results, leaving 72 *Evaluation Trials* in all.

[10] The Makah Tribe has proposed a hunt management plan with time and area restrictions to target migrating ENP whales, yet there is still a chance that PCFG whales are incidentally harpooned as bycatch to the targeted ENP gray whale hunt.
[11] The APL formula is provided in Annex E Appendix 2.
[12] Conditioning is the process of selecting the values for the parameters of the operating model such that the predictions from this model are consistent with the available data.

Table 5

The *Evaluation Trials*. Values given in bold type show differences from the base case trial. The final three columns indicate which trials apply to which 'broad' hypotheses (P=pulse, B=bias, I=intermediate – see IWC, 2012). For 'broad' hypotheses B and I, the number given is the pulse in 1999/2000. Unless specified otherwise $\phi_{PCFG} = 0.3$, the struck and lost rate is 0.5, and there are no stochastic dynamics or episodic events. *Trials B02C, I02C and P05A removed after reviewing condition results – see text.

Trial	Need to condition	Description	$MSYR_{1+}$ North	$MSYR_{1+}$ PCFG	Final Need	Annual Immigration	Survey freq.	Survey Bias (North)	Hypothesis P	Hypothesis B	Hypothesis I
1A	Y	$MSYR_{1+}$ = 4.5%/4.5%	4.5%	4.5%	340 / 7	2	10 / 1	1	20	Y	10
1B	Y	$MSYR_{1+}$ = 4.5%/2%	4.5%	2%	340 / 7	2	10 / 1	1	20	Y	10
1C	Y	$MSYR_{1+}$ = 4.5%/1%	**4.5%**	**1%**	340 / 7	2	10 / 1	1	20	Y	10
1D	Y	$MSYR_{1+}$ = 2%/2%	**2%**	**2%**	340 / 7	2	10 / 1	**0.5→1**	20	Y	10
2A	Y	Immigration = 0	4.5%	4.5%	340 / 7	**0**	10 / 1	1	20	Y	10
2B	Y	Immigration = 0	4.5%	2%	340 / 7	**0**	10 / 1	1	20	Y	10
2C	Y*	Immigration = 0	**4.5%**	**1%**	340 / 7	**0**	10 / 1	1	20	Y	10
2D	Y	Immigration = 0	**2%**	**2%**	340 / 7	**0**	10 / 1	**0.5→1**	20	Y	10
3A	Y	Immigration = 1	4.5%	4.5%	340 / 7	**1**	10 / 1	1	20	Y	10
3B	Y	Immigration = 1	4.5%	2%	340 / 7	**1**	10 / 1	1	20	Y	10
4A	Y	Immigration = 4	4.5%	4.5%	340 / 7	**4**	10 / 1	1	20	Y	10
4B	Y	Immigration = 4	4.5%	2%	340 / 7	**4**	10 / 1	1	20	Y	10
5A	Y*	Immigration = 6	4.5%	4.5%	340 / 7	**6**	10 / 1	1	20	Y	10
5B	Y	Immigration = 6	4.5%	2%	340 / 7	**6**	10 / 1	1	20	Y	10
6A		High Northern Need	4.5%	4.5%	**530 / 7**	2	10 / 1	1	20	Y	
6B		High Northern Need	4.5%	2%	**530 / 7**	2	10 / 1	1	20	Y	
7A		3 episodic events	4.5%	4.5%	340 / 7	2	10 / 1	1	20	Y	
7B		3 episodic events	4.5%	2%	340 / 7	2	10 / 1	1	20	Y	
8A		Stochastic events 10% every 5 years	4.5%	4.5%	340 / 7	2	10 / 1	1	20	Y	
8B		Stochastic events 10% every 5 years	4.5%	2%	340 / 7	2	10 / 1	1	20	Y	
9A		Episodic events with future pulse events	4.5%	4.5%	340 / 7	2	10 / 1	1	20	Y	
9B		Episodic events with future pulse events	4.5%	2%	340 / 7	2	10 / 1	1	20	Y	
10A		Relative probability of harvesting a PCFG whale, $\phi_{PCFG} = 0.6$	4.5%	4.5%	340 / 7	2	10 / 1	1	20	Y	
10B		Relative probability of harvesting a PCFG whale, $\phi_{PCFG} = 0.6$	4.5%	2%	340 / 7	2	10 / 1	1	20	Y	
11A		Struck & Lost (25%)	4.5%	4.5%	340 / 7	2	10 / 1	1	20	Y	
11B		Struck & Lost (25%)	4.5%	2%	340 / 7	2	10 / 1	1	20	Y	
12A		Struck & Lost (75%)	4.5%	4.5%	340 / 7	2	10 / 1	1	20	Y	
12B		Struck & Lost (75%)	4.5%	2%	340 / 7	2	10 / 1	1	20	Y	
13A	Y	Higher 1999-2000 Pulse	4.5%	4.5%	340 / 7	2	10 / 1	1	**30**		
13B	Y	Higher 1999-2000 Pulse	4.5%	2%	340 / 7	2	10 / 1	1	**30**		
13C	Y	Higher 1999-2000 Pulse	**4.5%**	**1%**	340 / 7	2	10 / 1	1	**30**		
14A	Y	Lower 1999-2000 Pulse	4.5%	4.5%	340 / 7	2	10 / 1	1	**10**		
14B	Y	Lower 1999-2000 Pulse	4.5%	2%	340 / 7	2	10 / 1	1	**10**		

8.1.8 Review results of trials

Evaluation of *SLA*s is based on the objectives accepted by the Commission (IWC, 1983; 1995a) which are to:

(a) ensure that the risks of extinction to individual stocks are not seriously increased by subsistence whaling;
(b) enable aboriginal people to harvest whales in perpetuity at levels appropriate to their cultural and nutritional requirements, subject to the other objectives; and
(c) maintain the status of stocks at or above the level giving the highest net recruitment and to ensure that stocks below that level are moved towards it, so far as the environment permits.

Highest priority is accorded to the objective of ensuring that the risk of extinction to individual stocks is not seriously increased by subsistence whaling.

As their name implies, *Evaluation Trials* are used to examine the performance of the variant *SLA*s against the Commission's objectives. *Robustness Trials* are more extreme trials that are primarily to ensure whether an *SLA* performs as expected in such cases.

Table 6
The *Robustness Trials*.

Trial	Need to Condition	Description	$MSYR_{1+}$ North	$MSYR_{1+}$ PCFG	Survey freq.	Hypothesis P	Hypothesis B
1A		6 year surveys	4.5%	4.5%	10 / 6	20	Y
1B		6 year surveys	4.5%	2%	10 / 6	20	Y
2A		Linear decrease in K^{1+} [K halves over years 0-99]	4.5%	4.5%	10 / 1	20	Y
2B		Linear decrease in K^{1+} [K halves over years 0-99]	4.5%	2%	10 / 1	20	Y
3A		Linear decrease in PCFG K [K halves over years 0-99]	4.5%	4.5%	10 / 1	20	Y
3B		Linear decrease in PCFG K [K halves over years 0-99]	4.5%	2%	10 / 1	20	Y
4A		Linear increase in M [M halves over years 0-99]	4.5%	4.5%	10 / 1	20	Y
4B		Linear increase in M [M halves over years 0-99]	4.5%	2%	10 / 1	20	Y
5A		Linear increase in PCFG M [M halves over years 0-99]	4.5%	4.5%	10 / 1	20	Y
5B		Linear increase in PCFG M [M halves over years 0-99]	4.5%	2%	10 / 1	20	Y
6A		Perfect detection; p_1 =0; p_2=0.01-0.05	4.5%	4.5%	10 / 1	20	Y
6B		Perfect detection; p_1 =0; p_2=0.01-0.05	4.5%	2%	10 / 1	20	Y
7A		p_1 = 0.5	4.5%	4.5%	10 / 1	20	Y
7B		p_1 = 0.5	4.5%	2%	10 / 1	20	Y
8B	Y	Survey bias PCFG + p_1 = 0.5	4.5%	2%	10 / 1	20	Y
9B	Y	Correlation (draw for N; same quantile in the range for PCFG)	4.5%	2%	10 / 1	20	Y
10B	Y	Double incidental catches	4.5%	2%	10 / 1	20	Y
11B	Y	Halve incidental catches	4.5%	2%	10 / 1	20	Y
12A		Sex ratio = 0.2: 0.8	4.5%	4.5%	10 / 1	20	Y
12B		Sex ratio = 0.2: 0.8	4.5%	2%	10 / 1	20	Y
13A		Relative probability of harvesting a PCFG whale, ϕ_{PCFG} = 1	4.5%	4.5%	10 / 1	20	Y
13B		Relative probability of harvesting a PCFG whale, ϕ_{PCFG} = 1	4.5%	2%	10 / 1	20	Y

Table 7.
Final depletion and rescaled final depletion statistics for *SLA*s 1 and 2 for the trials with $MSYR_{1+}$=1% and the trials with $MSYR_{1+}$=2% for which conservation performance might be considered to be questionable.

Trial	SLA variant 1				SLA variant 2			
	Final Depletion		Rescaled Final Depletion		Final Depletion		Rescaled Final Depletion	
	Low 5%	Median	Low 5%	Median	Low 5%	Median	Low 5%	Median
$MSYR_{1+}$=1%								
GB01C	0.259	0.343	0.314	0.383	0.290	0.365	0.352	0.414
GP01C	0.382	0.461	0.400	0.472	0.438	0.515	0.460	0.528
GP02C	0.231	0.272	0.255	0.295	0.299	0.347	0.334	0.372
GI01C	0.378	0.446	0.399	0.459	0.434	0.497	0.457	0.513
$MSYR_{1+}$=2%								
GB08B	0.357	0.458	0.505	0.594	0.396	0.504	0.560	0.656
GB10B	0.492	0.556	0.492	0.557	0.575	0.633	0.576	0.635
GP08B	0.330	0.442	0.475	0.578	0.364	0.482	0.528	0.635
GP10B	0.475	0.536	0.476	0.538	0.556	0.619	0.557	0.621

The results of all of the trials, expressed in tabular and graphical form (see examples in Annex D, Appendices 3-5) for all agreed performance statistics (conservation and need related) are available from the Secretariat.

The SWG (Annex E, Item 2.5.1) screened the trials for conservation performance to focus on those that required more detailed examination. The criteria used were:

(1) The lower 5%ile of the final depletion distribution < than 0.6 (the MSYL level) and the lower 5%ile of the rescaled final depletion is lower than 0.6 for any of variants 1-10.
(2) The trial involved episodic events.
(3) The lower 5%ile of the trend in 1+ population size indicated a decline in population size of 5% or larger over the final 20 years of the 100-year projection period for any of variants 1-10.

After this initial evaluation a number of features became apparent (see Annex E, Items 2.5.1 and 2.5.2)), primarily related to conservation performance (apart from variant 5 which had poor need satisfaction) that led the Committee to eliminate further consideration of all but variants 1 and 2.

8.1.9 Conclusions and selection of SLAs

In order to minimise the risk of taking PCFG whales, the management plan developed by the Makah Tribe restricts the hunt both temporally (to the migratory season for gray whales i.e. 1 December – 31 May) and geographically (to the Pacific Ocean region i.e. the Makah U&A except the Strait of Juan de Fuca). Some PCFG whales are present during the migratory season and thus the plan proposes an allowable PCFG limit (APL) during hunts that are targeting eastern North Pacific migrating whales with the aim of ensuring that accidental takes of PCFG whales do not deplete the PCFG. Whales struck in May might have a higher probability of being PCFG whales since they feed in this area in June. The management plan thus proposes an additional requirement that all animals struck-and-lost in May are assumed to be PCFG whales (i.e. count against the APL), whereas whales struck between December and April are not.

Weather conditions and availability of whales makes it likely that most hunting will occur in May. However, there are insufficient data to assess the number of strikes by month. Thus, it is not possible to reliably estimate the proportion of struck-and-lost whales that would count towards the APL. Given this uncertainty about how the plan would respond to failing to take into account struck-and-lost PCFG whales, the Tribe had proposed two *SLA* variants (1 and 2) spanning the options as to when the hunt might occur.

SLA variant 1 proposes that struck-and-lost whales do not count towards the APL i.e., there is no management response to PCFG whales struck but not landed. *SLA* variant 2 proposes that all struck-and-lost whales count to the APL irrespective of hunting month. i.e., the number of whales counted towards the APL may exceed the actual number of PCFG whales struck. A number of other *SLA* variants were proposed by the Tribe to explore additional management options. However, none of the variants precisely mimicked the final management plan proposed.

The *Trial* results revealed:

(1) *SLA* variants 1 and 2 were potentially satisfactory and performed well in nearly all 72 *Evaluation Trials*;
(2) *SLA* variants 1 and 2 performed acceptably for all *Robustness Trials*.

Given this, the Committee focussed on those few trials for which conservation performance required further consideration. Trials with 1% $MSYR_{1+}$ are the most challenging and the conservation performance for some of these trials for both variants was not satisfactory (see Table 7). However, given the available information for the eastern North Pacific population as a whole (the observed recovery rate from severe historical depletion, as well as the current recovery rate from the 1999/2000 mortality event), the most recent assessment (Punt and Wade, 2012) resulted in an estimated MSYR rate of 4.6% [90% posterior interval 2.2%, 6.4%]. Therefore, the $MSYR_{1+}$=1% trials are at the lower bounds of plausibility and the Committee **agrees** that the conservation performance for these trials alone was not reason to preclude the conclusion that both variants have overall satisfactory conservation performance.

The Committee then focussed on certain trials within the 2% $MSYR_{1+}$ set for which conservation performance might be considered questionable. Trial 8b (pulse and bias) involved 10% declines in abundance every five years as a proxy for random biological, environmental or anthropogenic events (e.g. disease or contamination). As noted in Annex E, Item 2.5.1, these trials are in effect trials with lower $MSYR_{1+}$ than the nominal 2% of the trial. Given this, it **agrees** that both variants 1 and 2 had acceptable performance for these two trials.

Trial 10b (pulse and bias) involves an assumption that the relative probability of harvesting PCFG whales in the Makah U&A is double the observed ratio of PCFG whales to migrating whales observed in the available photo-identification studies. The conservation performance of *SLA* variant 2 was considered acceptable for this trial but that for variant 1 was considered marginal (Table 7). In discussing the results of this trial, the Committee noted that the ratio of PCFG whales to migrating whales could be monitored directly from data collected during the hunting period allowing this assumption to be evaluated.

In conclusion, the Committee **agrees**:

(1) *SLA* variant 2 performed acceptably and met the Commission's conservation objectives for conservation while allowing limited hunting;
(2) *SLA* variant 1 performed acceptably for nearly all the trials and could be considered to meet the Commission's conservation objectives provided that it is accompanied by a photo-identification programme to monitor the relative probability of harvesting PCFG whales in the Makah U&A , and the results presented to the Scientific Committee for evaluation each year.

The Committee **endorses** these conclusions and commends them to the Commission. It also **agrees** that the *Implementation Review* is completed. Management advice is discussed under item 9.2.3.

However, the Committee noted that the *SLA* variants tested did not correspond exactly to the management plan proposed by the Makah to the IWC. The Committee **agrees** to test such a variant intersessionally and examine the results at the next Annual Meeting.

8.1.10 Other business

Spatial mixing between eastern and western North Pacific gray whale stocks along the Pacific coast of North America outside the feeding season raises issues about the population structure within the Sakhalin feeding area (see SC/64/BRG 10 and IWC, 2012). The broad issue of stock structure of North Pacific gray whales is being addressed through a basinwide research programme (see item 10.4). However, as noted last year, this finding raises concern about the possibility of whales feeding in the Western North Pacific being taken during the proposed Makah Tribe hunt in northern Washington.

Last year (IWC, 2012f p.16) the Committee had stressed three points.

(1) The new information on movements of gray whales highlighted the importance of further clarification of the stock structure of North Pacific gray whales. In particular, the matches of animals from the Sakhalin feeding grounds with animals seen in the PCFG area and other areas along the west coast emphasised the need for efforts to estimate the probability of a western gray whale being taken in aboriginal hunts for Pacific gray whales (noting that this did not require incorporation of western gray whales into the *Implementation Review).*
(2) It had strongly endorsed the basinwide research programme, noting that the results of the research may require further trials for future *SLA* testing; this would be a matter for consideration at the next *Implementation Review* if not before.
(3) The Committee will continue to monitor the situation and was willing to respond to any guidance or requests for further information from the Commission.

SC/64/BRG9 provided an initial modelling approach to address point (1) above. It was discussed extensively in Annex E, Item 2.6 and although welcoming this work, a number of questions were raised and further work identified before any conclusions could be agreed. The Committee **recommends** that a revised document be developed for further review at next year's meeting, noting its potential importance for the provision of management advice. An Advisory Group (Annex Q) was appointed to provide guidance to the authors of SC/64/BRG9.

8.2 Complete *Implementation Review* of Bering-Chuckchi-Beaufort Seas bowhead whales

The procedure and purpose of *Implementation Review*s for aboriginal whaling *SLA*s is summarised under Item 8.4. The Committee's task is to assess whether there is any new information that would suggest that the range of trials used to evaluate the *Bowhead SLA* is no longer sufficient to ensure that the *SLA* meets the Commission's conservation and user objectives.

8.2.1 Consideration of new information with a focus on whether this implies a need for new trials

A number of papers were submitted presenting new information on a variety of scientific matters relevant to *Implementation Review*. Full discussion of these papers is given in Annex E Item 3. The summary of discussions in the following sections is somewhat brief as it only focusses on the SWG's deliberations as to whether additional trials are required.

8.2.1.1 STOCK STRUCTURE

Four papers were relevant to stock structure issues.

SC/64/BRG1 reported on a satellite telemetry study of 57 BCB bowhead whales tagged during 2006–2011. The Committee commended the authors for providing relevant data on bowhead migration patterns, and recognised the cooperation of native hunters who were closely involved in all aspects of this study and deployed most of the tags. It **recommends** that such tagging and telemetry efforts continue.

SC/64/AWMP3 compared the use of SNPs and microsatellites for studying population structure, assignment and demographic analyses of bowhead whale populations in the Sea of Okhotsk, BCB and eastern Canada, SC/64/AWMP9 presented sequences from 3 mtDNA genes from 350 bowhead whales from the BCB, eastern Canadian Arctic and the Sea of Okhotsk and discussed methods to calculate gene and site specific mutation rates, while SC/64/AWMP1 investigated the demographic history the BCB

population of bowhead whales using a variety of analytical methods.

The Committee thanked the authors and **agrees** that the information in these papers provide no evidence to suggest that the trials evaluated during the previous *Implementation Review* (IWC, 2007b; 2008a; 2008d; 2008g) did not adequately address stock structure concerns.

8.2.1.2 ABUNDANCE AND RATE OF INCREASE

A new agreed abundance estimate is not required for completion of the BCB bowhead *Implementation Review*. When a new estimate becomes available it can be incorporated into the *Bowhead SLA* calculations to provide management advice.

SC/64/AWMP5 incorporates the 1985 and 2004 abundance estimates from aerial photography by Schweder *et al.* (2010) into the ice-based survey estimates to obtain an updated ROI for 1978-2004 (Fig. 1). The Committee **endorses** this estimate (3.5% with 95% CI of (2.2%, 4.8%)) as the best available estimate of annual rate of increase for the BCB bowhead population. It also **agrees** that the best estimate of current abundance is 12,631 (95% bootstrap percentile CI 7,900 -19,700; 5% lower limit 8,400) for 2004 (Schweder *et al.*, 2010).

The Committee was pleased to receive information from recent ice-based surveys (2011) that count whales migrating past Barrow, Alaska (SC/64/AWMP7). Full discussion of these surveys will occur in conjunction with the presentation of new abundance estimates within the next two years.

SC/64/BRG4 presented estimates of visual detection probabilities from the spring 2011 ice-based survey of bowhead whales migrating near Barrow, Alaska. The same methods will also be applied to similar data from the 2010 survey. These estimates are highly relevant since they constitute one foundation upon which a future population abundance estimate will be calculated from the 2011 survey counts. This abundance estimate will then be used as input to the *Bowhead SLA*. The authors intend to estimate 2011 abundance using detection probability estimates based only on the new independent observer data. The Committee **endorses** this approach, while also recognising that any possible implications of the shift to the superior IO method might merit future consideration in the context of long term trends. It **encourages** Committee members interested in abundance estimation to contact the authors of SC/64/BRG4 intersessionally with comments and suggestions so that the future abundance estimate for use in the *Bowhead SLA* can be based on an approved estimate of detection probabilities.

SC/64/BRG3 described an aerial photographic survey for BCB bowheads conducted from 19 April to 6 June, 2011. The field season was very successful, both in terms of total flight days and the very large number of whale images (approximately 6,800) obtained. These photographs are a significant contribution to the bowhead whale photographic catalogue. The Committee recognised the importance of this work as potentially providing an estimate of population abundance for use with the *Bowhead SLA* that is entirely independent of the ice-based survey estimate described in SC/64/BRG4. Analyses of the photo-id data may also provide better precision in estimates of bowhead whale life-history parameters such as adult survival rate. A detailed discussion of this paper is provided in Annex F.

8.2.1.3 CATCH DATA

SC/64/AWMP8 provides a preliminary summary of subsistence harvest of bowhead whales in Alaska from 1974 to 2011. Further discussion of the paper can be found in Annexes E and F. The Committee welcomes this information and noted that strikes have remained within the need envelope tested during development of the *Bowhead SLA*. It therefore **agrees** that no additional trials are warranted in this regard.

8.2.2 Discussion of new trials

In consideration of the evidence described above, the Committee **agrees** that there is no need for new trials or further simulation testing of the *Bowhead SLA*.

8.2.3 Conclusions and recommendations

The Committee thanked US scientists, the North Slope Borough, Alaska, and the native communities for continuing to provide a considerable body of high-quality scientific work which facilitated the SWG's *Implementation Review* process. The Committee **agrees** that the *Bowhead SLA* continues to be the most appropriate way for the Committee to provide management advice for the BCB population of bowhead whales. This completes the *Implementation Review* for the BCB bowhead whales. Management advice itself is provided under item 9.3.2.

8.3 Continue work on developing SLAs for the Greenlandic hunts (Annex E, Item 4)

In Greenland, a multispecies hunt occurs and the expressed need for Greenland is for 670 tonnes of edible products from large whales for West Greenland; this involves catches of common minke, fin, humpback and bowhead whales. The flexibility among species is important to the hunters and satisfying subsistence need to the extent possible is an important component of management for the hunters. For a number of reasons, primarily related to stock structure issues, development of *SLA*s for Greenland aboriginal hunts (especially for common minke and fin whales) will be more complex than previous *Implementations* for stocks subject to aboriginal subsistence whaling. The Committee has endorsed an interim safe approach to setting catch limits for the Greenland hunts in 2008 (IWC, 2009c), noting that this should be considered valid for two

blocks i.e. the target will be for agreed and validated *SLA*s, at least by species, for the 2017 Annual Meeting (assuming that the Commission sets 5-year block quotas in 2012 as scheduled).

The Committee noted the benefits in previous *CLA* and *SLA* developments of a co-operative competition amongst more than one developer. Several members of the SWG indicated that they may be interested in proposing *SLA*s. The Committee noted the multi-species nature of the Greenland hunts and Greenland's desire for flexibility amongst species in meeting its subsistence needs. It **reiterates** that its approach will first be to develop *SLA*s for individual species before considering whether and how to address multispecies considerations (e.g. IWC, 2010a; IWC, 2011i).

In response to a request made at the intersessional workshop (SC/64/Rep3), the Committee was pleased to receive four papers by Witting (SC/64/AWMP12-15) that summarised the available information on common minke whales, fin whales, humpback whales and bowhead whales off Greenland in the context of developing *SLA*s (summarised in Annex E, Appendix 6). In order to progress essential *SLA* development work, the Committee **agrees** that an intersessional workshop (to be held in winter 2013, probably in Copenhagen) was essential to maintain progress. As in previous years, the Committee also recommends maintenance of the AWMP Developer's Fund. Financial matters are discussed further under Item 23.

8.3.1 Common minke whales

The Committee notes that the SWG on the AWMP and the sub-committee on the RMP both have interest in North Atlantic common minke whales. It **endorses** the planned co-operative and collaborative process (Annex D, Appendix 6) developed that will culminate in a joint workshop on the stock structure of this species in the North Atlantic in early 2014. This is planned to inform the RMP *Implementation Review* process for common minke whales in the North Atlantic scheduled for 2014 as well as the *SLA* development process. The operating models developed for the RMP *Implementation* (perhaps with minor adjustment to take account of focus on different populations) will also serve as the basis for the *SLA* development process. The Committee also notes that aspects of the work to be undertaken by Punt described in Annex E Appendix 7 will assist developers of candidate *SLA*s for the Greenlandic hunts for common minke whales.

8.3.2 Fin whales

The Committee notes that the SWG on the AWMP and the sub-committee on the RMP both have interest in North Atlantic fin whales. A pre-meeting for a North Atlantic fin whale RMP *Implementation Review* is scheduled before the 2013 Scientific Committee meeting. The stock structure discussions at this meeting will provide useful input to the fin whale *SLA* development process. The operating models developed for the RMP *Implementation* (perhaps with minor adjustment to take account of focus on different populations) can also serve as the basis for the *SLA* development process. The Committee notes that aspects of the work to be undertaken by Punt described in Annex E Appendix 7 will also assist developers of candidate *SLA*s for the Greenlandic hunts for fin whales.

8.3.3 Humpback whales and bowhead whales

Development of *SLA*s for these hunts is relatively simple compared to the common minke whale and fin whale cases. The Committee **agrees** that it should be possible to develop an appropriate trial structures and operating models for the humpback and bowhead whale hunts before the next Annual Meeting to enable potential *SLA*s to be evaluated in the future. It **endorses** the proposal outlined in Annex E Appendix 7 to support this work.

8.4 Guidelines for *Implementation* Reviews

An integral part of the AWMP process is the undertaking of regular or 'special' *Implementation Reviews*, as noted for example during the development process of the *Bowhead Whale SLA* (IWC, 2003b).

The first BCB bowhead whale *Implementation Review* took place over two years and was completed in 2007 with most focus being on the issue of stock structure (IWC, 2007b; 2008a; 2008d; 2008g). No changes needed to be made to the *Bowhead SLA* after the review. The first *Implementation Review* for gray whales was completed in 2010 and the *Gray Whale SLA* was not changed with respect to providing advice on the Russian hunt off Chukotka (IWC, 2011f). However, as discussed above, during that review, information was received that led to the need to call for an immediate *Implementation Review* before providing advice for a potential hunt of gray whales by the Makah tribe on the west coast of the USA. That review is now complete (see item 8.1)

The Committee had agreed that it would be useful to develop guidelines for *Implementation Reviews*, given the experience gained thus far. The proposed guidelines are provided in Annex E, Appendix 8 and cover the following issues: (1) Objectives; (2) Timing of regular and special *Implementation Reviews*; (3) Outcomes; (4) Data Availability; (5) Computer programs.

The Committee **adopts** these guidelines.

8.5 Scientific aspects of an aboriginal whaling scheme (AWS)

In 2002, the Committee strongly recommended that the Commission adopt the Aboriginal Subsistence Whaling Scheme (IWC, 2003a). This covers a number of practical issues such as survey intervals, carryover, and guidelines for surveys. The Committee has stated in the past that the AWS provisions constitute an important

and necessary component of safe management under AWMP *SLA*s and it **reaffirms** this view. It noted that discussions within the Commission of some aspects such as the 'grace period' are not yet complete.

8.6. Conversion factors for edible products for Greenland hunts

In 2009, the Commission appointed a small working group (comprising several Committee members) to visit Greenland and compile a report on the conversion factors used by species to translate the Greenlandic need request which is provided in tonnes of edible products to numbers of animals (IWC/62/9). At that time the group provided conversion factors based upon the best available data, noting that given the low sample sizes, the values for species other than common minke whales should be considered provisional. The group also recommended that a focused attempt to collect new data on edible products taken from species other than common minke whales be undertaken, to allow a review of the interim factors; and that data on both 'curved' and 'standard' measurements are obtained during the coming season for all species taken.

Last year the Committee had welcomed an initial report, recognising the logistical difficulty of collecting these kinds of data. However, it had noted that considerably more detail was needed, and requested that a detailed report be presented for consideration at the present meeting.

This year, a further report was received from the Greenlandic authorities that provided information on the data collected thus far (Annex E, Appendix 9).

The Committee **welcomes** this report and the provision of data. A comparison of these values and the Recommended Conversion Factors Per Animal (RCPFA) from IWC/62/9 showed reasonable agreement for humpback and bowhead whales (within 1 SD), but the yield for fin whales was lower than expected. It was not possible to examine this difference *inter alia* because no lengths of the animals included in the analysis were provided.

Although welcoming the report, the Committee expressed some concerns over the insufficient level of detail provided, some inconsistencies within the report, the efficiency of the sampling regime (relatively poor sample sizes) and the extrapolation procedure in which only one meat tote or bin is weighed.

In response to the concern over the lack of samples, it was noted that the Greenland Institute of Natural Resources (GINR) has been asked to investigate this and is working with the hunters and authorities to improve the sample size in the future. The Committee greatly **encourages** this and looks forward to a report on progress made. It also **encourages** the GINR to develop improved protocols including weighing as many of the meat, mattak, and qiporaq bins as possible.

Providing a breakdown of products from bowheads would be valuable both for conversion factors and biological information.

Given these concerns, the Committee **reiterates** its recommendations from 2011 and 2011:

(1) the provision of a full scientific paper to the next annual meeting that details *inter alia* at least a full description of the field protocols and sampling strategy (taking into account previous suggestions by the Committee); analytical methods; and a presentation of the results thus far, including information on the sex and length of each of the animals for which weight data are available;

(2) the collection and provision of data on Recommendation No. 2 of IWC/62/9 comparing standard vs curvilinear whale lengths. This should be done for all three species on as many whales as possible. Guidelines and protocols are suggested in IWC/62/9.

8.7 Workplan

The Committees views on the workplan developed by the SWG on the AWMP are given under Item 21.

9. ABORIGINAL SUBSISTENCE WHALING MANAGEMENT ADVICE

The Commission is considering a change from annual to biennial meetings. This has raised the issue within two Commission working groups as to whether there are any scientific implications for the Commission moving to setting block quotas for an even number of years rather than the present five-year intervals. This issue was addressed at the intersessional AWMP workshop (SC/64/Rep3) and that report is endorsed by the Committee and the conclusions incorporated below

The Committee recalled that trials for the B-C-B bowhead and Eastern North Pacific gray whale *SLA*s had shown satisfactory performance for surveys at intervals of 10 years (and even for some *Robustness Trials* for 15 years). The Committee **agrees** that there are no scientific reasons for the Commission not to set catch limits for blocks of even numbers of years up to 8-years for these stocks. However, it draws attention to its discussions of the AWS where it noted that despite the trial results it would not be appropriate for catches to be left unchanged if new abundance estimates were not available after 10 years (IWC, 2004).

The Committee notes that it does not require changing its regular process of *Implementation Reviews* approximately every five years (with the provision for 'special' reviews should circumstances arise) or an annual examination of new information and provision of advice if requested.

The Committee also notes that the interim safe *SLA* for the Greenland hunts (see Items 9.1 and Items 9.4 – 9.6 below) had also been tested for surveys at 10-year intervals and shown satisfactory performance and had been adopted by the Commission in 2008 (IWC, 2009a). However, as noted at the time, those tests had been for a restricted number of scenarios than the wider range of hypotheses customarily considered for such trials. It had thus been agreed that this *SLA* was appropriate for the provision of advice for up to two blocks or approximately 2018. The Committee **agrees** that there are no scientific reasons why the next quota block for the Greenland hunts could not be for a 6-year period, noting that the long-term *SLA*s will be available for implementation for the following block quota.

9.1 Eastern Canada and West Greenland bowhead whales

9.1.1 Review new information on Eastern Canada and West Greenland bowhead whales

Discussion within the Committee in recent years has focussed on stock structure and associated abundance estimates. The present working hypothesis is that bowhead whales in eastern Canada - West Greenland comprise a single stock; the alternative hypothesis assumes two stocks: one in Hudson Bay - Foxe Basin and another in Baffin Bay - Davis Strait. However, the Committee agreed on the need for further genetic analyses last year (IWC, 2012k), recognising the complications arising out of the fact that existing data pertinent to the question of stock structure are held by a non-member nation, Canada.

The Committee was pleased to receive several papers on Eastern Canada and West Greenland bowhead whales and details can be found in Annex F Item 2.2.

Alter *et al.* (in press) presented a study on genetic diversity and differentiation across all five putative stocks of bowhead whales, including Baffin Bay-Davis Strait (BBDS), Hudson Bay-Foxe Basin (HBFB), Bering-Beaufort-Chukchi, Okhotsk, and Spitsbergen. Ancient specimens (500-800 years old) from Prince Regent Inlet (PRI) in the Canadian Arctic were also compared with modern stocks. Results show low differentiation between Atlantic and Pacific, consistent with high gene flow between these areas in the recent past. No difference was observed between the two putative/hypothesized Canada-Greenland populations (HBFB/BBDS), which differ from previous results with more samples and a longer fragment of mtDNA. Significant genetic differences between ancient and modern populations were observed, which suggests that PRI harbored unique maternal lineages in the past that have been recently lost, possibly due to loss of habitat during the Little Ice Age and/or whaling. Unexpectedly, samples from this location show a closer genetic relationship with modern Pacific stocks than Atlantic, supporting high gene flow between the central Canadian Arctic and Beaufort Sea over the past millennium despite extremely heavy ice cover over much of this period.

The Committee **welcomes** this work, and noted that this type of collaborative effort across research groups is valuable in advancing the understanding of bowhead whale stock structure.

Spatial overlap of the extreme summer range of bowhead whales was identified from the eastern and western Arctic in the Canadian High Arctic (Heide-Jorgensen *et al.*, 2011). In the summer of 2010, one satellite tagged bowhead whale from West Greenland and one from Alaska entered the Northwest Passage from opposite directions and spent approximately 10 days in the same area but not at the same time.

Wiig *et al.* (2011b) updated on an abundance estimate for bowhead whales in the Disco Bay area of West Greenland. The study employed multi-locus genotype and sex to identify individual bowhead whales at 4 localities in eastern Canada (Foxe Basin, Pelly Bay, Repulse Bay, and Cumberland Sound) and at one locality in West Greenland (Disko Bay).

9.1.2 Review recent catch information

In 2011, one female bowhead whale was landed in West Greenland and none were struck and lost (SC/64/ProgRepDenmark). Two bowhead whales were found dead in West Greenland in 2011, entangled in fishing gear for crabs.

During 2011, three bowhead whales were taken in Canada. More detailed information (e.g. sex, size) was made available by Canada to the Secretariat. The Committee is pleased to receive this information including catch as well as struck/lost data. It requests that in the future Canada also provides information on any strandings, entanglements and ship strikes of bowhead whales.

9.1.3 Management advice

In 2007, the Commission agreed to an annual strike limit of 2 animals (for the years 2008-12) with a carryover provision (IWC, 2008). The Committee agreed an approach for providing interim management advice in 2008 and this was confirmed by the Commission IWC (2009). The Committee recalled that the agreed abundance estimate for Eastern Canada / West Greenland is 6,344 ((95% CI: 3,119-12,906; IWC, 2009d) for 2002. The most recent agreed estimate (IWC, 2012k; Wiig *et al.*, 2011b) for the spring aggregation in the West Greenland area is 1,747 (95% CI: 966-2,528) for 2010.

Using the agreed interim safe approach and the 2010 estimate for West Greenland, the Committee **repeats its advice** that an annual strike limit of 2 whales in West Greenland will not harm the stock.

The Committee **agrees** that it will review the updated analysis for the 2010 West Greenland (Wiig *et al.*,

2011a) at next year's meeting, noting that although slightly lower, if adopted it does not alter the management advice. The Committee is also aware that catches from the same stock have been taken by a non-member nation, Canada. Should Canadian catches continue at a similar level as in recent years, this would not change the Committee's advice with respect to the strike limits agreed for West Greenland. Given the importance of this issue, the Committee **recommends** that the IWC Secretariat continues to contact Canada requesting information about catches and domestic catch limits for bowhead whales.

9.2 Eastern North Pacific gray whales

9.2.1 New information

SC/64/AWMP2 presented the results of comparison of the genetics of gray whales sampled off Vancouver, Canada (i.e., PCFG whales), and San Ignacio Bay, Mexico. Results supported the conclusion that PCFG and the larger population are from the same breeding group. However results from other studies of photo-identification and mtDNA indicate that during the summer, whales of the PCFG represent a seasonal subpopulation driven by maternally directed site fidelity. The Committee's work (Item 8.1) is based on treating PCFG as a separate management stock.

There are at least two sets of genetic samples for PCFG whales, one is possessed by the research group in Canada, and the other by the Southwest Fisheries Science Center in La Jolla, USA. The Committee **recommends** that the two groups consider merging these data sets as this will result in a more robust evaluation of PCFG gray whales. The Committee also **suggests** that future work uses a greater number of microsatellites and increased mtDNA length.

The Committee received two papers on photo-identification studies undertaken in Mexican waters. SC/64/BRG14 provided information about the number of eastern North Pacific gray whales using Laguna San Ignacio, Baja California during the 2011 and 2012 winter breeding season. High counts of female-calf pairs in 2011 and 2012 suggest that more females whales are using the Laguna San Ignacio region as a winter aggregation area than during the 2007-2010 period. SC/64/BRG23 presented information on a new photographic identification programme in the Bahía Magdalena lagoon complex of gray whales in 2012 (there is little recent information from there). A total of 275 individual whales photographically identified, of which 234 were single whales and 41 were mother-calf pairs. 83% of the mother-calf pairs were sighted in waters around the López Mateos, and the majority of singles (89%) were sighted in waters near to mouth of Bahía Magdalena.

The Committee **thanks** the authors for these studies in Mexican waters which are discussed further in Annex F, Item 4.3.1, It noted the value of long-term datasets and **encourages** updates in future years.

SC/64/BRG18 presented results from a linear model relating the average ice cover over the Bering Sea during the first 15 days of May with estimates of northbound gray whale calves the following spring for the years 1994-2010 (ice years 1993-2009) and further used to predict calf estimates for 2011 to 2013. There is a negative relationship between the area of the Bering Sea covered by seasonal ice during the first two weeks of May and the number of gray whale calves estimated by shore-based counts off central California the following spring (Perryman *et al.*, 2011; Perryman and Rowlett, 2002). It is not clear whether an ice-shortened feeding season has a significant impact on overall population condition or health. Measurements of southbound gray whales in vertical aerial photographs collected in 2012 indicated that overall population condition was comparable to that in previous years when the observed strandings were about average.

The Committee **thanks** the authors for this analysis of data from an extremely valuable long-term dataset. The Committee **recommends** that continued annual shore-based counts be accorded high priority. It also recommends aerial photogrammetric body condition studies be continued next year, and results compared to existing data to test the hypothesis that ice conditions in May influence gray whale body condition and reproductive output. The Committee also **encourages** a more integrated analysis using ice cover data for spring in the Chukchi Sea and spring and autumn for the Bering and Chukchi seas.

Last year (IWC, 2012k) the Committee had encouraged the undertaking of a more quantitative integrated analysis for the lagoon counts in Baja California, Mexico and the northbound calf counts in California, given the length of the time series. It was also suggested that correlations between calf production in western and eastern gray whales be examined. The Committee **reiterates** its advice from last year.

SC/64/BRG21 provided information about coastal counts of gray whales off Chukotka Peninsula, Russia, and monitoring of the harvest. The Committee was pleased to see a variety of biological information collected from the harvested whales and **recommends** the collection of additional data and samples, such as tissue for genetic analyses, tissue samples for understanding the cause of 'stinky whales' (and see Item 12), and photographs for comparison with catalogues. Catch data are discussed further below.

9.2.2 Review of recent catch information

Russian Federation reported that a total of 128 gray whales were struck in Chukotka, Russia in 2011[13]; two

[13] This updates the information in SC/64/BRG21 for 2011

were lost and 126 were landed. Of the landed whales, two were stinky and not used for human consumption.

9.2.3 Management advice

In 2007, the Commission agreed that a total catch of up to 620 gray whales was allowed for the years 2008-2012 with a maximum of 140 in any year. No new data were presented this year to change the advice for the large eastern North Pacific population and therefore the Committee agrees that the *Gray Whale SLA* remains the appropriate tool to provide management advice for eastern North Pacific gray whales apart from the consideration of the PCFG and the Makah hunt (see Item 8.1). The Committee **reiterates** that the current strike limits will not harm the stock.

With respect to the management plan variants provided by the Makah Tribe, the *Implementation Review* was completed this year (Item 8.1) and the Committee **agrees**:

(1) hunt variant 2 performs acceptably;
(2) hunt variant 1 performs acceptably provided that it is accompanied by a photo-identification programme to monitor the relative probability of harvesting PCFG whales in the Makah U&A, and the results presented to the Scientific Committee for evaluation each year.

Matters related to the possibility of an animal feeding in the western North Pacific being taken in the PCFG area are discussed under Item 8.

9.3 Bering-Chukchi-Beaufort (B-C-B) Seas stock of bowhead whales

9.3.1 New information

SC/64/BRG1 provided results of seasonal movements of the BCB stock of bowhead whales from a satellite telemetry study of 57 tagged whales during 2006–2011. All but one tagged whale migrated past Point Barrow in spring and went to Amundsen Gulf. That remaining whale was tagged at Barrow in summer, wintered in the Bering Sea and then summered along the Chukotka coast in the Chukchi Sea. While most whales summered within the Canadian Beaufort Sea, extensive summer movements included travel far to the north and northeast. Fall movements coincided in space and time with oil and gas activities and potentially with shipping activities. Likely important feeding areas included Amundsen Gulf in spring and summer; Barrow in summer and fall; Wrangel Island (some years) in fall; the northern Chukotka coast in fall; and the western Bering Sea in winter.

Full discussion of this paper can be found in Annex F Item 2. It was noted that this work indicates that earlier estimates of bowhead whales off Cape Pe'ek on the Chukchi Peninsula (Melnikov and Zeh, 2007) were probably BCB bowheads, and not a separate smaller stock. The Committee **encourages** the continuation of this work, including the future analysis of other environmental covariates (e.g. physical oceanography) relating to BCB bowhead migration and distribution.

Results of a year-long acoustic study of B-C-B stock of bowhead whales were reported (Moore *et al.*, 2012). Calls from bowhead whales were recorded in October 2008, and from March-August 2009, on a recorder deployed on an oceanographic mooring near the Chukchi Plateau (ca. 75°N, 168°W). The rate of bowhead whale call detection was highest from May through August, when sea ice diminished from nearly 100% surface cover to zero and corresponded to a period of very high zooplankton backscatter signal from June through August.

SC/64/BRG3 reported the results of aerial photographic surveys of bowhead whales near Point Barrow, Alaska during 2011. Aerial surveys have periodically been flown in this area since 1984. Sufficient photo recaptures from the 2011 surveys are expected to calculate a mark-recapture abundance estimate with reasonable precision. SC/64/AWMP7 provided details about a successful ice-based survey in 2011 (see Item 8.2.1.2 AWMP Chair's summary). An ice-based estimate of abundance is expected in 2014 and the photo-id estimate thereafter. This would provide a rare opportunity to compare two independent large-whale abundance estimates in the same season.

SC/64/BRG4 presented estimates of visual detection probabilities from the spring 2011 ice-based survey of bowhead whales migrating near Barrow, Alaska, based on a new method first discussed last year (Givens *et al.*, 2011). This paper is also discussed under Item 8.2. In discussion, it was noted that the estimates in SC/64/BRG4 were slightly lower but generally consistent with those from earlier surveys, and the precision of the new estimates was better due to the new experimental design and a larger dataset. The Committee **agrees** that the estimation approach and application of the resulting detection probabilities to applicable years of survey data represents a methodological improvement over previous efforts. As noted under Item 8.2. it **encourages** Committee members with any detailed comments to submit those to the authors intersessionally.

SC/64/BRG8 reported on progress being made to sequence the bowhead whale transcriptome. It was noted in discussion that this research has the potential to provide insights into the life history, ecology, evolution and genetics of bowhead whales, with broader implications for other great whales.

9.3.2 Management advice

SC/64/BRG2 presented information on the 2011 Alaskan hunt. A total of 51 bowhead whales were struck resulting in 38 animals landed. No bowhead whales were reported struck and lost at Chukotka.

In 2007, the Commission agreed that a total of up to 280 BCB bowhead whales could be landed in the period 2008-2012, with no more than 67 whales struck in any year and up to 15 unused strikes being carried over each year. In the light of the *Implementation Review* completed this year (see Item 8.2), the Committee **agrees** that the *Bowhead SLA* remains the most appropriate tool for providing management advice for this harvest. It **reiterates** that the present strike and catch limits are acceptable.

9.4 Common minke whales off West Greenland

9.4.1 New information

In the 2011 season, 174 minke whales were landed in West Greenland and 6 were struck and lost (SC/64/ProgRepDenmark). Of the landed whales, there were 133 females, 39 males, and two whales of unreported sex. Genetic samples were obtained from 90 of these whales. The Committee **re-emphasises** the importance of collecting genetic samples from these whales, particularly in the light of the proposed joint AWMP/RMP workshop (see Annex D).

9.4.2 Management advice

In 2007, the Commission agreed that the number of common minke whales struck from this stock shall not exceed 200 in each of the years 2008-12, except that up to 15 strikes can be carried forward. In 2009, the Committee was for the first time ever able to provide management advice for this stock based on a negatively biased estimate of abundance of 17,307 (95% CI 7,628-39,270) and the method for providing interim management advice which was confirmed by the Commission. Such advice can be used for up to two five year blocks whilst *SLA*s are being developed. Based on the application of the agreed approach, and the lower 5th percentile for the 2007 estimate of abundance, the Committee **repeats** its advice of last year that an annual strike limit of 178 will not harm the stock.

9.5 Common minke whales off East Greenland

9.5.1 New information

Nine common minke whales were struck (and landed) off East Greenland in 2011, and one was struck and lost (SC/64/ProgRepDenmark). All landed whales were females. Catches of minke whales off East Greenland are believed to come from the large Central stock of minke whales. No genetic samples were obtained from minke whales caught in East Greenland. The Committee **re-emphasises** the importance of collecting genetic samples from these whales, particularly in the light of the proposed joint AWMP/RMP workshop (see Annex D).

9.5.2 Management advice

In 2007, the Commission agreed to an annual quota of 12 minke whales from the stock off East Greenland for 2008-12, which the Committee stated was acceptable in 2007. The present strike limit represents a very small proportion of the Central Stock – see Table 8). The Committee **repeats** its advice of last year that the present strike limit would not harm the stock.

Table 8
Most recent abundance estimates for minke whales in the Central North Atlantic.

Small Area(s)	Year(s)	Abundance and CV
CM	2005	26,739 (CV=0.39)
CIC	2007	10,680 (CV=0.29)
CG	2007	1,048 (CV=0.60)
CIP	2007	1,350 (CV=0.38)

9.6 Fin whales off West Greenland

9.6.1 New information

A total of five fin whales (all females) were landed, and none were struck and lost, in West Greenland during 2011 (SC/64/ProgRepDenmark). No genetic samples were obtained from caught fin whales in 2011. The Committee **re-emphasises** the importance of collecting genetic samples from these whales, particularly in the light of the proposed work to develop a long-term *SLA* for this stock.

9.6.2 Management advice

In 2007, the Commission agreed to a quota (for the years 2008-12) of 19 fin whales struck off West Greenland. This was subsequently modified and at the 2010 Annual Meeting Greenland voluntarily reduced the limit to 10 until 2012 (IWC, 2011). The Committee agreed an approach for providing interim management advice in 2008 and this was confirmed by the Commission. It had agreed that such advice could be used for up to two blocks whilst *SLA*s were being developed. Based on the agreed 2007 estimate of abundance for fin whales (4,539 95%CI 1,897-10,114), and using this approach, the Committee **repeats** its advice that an annual strike limit of 19 whales will not harm the stock.

9.7 Humpback whales off West Greenland

9.7.1 New information

A total of eight (three males; five females) humpback whales were landed (none were struck and lost) in West Greenland during 2011 (SC/64/ ProgRepDenmark). Genetic samples were obtained from three of these whales. The Committee **re-emphasised** the importance of collecting genetic samples and photographs of the flukes from these whales, particularly with respect to the YoNAH and MoNAH initiatives (Clapham, 2003; YoNAH, 2001).

9.7.2 Management advice

In 2007, the Committee agreed an approach for providing interim management advice and this was confirmed by the Commission. It had agreed that such advice could be used for up to two five year blocks

whilst *SLA*s were being developed (IWC, 2009a, p.16). Based on the agreed estimate of abundance for humpback whales (3,039, CV 0.45, annual rate of increase 0.0917 SE 0.0124) and using this approach, the Committee **agrees** that an annual strike limit of 10 whales will not harm the stock.

9.8 Humpback whales off St Vincent and The Grenadines

9.8.1 New information

Last year the SWG noted that it had received no catch data from St Vincent and The Grenadines for 2010-11. This year the Secretariat received information from the government that a 35-foot whale was taken on 18 April 2011 (IWC/63/18) and a 33.75 foot female taken on 14 April 2012. 2.). After the meeting it was also informed of a struck and lost animal during the 2011 hunt. The Committee was pleased to hear that genetic samples and photographs were taken and that the United States and St Vincent and The Grenadines are discussing the transfer of tissue samples from this whale for analysis and storage at SWFSC (the IWC archive where *inter alia* SOWER samples are stored). Iñíguez reported information on a hunt on the 11 April 2012 and a struck and lost animal on the 22 March 2012.

It also repeats its previous strong **recommendations** that St Vincent and The Grenadines:

(1) provide catch data, including the length of harvested animals, to the Scientific Committee; and
(2) that genetic samples be obtained for any harvested animals as well as fluke photographs, and that this information be submitted to appropriate catalogues and collections.

9.8.2 Management advice

In recent years, the Committee has agreed that the animals found off St. Vincent and The Grenadines are part of the large West Indies breeding population (11,570 (95% CI 10,290-13,390) – (Stevick *et al.*, 2003). The Commission adopted a total block catch limit of 20 for the period 2008-12.

The Committee **repeats** its advice of last year that this block catch limit will not harm the stock.

10. WHALE STOCKS

10.1 Antarctic minke whales (Annex G)

The Committee is in the process of undertaking an in-depth assessment of the Antarctic minke whale. The primary abundance data are those collected from the 1978/79 to 2003/04 IWC-IDCR/SOWER cruises (e.g Matsuoka *et al.*, 2003) that had been divided into three circumpolar series (CPI, CPII and CPIII). Two different methods for estimating minke whale abundance from the last two circumpolar data series have been developed in recent years. Although they gave different estimates of abundance, both were consistent in estimating a decline in circumpolar abundance between CPII and CPIII (IWC, 2012l). The Committee has been working to resolve the differences between the estimates for some time and last year believed that it would be possible to present an agreed abundance estimate at this year's meeting. The Committee has also been discussing uncertainties about stock structure, especially in the Indian Ocean and Pacific sectors, which are the sectors where catches have been taken in recent years (IWC, 2008b).

10.1.1 Stock structure

Two genetically distinct populations of Antarctic minke whales have been identified in the Area IIIE-VIW feeding grounds (IWC, 2008b). There is no sharp boundary between them, only a "soft" boundary; the two populations overlap, but one predominates in the East, called the Pacific or P-stock, and the other in the West, called the Indian Ocean or I-stock. The extent and location of overlap is an important issue for assessment.

SC/64/IA4 presented a new integrated analysis of three different sources of data: morphometrics, microsatellites and mitochondrial DNA. The goal is to estimate longitudinal segregation of the breeding populations on the Antarctic feeding grounds. The model is intended to allow the location of the soft boundary to move from year to year. The method was applied to the extensive data for the Antarctic minke whales taken by the JARPA and JARPA II surveys. The results indicated that the spatial distribution of the two populations have soft boundary in Area IV-E and V-W, which does vary clearly and significantly by year. The results also suggest that the boundary is sex-specific.

The Committee noted that the approach used is simple and potentially powerful. Aside from the general relevance of the results to understanding Antarctic minke whale dynamics, it might in the future prove useful in allocating historical catches to stocks. The Committee **endorses** the specific investigations for further statistical analysis given in Annex G Item 5.1.

10.1.2 Abundance estimation of Antarctic minke whales

In order to reach its goal of having agreed abundance estimates by the 2012 Annual Meeting, an intersessional workshop was held in Bergen, Norway, in May 2012 (SC/64/Rep4). It made substantial progress in identifying reasons for the large differences between earlier 'trackline conditional independence' and 'hazard probability based' estimates of Antarctic minke whale abundance (the 'SPLINTR' model, Bravington and Hedley, and the 'OK' model, Okamura and Kitakado, respectively). It also identified aspects of the OK model that needed adjustment related to plausibility of mean dive-time estimates from fits of the model and the resultant effects on g(0), compared to independent estimates of g(0). A work programme was

agreed for completion by the 2012 Annual Meeting which resulted in three papers - SC/64/IA2, SC/64/IA12 and SC/64/IA13. The Committee thanked the authors for completing the workplan. Detailed discussions can be found in Annex G Item 5.3.

SC/64/IA12 analysed data from the IWC/SOWER 2004/05 video dive time experiments. The Committee was pleased to receive these estimates, which after discussion within the intersessional steering group became key inputs for the OK method. SC/64/IA2 presented a revision of the 'Norwegian Product' formulation of the OK model and investigated sensitivity to a number of factors. The abundance estimates were lower than previously estimated by versions of the OK model, after incorporating the new mean dive-times and the resultant lower g(0) values. SC/64/IA3 presented a 'Norwegian Product' version of SPLINTR, also using the externally-estimated dive-times. The authors noted that their fits showed some problems and counterintuitive results but also noted that they had insufficient time to investigate the model. They thus considered that although the framework of the model therein seemed reasonable, the actual estimates were not ready for consideration.

Based on considerable experience from previous years, the intersessional workshop had identified a core set of diagnostics most capable of revealing important model deficiencies when modelling IDCR/SOWER minke whale data (SC/64/Rep4). The main issue for SC/64/IA2, the OK model, was that the observed proportion of near-simultaneous compared to delayed duplicates was considerably lower than the predicted; this is potentially important in terms of estimating g(0) and thus overall abundance, because of the close link to mean dive-time. The likely cause of the misfit is the aggregation-over-time that is required in order to deal with rounding and measurement errors in timing and distance estimates in IDCR/SOWER, in conjunction with the clumped nature of real whale dive patterns (in contrast to the independence of successive dive-times assumed by OK models). For the reasons discussed in Annex G, however, the Committee **agrees** that the within-duplicate lack-of-fit was unlikely to imply serious bias in abundance estimates.

Given the progress made and results presented and discussed in Annex G, it was agreed that there was no need to consider further the process of averaging estimates from the two models proposed last year (IWC, 2012l). It was reassuring that two completely independent implementations of the Norwegian Product (NP) model appear to be giving consistent results and showed little sensitivity to the input values for mean dive-time in the neighbourhood of the best independent estimates of dive time from SC/64/IA12.

The starting point for determining the best available consensus estimate, was the authors' 'preferred estimates' in SC/64/IA2 using the best estimates of mean dive-time from SC/64/IA12, and then applying the appropriate adjustment factors agreed last year (IWC, 2012e) with some minor changes. All the adjustments are estimates, but are modest enough that their impact on CV can reasonably be neglected. A CPII spatial adjustment of 15% is the largest adjustment, and reflects some imbalance of coverage within survey strata in CPII, something that was much reduced in CPIII. All other adjustments are minor.

The resulting estimates are shown in Table 9. Because the northern extent of the surveyed regions differs between CPII and CPIII, two sets of estimates are given, 'survey-once' and 'CNB' (Common Northern Boundary). The survey-once estimates cover all of the surveyed regions in each CP series (using the most recent or most complete survey in cases of duplication). The CNB estimates exclude part of the surveyed regions in each series to ensure a consistent northern limit; these are the most appropriate estimates for a comparison of abundance estimates between CPII and CPIII. The CNB estimates are also the basis for the Additional Variance (AV) calculations (SC/61/Rep9) which address the non-synoptic nature of the surveys, i.e. that whales may move into and out of any given surveyed area from year to year. The 'CV internal' row reflects the uncertainty associated with the abundance estimate of whales in the surveyed region at the time of the survey, whereas the "CV with AV" row reflects the uncertainty associated with the average number of whales present in the surveyed region across the whole of that CP series, and is more useful for most subsequent analyses. CVs are approximately the same for survey-once as for CNB, so only one set is shown. Note that there are also correlations between the estimates (not shown) in different *Management Areas* within each CP (but not between CPs) since model parameters are estimated jointly for each whole CP.

The Committee **agrees** that the numbers in Table 9 represent the best available abundance estimates of Antarctic minke whales in the surveyed areas during the years of CPII and CPIII. The potential sources of bias have now been much more thoroughly addressed than in the existing "standard method" estimates (Branch, 2006), and the results are consistent with recent external datasets (e.g. the post-2004 SOWER cruise experiments on school size estimation, video dive time and BT-mode). The explanation for the large difference between the estimates from original OK (e.g Okamura and Kitakado, 2011) and original SPLINTR (e.g Bravington and Hedley, 2009) methods has been identified as the interaction between diving behaviour and timing errors and the difference has been reduced to plausible levels by imposing direct estimates of mean dive-time in the NP models. The Committee agrees that it is unlikely that any remaining bias is substantial.

Table 9
Best estimates of Antarctic minke whale abundance by *Management Area* adjusted by the factors agreed in Table 1. See text for explanation.

		IWC Management Area						
CP		I	II	III	IV	V	VI	TOTAL
II	Survey once	85,688	130,083	93,215	55,237	300,214	55,617	720,054
	CNB	84,978	120,025	86,804	51,241	285,559	49,885	678,493
	CV internal	0.16	0.14	0.20	0.17	0.13	0.22	0.08
	CV with AV	0.34	0.40	0.44	0.39	0.31	0.39	0.18
III	Survey once	38,930	57,206	94,219	59,677	183,915	80,835	514,783
	CNB	34,369	58,382	68,975	55,899	180,183	72,059	469,866
	CV internal	0.20	0.19	0.15	0.34	0.11	0.14	0.09
	CV with AV	0.39	0.38	0.35	0.49	0.36	0.37	0.18
CPIII:CPII		0.40	0.49	0.79	1.09	0.63	1.44	0.69

The new **agreed** estimates for the survey-once case are 720,000 for CPII (1985/86-1990/91) with 95% CI [512,000, 1012,000], and 515,000 for CPIII (1992/93-2003/04) with 95% CI [361,000, 733,000]. The estimates are subject to some degree of negative bias because some minke whales would have been outside the northern and southern (surveyable, ice edge) boundaries. The improved analyses have resulted in many estimates differing appreciably from the 'Standard Method' estimates (Branch and Butterworth, 2001; IWC, 2006b, p.21). For CPII, the new best estimate of total abundance is slightly lower (720,000 compared to 769,000 standard estimate) whereas for CPIII the new best estimate is substantially higher (515,000 compared to 362,000). There are two primary reasons for the differences: (1) the spatial adjustment required for CPIII is much less than for CPII; and (2) the mean school size is appreciably smaller in CPIII than CPII which affects the net adjustment for g(0). The ratio of total abundance in CPIII to CPII, formerly 0.47 with the standard method, is now estimated to be 0.69 with 95% CI [0.43, 1.13] for the 'CNB' estimates.

Annex G Item 5.3.2 identified some future work, partly to check and deal with any small remaining bias issues, and also for the benefit of other abundance estimation in general. A valuable aspect of SOWER/IDCR is the consistency of its protocols and its large sample size, unparalleled amongst cetacean sightings datasets, which allow the development of realistic tests and sophisticated estimation methods applicable to many cetacean abundance estimation cases beyond Antarctic minke whales.

The Committee **expresses** its thanks to the Abundance Estimation Working Group for their tremendous collaborative efforts in obtaining agreed estimates after several years of intensive and innovative work. The developers (Bravington, Hedley, Kitakado and Okamura) are to be particularly commended as is the recent input and enthusiasm of Butterworth, Skaug and Walløe. The Committee now has confidence in these open-water estimates and a more comprehensive understanding of the modelling requirements for IDCR/SOWER data. The Committee also places on record its considerable appreciation to all those involved in the IDCR/SOWER cruises (1978/79 - 2009/10) – the Japanese Government (and in the early years the government of the then USSR), the IWC, the originators of the programme, the scientists and crews of the participating vessels, the planners of the cruises and the analysts, whose dedication and hard work over many years have led to this agreed result.

10.1.3 Reasons for differences between estimates from CPII and CPIII

The confidence interval for the ratio of the total estimated abundance from CPII and CPIII included 1.0 and thus a null hypothesis of no change in overall abundance between the two periods would not be rejected. Nevertheless, the Committee considered that a change was quite likely, and discussed possible reasons for a decline in the estimated abundance of whales in the surveyed areas.

Between CPII and CPIII, the point estimates of Antarctic minke whale abundance show a large decline in three Management Areas (I, II, and V) and an increase in Areas IV and VI (Table 9). Overall, the circumpolar estimates are some 30% lower between CPII and CPIII. Since the Committee is now satisfied that the remaining biases in the agreed estimates are unlikely to vary greatly over the duration of the CPII and CPIII cruises. Therefore the differences seen in Table 9 probably do reflect real changes in abundance in the open-water areas surveyed.

The Committee is exploring possible reasons for this. Noting that the IDCR/SOWER cruises were neither synoptic nor did they cover the entire range of potential minke whale habitat, one hypothesis is that the decline in estimated abundance was due to more whales being in unsurveyed regions during CPIII than in CPII. This suggests the following (not mutually exclusive) possibilities:

(1) a much higher proportion of whales in the pack ice or in open-water areas (polynyas) within the pack ice in CPIII, as compared to CPII

(2) extensive longitudinal (east-west) whale movements from year to year, and surveys conducted as part of CPII happened to encounter higher densities in certain areas, as compared to those during CPIII,
(3) a much higher proportion of the total population was north of 60ºS during CPIII,
(4) intra-year movements in open water within the surveyed areas that were not adequately covered by the trackline design in space and time, with respect to environmental variables, and
(5) a genuine decrease in abundance of Antarctic minke whales.

In order to examine (1) above, a sea ice intersessional group was established last year to: (i) consider technical aspects of sea ice data which will be used to bound or estimate the abundance of Antarctic minke whales in the south of the ice edge, and (ii) consider appropriate analysis methods to bound or estimate the abundance of whales south of the ice edge.

SC/64/IA3 reviews some technical aspects of the sea ice data obtained by IDCR/SOWER, ASPeCt (Antarctic Sea Ice Processes and Climate), satellite sensors and NIC (National Ice Center). The definitions of the sea ice edge vary between the different data sources because their objectives and applied techniques are different. The IDCR/SOWER definition of the sea ice edge is somewhat operational compared to that for other data sources. However, its definition is believed to be consistent for the period 1978 to 2003, and the authors believe it is the most appropriate boundary for abundance estimation in years and areas where IDCR/SOWER surveys were undertaken. They also conclude that the sea ice concentrations derived from passive microwave (PM) remote sensing are probably the best sea ice data to be used for the purpose of estimating abundance of Antarctic minke whales to the south of sea ice edge in areas where IDCR/SOWER observations are not available (the PM records date back to 1979).

SC/64/IA10 is an appraisal of methods and data to estimate abundance of Antarctic minke whales within sea ice covered areas of the Southern Ocean. With new estimates of densities of Antarctic minke whales (from aerial surveys) in certain areas of sea ice (i.e., Weddell Sea and east Antarctica), and model-based abundance methods which allow extrapolation, there is an opportunity to compare bounds and magnitudes of abundances, both inside and outside of the sea ice region, to assess how likely the 'moved-into-sea ice' hypothesis is. In the first instance, the authors recommended that comparisons of inside/outside abundances be made for areas and years where the aerial surveys were conducted. If these analyses are inconclusive from the perspective of the 'moved-into-sea ice' hypothesis, there is a recommendation to extend the analysis to estimating circumpolar densities, and extrapolating back over the period of CPII and CPIII. The recommended analysis will give full consideration to how variable minke whale densities can be over space and time. Furthermore it should be recognised that such analyses will involve a great deal of work and may not yield helpful results.

Since Antarctic minke whales congregate along the ice edge, potential problems in estimating abundance inside/outside of an ice region using satellite data were discussed in Annex G Item 5.3.3. The Committee **recommends** that sensitivity analyses as to the position of the sea ice boundary on Antarctic minke whale abundances derived from aerial survey data be assessed before any in-depth calibrations and analyses of operational sea ice boundaries be attempted.

It is not possible to obtain reliable absolute abundance estimates of Antarctic minke whales in sea ice regions corresponding in space and time with IDCR/SOWER surveys. The Committee thus **recommends** that relatively simple analyses be conducted to generate abundances using aerial survey data. These abundances, with a range of potential availability biases, will help in producing an overall magnitude or upper bound on the numbers of Antarctic minke whales in sea ice regions during CPII and CPIII.

At present, the Committee is unable to exclude the possibility of a real decline in minke whale abundance between CPII and CPIII. Population dynamics analyses of catch-at-age data from Area IIIE to VIW (e.g. as in SC/64/IA1) can potentially account for the changes in overall abundance in terms of variations over time in mortality and recruitment. Such explanations are descriptive but they do not attempt to explain why, for example, recruitment might have dropped commencing in the 1970s. There is a second class of more mechanistic explanations concerned with, for example, why pregnancy rates might fall; this is where ecosystem effects, competition, climate, etc. would need to be considered.

As noted in Annex G Item 5.3.3, Murase and Kitakado suggested that the difference in abundance estimates between CPII and CPIII can (to a large extent) be attributed to process error (i.e., additional variance), reflecting a large inter-annual variation in distribution of the Antarctic minke whales (Kitakado and Okamura, 2009). However, they also suggested that systematic environmental changes observed in some areas do not alone account for the process error. Others suggested that the that JARPA and JARPA II data can assist the interpretation of the CPII and CPIII differences given the long time series data in Areas IIIE, IV, V and VIW (e.g see Matsuoka *et al.*, 2011). Hakamada will present information on some diagnostics from analyses to estimate minke whale abundance from JARPA next year.

In conclusion, the Committee noted that after many years work it had now been able to **agree** on estimates of minke whale abundance within the areas surveyed in CPII and CPIII. As yet, though, there was no conclusion on whether (and if so to what extent) these numbers indicate a real decline in abundance of Antarctic minke whales between the periods of the two surveys. Time constraints meant that it was possible to have only preliminary discussions of this question this year; discussions will continue at next year's meeting.

10.1.4 Continue development of the catch-at-age models

Population dynamics modelling provides a way to explore possible changes in abundance and carrying capacity within Areas IIIE-VW, where appropriate data are available. The inputs are catch, length, age, and sex data from the commercial harvests and both JARPA programs, as well as abundance estimates from IDCR/SOWER. Early attempts used the ADAPT-VPA approach of Butterworth and Punt (1999); Butterworth *et al.* (2002); and Butterworth *et al.* (1996). A number of issues and concerns were raised with respect to that particular modelling framework for Antarctic minke whales, and it was concluded that an integrated statistical catch-at-age (SCAA) model was the most appropriate modelling framework (IWC, 2003c). Punt and Polacheck (2005; 2006) developed such a model, and it has been refined over the last few years. The SCAA approach allows for errors in catch-at-age data, more than a single stock, time-varying growth, multiple areas, environmental covariates, fleet-specific vulnerabilities, and changes over time in vulnerability. The technical problems and inconsistencies identified in previous years have largely been resolved (JCRM 2012, p180).

SC/64/IA1 provides a summary of the specifications of the current SCAA. The approach allows for multiple breeding stocks, which can be allowed to mix across several spatial strata on the summer feeding grounds where catches are taken. It also allows carrying capacity and the annual deviations in juvenile survival to vary over time. The model is fitted to length and conditional age-at-length data collected from the Japanese commercial and scientific permit catches, as well as indices of abundance from the IDCR/SOWER and JARPA/JARPA II cruises. The results provided in the paper are illustrative primarily because the IDCR/SOWER abundance estimates used had not been finalised, and the age-at-length data for recent years from JARPA II are not yet available.

As noted in Annex G Item 5.2, a number of suggestions for further work were made in this regard. Until now, application of the SCAA has been held up by the lack of agreed IDCR/SOWER abundance estimates, but that obstacle has now been removed, and the application of the SCAA in testing hypotheses concerning changes between CPII and CPIII abundance estimates has become a high-priority task. The time series of earplug age data, which is an important input that would improve the resolving power of the SCAA, has not been updated since 2004 or 2005 although samples are available through to 2011/12, because of difficulties in finding and validating age-readers. Preliminary age readings have been made from the 2006-2008 samples, but have not yet been validated. Last year, the Committee had recommended that these preliminary data be made available and included in the SCAA on a provisional basis pending validation (IWC, 2012l, p.180). This year, the Committee **reiterates** this recommendation; the recent age data should be incorporated into the SCAA model as soon as possible. The Committee recommends the SCAA modeless request the new data via the Data Availability Group and the data owners provide it as soon as possible.

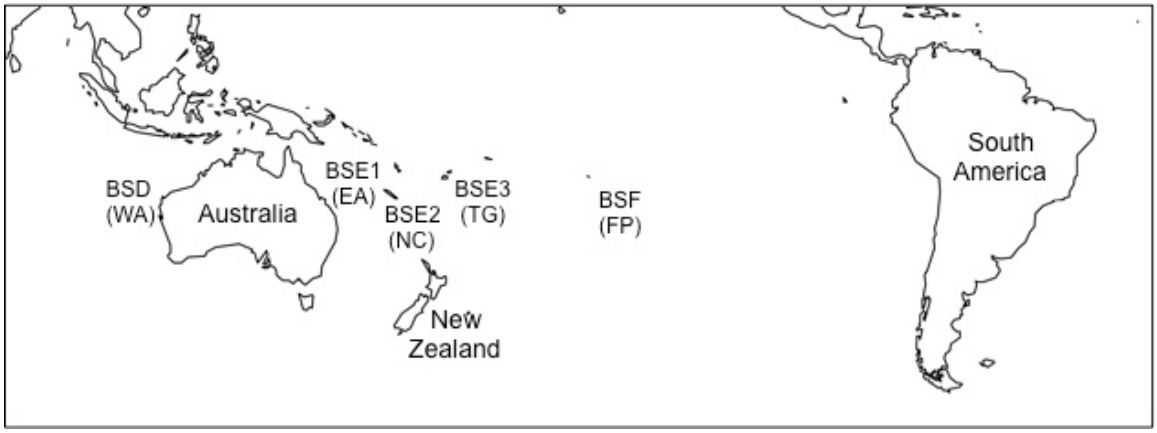

Fig 1. Distribution of Southern Hemisphere humpback whales breeding stocks grounds for BSD, BSE1, BSE2, BSE3 and BSF2 (WA = Western Australia, EA = Eastern Australia, NC = New Caledonia, TG = Tonga and FP = French Polynesia).

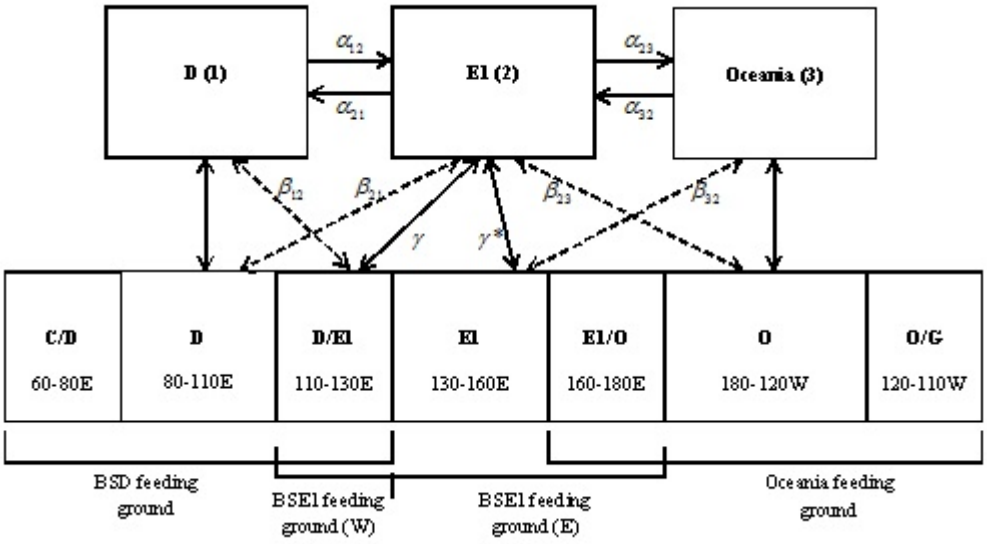

Fig. 2. Proposed model structure for breeding stocks D, E1 and Oceania. Arrows indicate possible interchange between stocks. These interchange rates will be estimated in the model, informed by data given in Table 1 of Annex H. Solid lines indicate movement of a breeding population to its own feeding ground, while dashed arrows indicate whales moving to a neighbouring feeding ground. Note that in order to avoid three breeding stocks mixing in the E1 feeding ground, an artificial boundary for catch allocation has been imposed. No catches taken east of this boundary will be allocated to BSD, while no catches taken west of the boundary will be allocated to Oceania. The longitude 130˚E was chosen based on the longitudinal range of documented connections between BSD, Oceania and the Antarctic (J. Jackson, *pers. comm.*)

10.2. Southern Hemisphere humpback whales

The IWC Scientific Committee currently recognises seven humpback whale breeding stocks (BS) in the Southern Hemisphere (labelled A to G; IWC, 2011k), which are connected to feeding grounds in the Antarctic. An additional population that does not migrate to high latitudes is found in the Arabian Sea. Assessments of BSA (western South Atlantic), BSD (eastern Indian Ocean) and BSG (eastern South Pacific) were completed in 2006 (IWC, 2007d) although it was concluded that BSD might need to be re-assessed with BSE and BSF in light of mixing on the feeding grounds. An assessment for BSC (western Indian Ocean) was completed in 2009 (IWC, 2010) and for BSB in 2011 (IWC, 2012).

10.2.1 Begin assessment of breeding stocks D, E and F

Last year, the sub-committee on Southern Hemisphere whales initiated the re-assessment of BSD, and the assessment of BSE and BSF (IWC, 2012m). These stocks correspond, respectively, to humpback whales wintering off Western Australia (stock D), Eastern Australia (sub-stock E1) and the western Pacific Islands in Oceania including New Caledonia (sub-stock E2), Tonga (sub-stock E3) and French Polynesia (sub-stock F2) (Fig 1). For simplicity the combination of BSE2, BSE3 and BSF2 will be referred to as Oceania.

10.2.1.1 ABUNDANCE, TRENDS AND POPULATION STRUCTURE

SC/64/SH6 presented a POPAN open model abundance estimate of 562 whales (CV=0.19, CI 351-772) from the New Caledonia humpback whale breeding ground (BSE2) using fluke photo- identification data collected over 16 years (1996-2011). Beginning in 2006 through to the current estimate, all population models examined show a trend of increasing abundance with a large 'pulse' after 2008. Whether these whales represent part of the New Caledonia sub-stock or permanent or temporary immigration from different regions is currently unclear.

In discussion, it was noted that a phenomenon similar to that observed in New Caledonia in the late 2000s had also been recorded off Eastern Australia in the late 1980s (Chaloupka *et al.*, 1999). To attempt to examine this apparent increase, the Committee noted that a possible movement of Eastern Australia whales to New Caledonia was consistent with an observed decrease in the rate of population growth of whales migrating off the Australian coast (Noad *et al.*, 2011) and levels of F_{st} differentiation between E1 and E2 (0.01, Olavarría *et al.*, 2006) were the lowest among any pair of populations in Oceania. However, at this time the available data are not sufficient to explain the observed patterns.

Salgado Kent *et al.* (2012) provided new estimates of abundance and trends for Western Australian humpback whales. A number of statistical issues were raised in discussion as can be seen in Annex H. The Committee **encourages** further analyses and intersessional contact with the authors and that, if

necessary they are invited to SC65 for further discussion of their work.

SC/64/SH28 reported on the outcome of a workshop held in November, 2011 to discuss future surveys and analyses of Breeding stock D humpback whales at two locations off Western Australia - North West Cape and Shark Bay. The workshop proposed a pilot survey to trial both cue-counting and racetrack aerial abundance survey methods, in conjunction with land-based work at both locations, to determine the most appropriate survey method for a full-scale absolute abundance survey in the near future. Prior to the survey, simulation work will be conducted to determine the operational protocols for the racetrack abundance estimation method as applied to humpback whales. The Committee **concurs** that a pilot study is the appropriate next step in method development for the provision of an absolute abundance for the Western Australian stock of humpback whales.

Four documents were available for discussion of stock structure issues, SC/64/SH5, SC/64/SH15, SC/64/SH22, and Pastene *et al.* (2011). These documents were reviewed by the Working Group on Stock Definition and their conclusions are reported in Annex I, Item 3.1.1.

10.2.1.2 ASSESSMENT MODELS

In order to facilitate discussions and identification of further model runs, SC/64/SH29 provided initial results of population model fits to the Southern Hemisphere humpback whale breeding grounds D (West Australia; BSD), E1 (East Australia; BSE1) and Oceania (BSE2, BSE3, and BSF2). As anticipated, this led to considerable discussion and the details can be found in Annex H. As a result, the Committee **agrees** on a series of recommendations (details are in Annex H) regarding future work to facilitate the assessment:

(1) authors of some of the abundance estimates should be contacted to learn more about the estimates and how they might be incorporated into the assessment;

(2) a multinomial likelihood should be incorporated into the Bayesian population dynamics model;

(3) the new movement model structure (Fig. 2) should be incorporated to take into account the documented connectivity between breeding grounds in Western (D) and Eastern Australia (E1) and Oceania (E2+E3+F2) and between the breeding and feeding grounds;

(4) a two stock model for Eastern Australia and Oceania should be explored;

(5) catches should be allocated to the feeding areas associated with each of the three breeding stocks according to Hypothesis 1 of (IWC, 2010e);

(6) 'Discovery' mark data from the whaling period which contains information on movements between breeding grounds, between feeding grounds, and between breeding and feeding grounds, should be explored in the context of the assessments.

(7) the Pastene *et al.* (2011) analysis on relative proportions of mixing in the feeding grounds should be expanded to include samples from Eastern Australia (E1).

The Committee also **endorses** the input data for the population dynamics model given in Table 1 in Annex H and **agrees** that any additional datasets must be provided by 31 December 2012, after which time no more new data will be used for this assessment. The results of the analyses using the agreed model will be presented for discussion at the 2013 Annual Meeting. To ensure this work is completed, a work plan has been developed which identifies who will do each task (Table 2 in Annex H) and an intersessional working group has been appointed convened by Muller (Annex Q). The Committee anticipates that the assessment of these stocks should be completed in 2014.

Reconciliation of the large photo-identification catalogue (6,500 + IDs from 1984-2011) held by Pacific Whale Foundation with existing catalogues from Western Australia, Oceania and the Antarctic humpback whale catalogue is also encouraged to inform estimates of interchange for future assessments.

10.2.2 Review new information on other breeding stocks

10.2.2.1 BREEDING STOCK A

SC/64/SH17 reported 58 stranded humpback whales that were recorded between 1981 and 2011 off the coast of Rio de Janeiro, southeastern Brazil (annual mean 2.6, maximum 13 records in 2010). Reported strandings have increased over the past 20 years, which is consistent with the population increase observed for this stock. Three cases of entanglement were found (two were calves). Bacteriological agents in three live stranded whales assessed indicated evidence of animal impairment that resulted in or were associated with the cause of death.

The Committee **welcomes** this information but expressed concern that information is available from only a small part of the total Brazilian population. It **encourages** the provision of information from the full range of animals passing along the coast.

10.2.2.2 BREEDING STOCK B

SC/64/SH4 described a newly-discovered humpback whale wintering ground off northwest Africa with a seasonal signature consistent with a South Atlantic stock; the presence of adult/calf pairs, suggests it may be a nursery ground. Since the observations were six

months out of phase with the nearest (and only) known breeding ground in the northeast Atlantic – the Cape Verde Islands, these sightings possibly comprise the most northwestern component of the Southern Hemisphere BSB.

During a joint cruise organised by the South African Department of Environmental Affairs and the University of Pretoria in November 2011, a total of 107 biopsies were collected and numerous images obtained from humpback whales on the west coast of South Africa.

In discussion, numerous sightings of humpbacks have been made alone on the Atlantic African coast. The Committee **recommends** that the location and timing of all the existing Atlantic African records of distribution, seasonality, and timing of sightings should be synthesised in a single map/database to show the extent of range and movements for humpback whales within a calendar year.

10.2.2.3 BREEDING STOCK C

SC/64/SH3 provided the first description of humpback whale movements between breeding grounds in the Comoros Islands and coastal western Madagascar. During 11-14 October 2011, five satellite transmitters were deployed on humpbacks off Moheli Island (12° 24'S, 43° 45'E) in the Comoros Archipelago. Three individuals were tracked successfully: mean tracking duration was 18 days (range 8-28 days); mean distance travelled was 467 km (146-749 km) and mean travelling speed 26.7 ± 22.3 km/day. This is the first record of whales visiting different islands of the Comoros and western Madagascar in the same season.

Ersts *et al.* (2011) reported that between 1996 and 2006, nine whales (six males and three females) were identified using two breeding areas in separate years: the northern Mozambique Channel, currently the breeding region for sub-stock C2; and eastern Madagascar, currently a breeding region for sub-stock C3. This led the authors to believe that sub-stocks C2 and C3 were probably the same breeding sub-stock.

10.2.2.4 BREEDING STOCK D

Information was presented on examinations of eight neonatal humpback whales stranded on the Western Australian coast in 2011, all at least 1000 km south of the currently known major breeding grounds off the Western Australian northwest coast (see Annex H, item 2.3.4). Examinations indicated that all but one of the eight neonates was severely malnourished, and were believed to be non-viable from birth due to a lack of energy reserves and a compromised ability to thermoregulate and control buoyancy. Similar examinations are expected to be conducted on strandings on the Western Australian coast in 2012 and, hopefully, in future years.

10.2.2.5 BREEDING STOCK G

SC/64/SH16 provided information collected from whale-watching boats on distribution and behaviour of humpback whales from the south Pacific coast of Costa Rica, as discussed in Annex H, item 2.3.5.

In discussion, attention was drawn to the unusually high number of cow/calf pods reported together: nine groups with three or more adults with calves. The Committee **encourages** structured surveys to more completely document the distribution of these animals and **recommends** comparisons with catalogues from other areas, including breeding grounds, in the Southern Hemisphere.

SC/64/SH23 presented information on 1,580 individually photographed humpback whales off Ecuador that were compared with 611 animals identified in the southeast Pacific in four different catalogues. This confirmed Antarctica as the main feeding ground for humpback whales found off Ecuador and suggested that feeding areas for whales identified off Ecuador may extend as far east within Area II as the South Orkney Islands. The Committee was also informed that individual animals may migrate either to the Magellan Strait or the Antarctic Peninsula, but not to both. Comparison with the catalogue of animals found off Chiloe Island, Chile, had yet to be undertaken, and the Committee **recommends** that this comparison be undertaken and looks forward to receiving further information.

Information on 15 long-term resightings of humpback whales off Ecuador was reported in SC/64/SH24. One animal was resighted over a 26 year time span. The paper also provided the earliest connection from Ecuador to Antarctica and further supports the findings that waters around the Antarctic Peninsula are the main feeding area of humpback whales migrating to Ecuadorian waters. The Committee **endorses** plans to extend comparison of the Ecuadorian catalogue with animals from around South Georgia and Area II and looks forward to receiving a report at next year's meeting.

SC/64/O15 discussed observations from small boats during 2006-2012, within the Golfo Duce, Costa Rica and the surrounding area of Osa Peninsula. It was shown the area is an important wintering ground, where the whales' distribution was determined by bathymetry, water temperature and possibly currents. For example, whales seem actively to avoid areas with eddies. The area seems to be used mainly by singing adults and there were competitive groups present in depths less than 60m, suggesting that mating occurs there.

The Committee **endorses** the view that spatial distribution information obtained from this study should be taken into account in establishing guidelines for appropriate management of this important Costa Rican marine coastal habitat.

10.2.2.6 FEEDING GROUNDS

SC/64/SH21 presented new information about abundance, population structure, demographic, and reproductive trends of humpback whales from the Strait of Magellan feeding area using long-term data on sightings, photo-identification and molecular analysis. The waters of Chilean Patagonian fjords and the Strait of Magellan remain today as the only recorded Southern Hemisphere feeding area for humpback whales of breeding stock G outside Antarctic waters.

The Committee thanked the authors for bringing this new information forward. It noted that it could not fully evaluate the abundance estimates with the information provided in the document and looked forward to seeing additional documentation next year. The Committee **expresses concern** regarding the potential for ship strikes and habitat displacement if the coal mining development results in a substantial increase of ship traffic in the region. It **recommends** that potential impacts are carefully assessed and that effective mitigation measures are adopted where necessary.

10.2.2.7 ANTARCTIC HUMPBACK WHALE CATALOGUE

SC/63/SH1 provided an update on the Antarctic Humpback Whale Catalogue (AHWC). The recent submissions bring the total number of catalogued whales identified by fluke, right dorsal fin/flank and left dorsal fin/flank photographs to 4635, 414 and 409, respectively. Opportunistic data represent a significant portion of the AHWC. Progress continues in efforts to stimulate submission of opportunistic data from eco-tourism cruise ships in the Southern Ocean and from research organizations and expeditions working throughout this region and the Southern Hemisphere.

The Committee thanked the authors for their hard work and **recommends** that the AHWC continue. This item has financial implications as discussed under Item 23.

10.2.3 Work plan

The work plan for the assessment of Southern Hemisphere humpback whales is described in Table 2 in Annex H and will be furthered by an intersessional working group (Annex Q). The Committee's discussions of the workplan are discussed under Item 21 and financial implications under Item 23.

10.3. Southern Hemisphere blue whales

10.3.1 Review new information

10.3.1.1 PHOTO-IDENTIFICATION CATALOGUES

SC/64/SH8 provided an update on the Antarctic Blue Whale Photo-Identification Catalogue, which includes photographs collected during 20 years of IWC IDCR/SOWER cruises (1987-88 to 2009-10). In 2011 and 2012 the photographs of eight new whales and one re-sighted whale (2007-2010) were added. Currently the catalogue contains a total of 227 identified whales. Seven whales were re-sighted in multiple years. Mark-recapture analysis of Area III in the 3-year time period 2004/2005-2006/2007 yielded estimates of abundance ranging from 818 to 1097 whales.

The Committee welcomed this update and recognised that the data have also been submitted to the Southern Hemisphere Blue Whale Catalogue. Photographs of blue whales from the JARPA programme has not yet been included in the ABWPIC but have been submitted to the IWC Secretariat. The Committee **reiterates** that the photographs should be added to the catalogue and reconciled and a proposal to achieve this has been developed. This is discussed further under Item 23..

SC/64/SH20 presented an update on the Southern Hemisphere Blue Whale Catalogue that holds photo-identification catalogues of research projects from major areas off Antarctica, Eastern South Pacific and the Eastern Tropical Pacific (ETP). A total of 822 and 826 individual blue whales photographed from left and right sides respectively are held in this Catalogue. Left-side comparisons have been completed and right-side comparisons are underway for ETP and the other areas. There are re-sightings both within Chile and in the Southern Ocean. However, none of the 84 whales photographed off ETP have been re-sighted within or outside of the ETP.

The Committee **encourages** contributions of regional catalogues not yet in the Southern Hemisphere Blue Whale Catalogue (e.g. eastern and western Australia) to facilitate full reconciliation of the catalogue for the Southern Hemisphere blue whales and a proposal to achieve this has been developed. This is discussed under Item 23.

10.3.1.2 ANTARCTIC BLUE WHALES

SC/64/SH14 reported methodological developments for estimating relative abundance from historic Antarctic whaling records using catch per unit effort data (CPUE). Once the work has been completed and accepted by the Scientific Committee, the Committee welcomed the commitment of the authors to submit the datasets and script to the IWC Secretariat.

SC/64/SH11 summarised two voyages conducted by the Australian Antarctic Division off southeastern Australia to refine acoustic tracking methodologies to address the aims of the Southern Ocean Research Partnership's Antarctic Blue Whale Project (see Item 19 and Annex H, item 3.1.2.1). The primary aim of this project is to estimate the circumpolar abundance of Antarctic blue whales using mark-recapture methods. The passive acoustic tracking system, using DIFAR sonobuoys, operated continuously during the voyages recording nearly 500 hours of audio, while acousticians processed over 7,000 blue whale calls in 'real-time'. The two voyages yielded 52 sightings (104 animals) of blue or like-blue whales; 48 animals were identified photographically (one on both voyages). Some blue whales that had been seen were not heard.

SC/64/SH12 summarised the methodological development of the use of DIFAR sonobouys for real-time tracking of blue whales. The results indicate that acoustic surveys may offer increased effective range over purely visual surveys of blue whales.

SC/64/SH26 presented an exploration into what encounter rates are plausible using acoustic-assisted tracking of whales, as opposed to a traditional visual-only survey (such as IDCR/SOWER). Given the lack of data, and the number of assumptions, abstractions, and approximations required in this simulation exercise, the authors stressed that the estimates in the paper should not be considered accurate or precise.

SC/64/SH10 presented a great advancement on the feasibility study of methods to obtain a new estimate of circumpolar abundance of Antarctic blue whales. Using the seasonality and location of sightings and acoustic detections from IWC-SOWER surveys, and historical catch data, it was concluded mark-recapture surveys should target putative hotspots and make use of passive acoustic tracking to increase encounter rates. With a reasonable level of effort a viable estimate of circumpolar abundance could be obtained for Antarctic blue whales within a ten-year period (and see Item 19).

The Committee recognises that the longer-term timeline to estimate abundance of Antarctic blue whales is more appropriate and logistically more feasible than the shorter periods considered earlier in the project's development. It **welcomes** the suite of papers linked to the Antarctic Blue Whale Project and the considerable advancement in the project's development. Further mark-recapture simulations studies may be valuable to investigate the effects of variability in effort between years within the suggested ten year timeframe and also to investigate the interaction between spatial variability in effort and possible population structure. This simulation could assess the consequences of only targeting 'hotspots' and the potential heterogeneity in capture probability potentially generated through this approach.

Further the Committee **encourages** ships contributing to the ABWP to, whenever possible, also collect environmental data for habitat modelling and data on other whale species sighted. In some circumstances environmental data can be collected through remote sensing but this is often problematic around Antarctica due to extensive cloud cover. Gliders and floats may provide another opportunity to collect high resolution water column data.

10.3.1.3 PLANNING OF FUTURE RESEARCH

The Committee was pleased to receive a number of papers on future blue whale research (see Annex H, item 3.1.2.2 for full discussion of these).

SC/64/SH13 presented a preliminary plan for an Australian funded voyage to contribute to the SORP Antarctic Blue Whale Project. The aim of the Antarctic Blue Whale Project is to develop technologies and collect data that will ultimately deliver a new circumpolar abundance estimate for Antarctic blue whales. The voyage will focus on blue whales in waters west of the Ross Sea (i.e., 135-175°E), an area that has been associated with higher densities of blue whales. The plan will be further developed and reviewed once the project management structure for the Antarctic Blue Whale Project is established which includes the formation of technical committees on passive acoustics, individual identification, and survey design.

The Committee **emphasises** the importance of collecting opportunistic data on other whales (sightings, faecal collection, biopsies) and environmental data, while recognising the value of clear priorities, particularly when the number of days 'on-site' in good weather can be few, even for longer Antarctic voyages.

SC/64/O16 presented the South African Blue Whale Project which is intended to initiate a long-term monitoring programme of blue whales in the Antarctic sector east of the Greenwich meridian, coupled with investigations of their seasonal pattern of abundance at lower latitudes. Acoustic technology will be combined with traditional line transect sighting survey and mark-recapture methodology to study the distribution, abundance and movements of blue whales in the southeast Atlantic. This joint study is conducted by the University of Pretoria and the University of Washington, and has received funding for 3 years from the South African National Antarctic Programme, starting in 2012/13. One team member will receive training in AAR deployment during a cruise off Greenland this summer (SC/64/O17) under the SORP programme. Although data valuable to the SORP Antarctic Blue Whale Project will be collected on this voyage (photo-ID and biopsy samples), the project is more closely linked with another SORP project 'Acoustic trends in abundance distribution and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean (see SC/64/O13).

SC/64/SH25 proposed a project on the genetics of Antarctic blue whales in part using IWC samples. The contemporary Antarctic blue whale has been described by a relatively high mitochondrial DNA (mtDNA) haplotype diversity, and may have escaped a greater loss of genetic diversity due to its long life span, overlapping generations and the brief period of the bottleneck. The impact of 20th century commercial whaling on genetic diversity can be explored through a comparison of historic and contemporary genetic diversity. The Committee **recommends** that access to the samples continues for this work and encourages further sampling in South Georgia.

The Committee **endorses** these research projects and looks forward to reviewing the results.

10.3.1.4 PYGMY BLUE WHALES

SC/64/SH27 presented a study on the identity of blue whales that are regularly sighted in the Geographe bay region of Western Australia. Preliminary results based on measures of genetic structure indicate that the whales were all of the pygmy subspecies. Further samples from Geographe Bay are required to clarify whether these blue whales have fine scale genetic differentiation.

The Committee **welcomes** this paper which is discussed fully in Annex H, item 3.1.3, noting the contribution made by IDCR/SOWER samples to the study.

10.3.1.5 CHILEAN BLUE WHALES

The Committee was pleased to receive three papers on blue whales in Chilean waters and a full discussion can be found in Annex H, item 3.1.4.

Galletti Vernazzani et al. (in press) described the results of a collaborative research programme (the Alfaguara Project) conducted by Centro de Conservacion Cetacea on Chilean blue whales. From 2004 to 2010, eight aerial and 85 marine surveys were conducted off Isla de Chiloe, southern Chile, where a total of 363 individual blue whales were photo-identified. Recapture data support the hypothesis that the feeding ground off southern Chile is extensive and dynamic. Blue whale distribution off southern Chile was assessed and relative abundance, using sighting per unit effort and kernel density estimators was obtained.

SC/64/SH18 provided an update on the 2012 blue whale field season that reported the occurrence of a shift in blue whale distribution during 2012 from the southern Chile feeding area (Isla de Chiloe), as reported in previous years, to an additional feeding aggregation of blue whales in northern Chile (Isla de Chanaral).

The Committee recognized the value of such long-term datasets for understanding blue whale populations and **recommends** that they continue.

SC/64/SH19 presented an abundance estimate of Chilean blue whales by mark-recapture and line-transect techniques.

The Committee recognised that the area covered by the line-transect survey does not include the entire range of the population and so will underestimate the total population size. There are also issues related to possible structure amonf feedin groups and sampling that require further consideration with respect to mark-recapture estimation. The Committee **encourages** further work on this and looks forward to receiving additional analyses.

10.4 Western North Pacific gray whales

10.4.1 New scientific information

Results regarding mixing of western (WNP) and eastern (ENP) North Pacific gray whales illustrate the great conservation and management importance of a more comprehensive examination of gray whale movement patterns and population structure in the North Pacific. At last year's meeting the Committee noted that for such an effort to be successful it must be international and collaborative (Weller *et al.*, 2012). To facilitate this, and noting the existing safeguards for collaborators provided under the Committee's Data Availability Agreement, it recommended that a collaborative Pacific-wide study be developed under the auspices of the IWC, recognising that *inter alia* this will contribute to the Committee-endorsed Conservation Plan for Western North Pacific Gray Whales and incorporate previous recommendations made by the Committee. Appendix 7 of Annex F provides an update on progress made to date.

The Committee **commends** the highly collaborative, international research effort for the progress made to date and look forward to future updates. The Committee also received several papers on stock structure and movements of north Pacific gray whales that resulted from this or other related programmes. Details can be found in Annex F, Item 4.1.

10.4.1.1 SATELLITE TAGGING

Mate summarized results regarding the recent collaborative efforts between Russian and US scientists to satellite track western gray whales under a programme undertaken with guidance from the IWC Scientific Committee and the IUCN WGWAP (Western Gray Whale Advisory Panel). The main goal of the project was to determine migration routes and breeding areas of tagged gray whales from the western North Pacific in order to develop improved conservation measures for this very small population. A total of seven whales were tagged in 2010 and 2011. The three longest tracked whales moved east across the Bering Sea and into the northeast Pacific where they overlapped with the range of eastern gray whales. Each animal followed a different route. The transmitter for a whale tagged in 2011 has lasted almost a year and continues to transmit. It travelled to near the southern tip of Baja California, Mexico during the winter and returned to near Sakhalin Island, Russia this spring. The autumn and spring migratory routes differed. These results, along with those from photo-identification matches from the eastern and western Pacific have caused the Committee to examine overall stock structure of gray whales in the North Pacific and to initiate the ocean wide research programme referred to above.

Mate also presented information on a plan for the A.N. Severtsov Institute of Ecology and Evolution of the Russian Academy of Science (IPEE) and Marine Mammal Institute of the Oregon State University to continue tagging western gray whales following the guidelines already developed by the IWC (IWC, 2012k). It is intended to tag up to 20 animals off Kamchatka (there is some interchange between animals

off Kamchatka and Sakhalin) beginning in early July. The objective is to provide additional information on stock structure and to assist in developing conservation measures. The programme will also involve photo identification and biopsy work. Photos will be made available to all catalogues and genetic samples will again be submitted to the IWC archive.

There was some discussion about whether tagging in Kamchatka was as beneficial as further tagging off Sakhalin as detailed in Annex F. The Committee **agrees** on the value of future telemetry work off Kamchatka and Sakhalin and **reiterates** its previous guidelines for such work (IWC, 2012k). Advice from the IWC/IUCN steering group chaired by Donovan on the full proposal will be provided to the research team in sufficient time to assist preparations for the field programme. The Committee also **recommends** that an evaluation of healing of the wounds caused by the satellite tags be undertaken and provided at next year's meeting. .

The Committee also received information on plans for telemetry work on eastern gray whales. Quakenbush and her colleagues plan to tag up to 10 gray whales near Barrow and Saint Lawrence Island in 2012. The main goal is to document the distribution, movements, and feeding areas of gray whales relative to oil and gas activities in the Chukchi Sea. The project will include the collection of photographs and biopsies. Data will be shared with other gray whale research groups. Mate plans to tag some additional PCFG gray whales in 2012 in Oregon and northern California. The objective is to investigate if the variable migratory timing, routes, and Baja California destinations are similar to those found in 2009 and 2010.

10.4.1.2 PHOTO-IDENTIFICATION

SC/64/BRG13 provided results from a photographic comparison of gray whales off Sakhalin Island, Russia with animals in lagoons of Baja California, Mexico. Additional information about another match was reported subsequent to the submission of SC/64/BRG13. In total, photographs of 217 identified gray whales were obtained from the Sakhalin Island feeding grounds and compared with 6,546 photo-identified individuals from the Baja California breeding lagoons. The research team found a total of 14 matches from the 217 Sakhalin whales, including six males, six females and two animals of unknown sex. Thirteen whales had sightings in Russia prior to and after their respective sighting in Mexico. Five females with calves were sighted in the winter in Mexican waters and in the next summer off Sakhalin, three of them without calves suggesting that these females had either separated from their calves or that their calves did not survive. The matches made between whales sighted off Sakhalin and the Mexican Pacific are the first results of the multinational collaboration.

The Committee **thanks** the authors and their colleagues for reconciling the Mexican photo catalogue. This will be a useful tool to address many questions, such as the relationship between Sakhalin and Mexico gray whales. The Committee also **acknowledges** the collaboration among the international group of gray whale researchers as a great example of how scientists can work together to address questions of great importance.

Another example of the multinational collaboration involves the photo comparisons being conducted among three: the Russia-US Sakhalin catalogue, the Institute of Marine Biology (IBM) Sakhalin catalogue, and the IBM Kamchatka catalogue (Appendix 9 of Annex F presents preliminary results from this study).

Updated information on research and conservation in Japan was presented in SC/64/O8. In March 2012, a gray whale was sighted on the Pacific coast of Aichi Prefecture, in the middle of Japan and some photos of the animal were taken. No stranding or entanglement of this animal occurred. The Committee was also informed that there are some photographs (and genetic samples) in Japan that might contribute to a better understanding of stock structure of north Pacific gray whales. Japan expressed interest in joining the international collaboration and named Kato as the contact person. The Committee welcomes this news and **encourages** sharing of photographs and genetic samples with existing catalogues and genetic databases.

The Committee **commends** the above highly collaborative, international research effort for the progress made to date and **encourages** enhanced collaboration, if at all possible. The Committee **strongly recommends** the continuation of the IWC collaborative programme as outlined in Annex F, especially the plans to collect additional biopsy samples for genetic comparisons and photographs for catalogue comparisons. It was suggested that analyses be conducted to assess whether any patterns in the genetic data could be identified when Sakhalin whales known to have overwintered in the Eastern North Pacific are compared to the other sampled animals off Sakhalin as well as to those sampled in the Eastern North Pacific. The Committee also **recommends** that existing data be used to attempt to estimate the proportion of animals that regularly feed off Sakhalin and also migrate to the eastern North Pacific in the winter.

10.4.1.3 OTHER

SC/64/BRG10 provided a summary of past and current records of gray whales off the coasts of Japan, China and Korea. There are only 13 known sighting or stranding records in Japanese waters between 1990 and 2007 (Nambu *et al.*, 2003). Observations of gray whales in China are also exceptionally rare. Gray whales were once common and hunted off the coast of the Korean Peninsula but the last reported commercial catches were in 1966 and the last known sighting off

Korea was in 1977. This suggests that they have abandoned the migration corridor along the Korean Peninsula or that a subpopulation using the Korean Peninsula is now extinct. The evidence that some Sakhalin animals migrate to the west coast of North America during the winter/spring, along with observations off Japan, Korea and China during the winter/spring, in combination with significant genetic differences between the eastern and western populations (Lang *et al.*, 2011) suggest that the number of whales in the western North Pacific population is potentially smaller than the currently estimated ~150 whales that use the Sakhalin summer feeding area.

This paper stimulated considerable discussion as can be seen in Annex F. The Committee emphasises the importance of the collaborative oceanwide programme and the need to review stock structure of gray whales throughout the North Pacific. It was noted that photographs (albeit low quality) of a gray whale that died in fishing gear in China in November 2011 have been compared with several catalogues (i.e., the Russia-US, IBM Sakhalin, and IBM Kamchatka) but no matches have been made.

In conclusion, the Committee **welcomes** all of the information on this critically endangered population and the broader question of stock structure. It **encourages** further work and as in previous years, **re-emphasises** the importance of continued long-term monitoring. Recognising some difficulties of interpretation given the new information on movements, the Committee also encourages Cooke to complete and publish his assessment of the gray whales feeding off Sakhalin using the combined photo-identification datasets. This rich dataset can provide valuable information for assessing possible anthropogenic impacts on animals feeding in the area.

10.4.2 Conservation advice

As in previous years, the Committee **acknowledges** the important work of the IUCN Western Gray Whales Advisory Panel. This year's update on the panel's activities is given in Appendix 10 of Annex F. The Committee **re-emphasises** its view of the importance of the Panel's work and reiterates its support. Furthermore, the Committee **recommends** that appropriate monitoring and mitigation plans be implemented for all oil and gas activities that occur in the range of western gray whales, especially if another platform is to be built or installed off Sakhalin.

The Committee again **recognises** that the problem of net entrapment of western gray whales is a range-wide issue. It **welcomes** Japan's administrative actions related to conservation of gray whales (SC/64/O8) and the efforts of other range states to reduce mortality, such as net entrapments that occur in other range states, including Canada, US and Mexico on the eastern side of the Pacific. Continued international collaboration to elucidate population identity and stock structure, as emphasised above, will provide valuable information for future management advice.

10.5 Southern Hemisphere right whales

10.5.1 Review report from intersessional workshop

Bannister introduced the report of workshop, held in Buenos Aires, Argentina, from 13-16 September 2011 (see SC/64/Rep 5). He noted that although substantial progress had been made on much of the agenda, additional work was needed on some sections, especially the completion of analyses related to abundance and assessment. It was also noted that subsequent revisions of some analyses meant that sections of the report required clarification or amendment. As a consequence, two groups (an assessment group and a drafting group) were established to complete this work.

The Committee recognises the substantial work undertaken at the workshop and **welcomes** the report, thanking particularly the Chair, rapporteurs and the host. It noted the large number of recommendations the report contained and prepared the following consolidated version incorporating additional comments and recommendations from the Committee as appropriate.

10.5.1.1 LONG-TERM POPULATION MONITORING

The Committee has long recognised the value of long time-series in informing, prioritising and evaluating conservation and management actions for whales, including monitoring the effectiveness of mitigation measures and Conservation Management Plans. In particular, it stresses the value of maintaining annual data sets, especially those that include information on the calving intervals of individual females, for their potential importance in analysing the influences of climate and environmental variables on southern right whale reproduction. The Committee therefore **strongly recommends** that all existing southern right whale data sets of this nature (e.g. in Argentina, Australia and South Africa) be continued on an annual basis, and that similar programmes be established wherever possible for other areas.

In this connection, the Committee received a proposal requesting interim relief funding for the 2012 aerial survey off South Africa (Annex F, Appendix 2) and **recommends** its support (see item 23).

In addition, the Committee **recommends** that the annual CENPAT programme of aerial surveys around Península Valdés, which is independent of the long-term aerial photo-identification programme and substantially increases the areal and temporal survey coverage, should be continued on an annual basis.

10.5.1.2 POPULATION STRUCTURE AND LINKAGES

The population structure and stock identity of southern right whales remain incompletely described. A

particular challenge is to distinguish adjacent stocks with different demographic histories and apparent rates of recovery. To address this, the Committee **recommends** that a circumpolar collaboration proceed to assemble standard genetic information from all available samples (see SC/64/Rep5, Table 5), that could *inter alia* update the previous analysis by (Patenaude *et al.*, 2007) of the genetic structure of southern right whales on their calving/nursery grounds.

A number of standard genetic protocols are **recommended,** including standardisation of mtDNA preparation and nomenclature, standardisation of microsatellite loci, and the exchange of samples between laboratories to establish allelic standards and provide quality control (see SC/64/Rep5). Further tissue sampling is also **strongly recommended** in a number of areas including Australia, Chile/Peru, Southern Africa and Brazil (see Annex F and SC/64/Rep5 for more details). In addition, to investigate relationships with other southern populations, further analysis of existing genetic samples from South Africa (n = ~600) is **recommended**.

Recognising the importance of being able to allocate offshore ('pelagic') catches in the Southern Ocean and in low-latitude areas to the appropriate calving/nursery/breeding grounds, the Committee **recommends** that genetic (biopsy), photo-identification and satellite tagging data are applied to identify linkages.Further investigation is **recommended** of: (a) connections between whales in the New Zealand sub-Antarctic and those in mainland New Zealand and (b) philopatry to mainland New Zealand (for details see Annex F and SC/64/Rep3). It is also **recommended** that biopsy samples, satellite tagging data and photo-identification data be linked, where possible.

While recognising the value of genetic analyses in solving the problems of population structure and linkages, the Committee also **recommends** other approaches such as inter-catalogue comparisons. Similarly, the value of strategically deployed satellite tags in depicting movements has already been demonstrated for southern right whales, and the Committee **recommends** that such studies continue.

10.5.1.3 MODELLING

The Committee **recommends** further investigation of the conversion factor used to estimate total population size from the estimated adult female component. Such investigation needs to consider that there has been only a relatively short period of recovery and that therefore the age distribution is unlikely to be steady and the estimated survival rate is likely to be biased upwards from the average that would apply in a steady situation.

10.5.1.4 JOINT ARGENTINA/BRAZIL ASSESSMENT

Noting the preliminary nature of Cooke's analyses, the Workshop had decided not to append the results to their report. It had recommended that progress towards the 'joint assessment', using data from both Argentina and Brazil, be made as quickly as possible and that an update also be presented on this work at the 2012 Scientific Committee meeting. Cooke provided an assessment of the 2010 Argentine population including a rate of increase from 2000-2010 to the meeting (Annex F, Appendix 3). The Committee **welcomes** this and **agrees** to include the results in the Workshop's assessment of the status of the southern right whale population in 2009, appreciating that until a joint Argentine/Brazilian assessment had been completed these results must be considered preliminary in nature. The Committee **recommends** that the joint Argentine/Brazilian assessment be completed as soon as possible, and the results presented to the 2013 Annual Meeting.

10.5.1.5 ASSESSMENT OF THE CHILE/PERU POPULATION

In order to obtain information on the distribution and abundance of this Critically Endangered population, to clarify its status and identify any threats and possible mitigation actions, the Committee **recommends** that surveys, photo-identification and genetic studies should be conducted as a priority. Specifically, the following steps should be taken:

(1) determine geographical/temporal areas where quantitative studies can best be conducted, through analysis of existing historical whaling and sighting data and appropriate temporal/geographical spatial modelling;

(2) design a systematic survey programme (aerial surveys may be the most efficient) to cover potential calving or nursery areas, bearing in mind logistical and practical limitations; and

(3) further consider stock structure issues by examining existing genetic samples (including museum specimens where possible) and collect new samples in southern Chile/Argentina.

10.5.1.6 IDENTIFICATION OF CONCERNS AND THEIR MONITORING

Given that there was evidence of continuing direct removals via entanglements in fishing gear and ship strikes, the Committee **recommends** all countries to include reports of ship strikes and entanglement events in their annual progress reports to the IWC through the new online portal (see item 3.2).

The Committee **strongly reiterates** the research and management recommendations made at the Workshop on the Southern Right Whale Die-off (IWC, 2011h). In addition, in view of the severe impacts of gull attacks documented at Península Valdés and the risk that this learned behaviour on the part of gulls could proliferate, the Committee **recommends** that Brazilian authorities consider taking immediate action if and when similar gull behaviour is observed. Some members felt that this

action should specifically include the removal of attacking gulls, following similar steps being undertaken by Argentina in the Peninsula Valdes area.

The Committee noted that some concerns have been raised about the potential effects of fishing and climate change on krill and hence on krill predators. The Committee also noted that the CCAMLR Scientific Committee was investigating these matters and encourages further collaboration between IWC and CCAMLR on the development of relevant ecosystem models.

10.5.1.7 DEVELOPMENT OF CONSERVATION MANAGEMENT PLANS (CMPS)

The Committee **recommends** that any draft CMPs take into account the recommendations made at the Buenos Aires workshop and the workshop on the die-off of southern right whales and use these as the basis of action development (IWC, 2011h). The Committee was pleased to note that this was the case for the two draft CMPs it received (see below).

10.5.1.8 CONCLUSION

The Committee noted that the Workshop Report (SC/64/Rep5) had reached conclusions on the current status of the overall Southern Hemisphere right whale population based on a modelling exercise undertaken during the workshop using the best available parameter values. However, the Workshop had recognised that the calculations were very dependent on (1) the results of the as yet incomplete analysis of the Argentinian/Brazilian population to be provided by Cooke, and (2) on different conversion factors from mature female to total population size derived from the Argentine and South African populations.

Cooke advised that the parameter values for Argentina he had provided during this meeting (Annex F, Appendix 3) still required some updating. However, he agreed that he would forward them by 1 July 2012 to Butterworth and his colleagues so that a revised circumpolar analysis using the same approach as in Buenos Aires could be completed. It was agreed that the updated analysis would be incorporated into the Buenos Aires workshop report with an appropriate editorial note. This full report would then be circulated to workshop participants for any final comments and included in the published version in JCRM.

Cooke reported that it was impossible to undertake the recommended joint Argentina/Brazilian assessment until matching between photo-identification catalogues had been completed. However, he confirmed that excluding Brazil from the overall assessment was unlikely to have a major effect on the resultant circumpolar estimate because of its relatively small size (some other small populations for which no estimates exist are also excluded from the assessment). It was also noted that updated calculations using the Argentina and South African data had resulted in a convergence of conversion factors (Annex F, Appendix 3) so that these are no longer a major issue in estimating total population size for use in the assessment.

10.5.2 Review new information

10.5.2.1 SOUTHWEST ATLANTIC

The Committee received three papers on this population. They are briefly summarised below but a full discussion can be found in Annex F, Item 3.3.2.

SC/64/BRG12 presented updated information on the southern right whale die-offs at Península Valdés, Argentina for the 2010-2011 seasons. Systematic efforts to study the strandings have continued since 2003. A total of 482 dead whales were recorded at Península Valdés between 2003 and 2011. At least 55 whales died in 2010 and 61 died in 2011. As in previous years, the vast majority of strandings were calves of the season.

SC/64/BRG7 reported an analysis of metal levels in the skin of living southern right whales at Península Valdés, Argentina, as part of efforts to investigate the recent die-offs. The levels of nonessential and essential metals in the skin of 10 animals were on the low end of the spectrum of measured concentrations when compared to other studies. The authors cautioned that these low levels should not necessarily be interpreted as being safe since the effects of metals in marine mammals are largely unknown.

There was lengthy discussion on the possible reasons for changes in the observed calving interval. In conclusion, the Committee **reiterates** the recommendations of the southern right whale die-off workshop (IWC, 2011h) and **encourages** the continuation of the studies presented in SC/64/BRG7 and SC/64/BRG12 to better understand the mechanism(s) behind the observed mortality.

SC/64/BRG20 presented an abundance estimate of southern right whales by aerial line-transect surveys for a bay area of Bahía San Antonio, Argentina, from late summer to fall in 2009-2011. A corrected abundance estimate using g(0) is 207 (CI=99-315) in 2010, which is the maximum among the three years. These aerial surveys resulted in the first specific estimates of southern right whale abundance in this north Patagonian bay although more consistent aerial surveys should be conducted.

10.5.2.2 SOUTHERN AFRICA

SC/64/BRG24rev applied the three-mature-stages (receptive, calving and resting) model of Cooke *et al.* (2003) to photo-identification data available from 1979 to 2010 for southern right whales in South African waters. The 2010 mature female population is estimated to be 1,309, the total population is 4,725, and the annual population growth rate 6.8%. Information from re-sightings of grey blazed calves as adults with calves allows estimation of first year survival rate of

0.914 and an age at 50% maturity of 6.4 years. In contrast, the relative proportions of grey blazed animals amongst calves and amongst calving adults suggest rather a value of 10% (SE 8%). If the proportion losing markings is in fact 10%, first year survival rates estimate drops to [0.859] and the population growth rate to [6.6%] per year.

Best presented an analysis in which he had assembled data from foetuses, biopsied calves and stranded calves to test the assumption that the neonatal sex-ratio in southern right whales was 50:50. The most appropriate data set suggested a ratio closer to 46 male: 54 female (Annex F, Appendix 4). The base case model of SC/64/BRG24 with this alternative sex ratio of 54:46 resulted in the total population 4,359 (Annex F, Appendix 5). The main differences in the parameter estimates were a lower first year survival rate with a corresponding higher value of the estimate for the probability that a grey blazed calf maintains its markings until becoming an adult.

10.5.2.3 SOUTHWEST PACIFIC AND NEW ZEALAND

Carroll et al. (*in press*) provided results on paternity assignment and 'gametic recapture' to examine the reproductive autonomy of southern right whales on their New Zealand calving grounds. The 'gametic mark-recapture' estimate of male abundance 1,001 was directly comparable with the 'census estimate' of male abundance, N=1,085, for the stock, based on standard genotype mark-recapture modelling. Simulations indicated the assumption of equal reproductive success amongst males was not violated. Power analyses suggested that these findings would be highly unlikely if the population was open to gene flow from other, larger populations in the Indo-Pacific region. The authors concluded that these findings are consistent with the hypothesis that southern right whales returning to the New Zealand calving ground are reproductively autonomous on a generational timescale, as well as isolated by maternal fidelity on an evolutionary timescale.

10.5.2.4 AUSTRALIA

SC/64/ProgrepAustralia provides information on southern right whales obtained on survey flights off the southern Australian coast between Cape Leeuwin and Ceduna in August 2011. The most recent updated increase rate for this Australian 'southwest stock' for 1993-2011 is 6.82% for all animals (CI 4.24-9.47), and 7.21% for cow/calf pairs (CI 3.70-10.85) with current population size *ca* 2,900; including the much smaller 'south east' Australian stock, the Australian population as a whole is likely to number *ca* 3,500.

10.5.2.5 SOUTH EAST PACIFIC RIGHT WHALES

Off northwestern Isla de Chiloe, four sightings of the critically endangered Chile/Peru "sub-population" between September and November 2011 were documented, including the first incidence of reproductive behaviour and the first resighting of a known individual in Chile. In addition, some 30km north, the southernmost record of a mother-calf pair was recorded. These observations suggest that northwestern Isla de Chiloe is part of a breeding area with undetermined boundaries. This highlights the importance of these coastal waters and the need to continue long-term studies, both dedicated and opportunistic, to monitor this critically endangered population.

10.5.2.6 GENETIC RESEARCH

SC/64/BRG15 reported on progress with the investigation of the worldwide genomic diversity and divergence of right whales. Through collaborative agreements, the investigators have obtained representative samples from all three oceanic species. The investigators have used next-generation sequencing technology to develop genomic profiles by sequencing the complete mitochondrial genomes and multiple nuclear genes for each individual. To date, the results provide greatly increased resolution of the divergence between the three recognised species, and the diversity within each oceanic population.

The Committee noted that the project was generally methodologically sound and the objectives of the study were likely to be achieved. Although some concerns were expressed about limited number of samples and a possible need for more emphasis on the nuclear aspect of the survey, the Committee **recommends** funding the final stage of the project (see Item 23).

Review of "Draft Conservation Management Plans for Southern right whales"

The Commission has agreed that Southern right whales of South America should be candidates for IWC Conservation Management Plans (IWC, 2012b). As discussed in Annex F, two draft plans were available, one for Southwest Atlantic southern right whales (IWC/64/CC7Rev1) and one for southeastern Pacific southern right whales (IWC/64/CC9).

The Committee examined these draft CMPs for their scientific content and related actions and found them to be in accord with the results and recommendations from the IWC workshops on the Status of Southern Right Whales (SC/64/Rep3) and the Southern Right Whale Die-off (IWC, 2011h).

10.6 Other stocks of right whales and small stock of bowhead whales

An update was provided on North Atlantic right whales for the period November 2010 - October 2011, reflecting the work of North Atlantic Right Whale Consortium, 2011. A collaborative photographic catalogue suggested that there were 490 North Atlantic right whales in 2010. Five right whale deaths were documented during the report period. Additionally, there were 11 new entanglement cases documented.

The Committee **thanks** the authors for this update and looks forward to receiving further information next year.

SC64/ProgRepJapan reported that in February 2011, a right whale was found dead in a set net in Oita prefecture. A skin sample was sent to the Institute of Cetacean Research (ICR), where DNA was extracted and it was confirmed as a right whale. However, the ICR branch in the Tohoku region was hit by the tsunami on 11 March 2011 and the sample was lost.

SC/64/O6 reported sighting information for North Pacific right whales from sighting surveys conducted in May 2011 in the western North Pacific. A total of 13 schools (20 individuals) was sighted, from which 19 individuals were photographed and 14 biopsied successfully.

The Committee **welcomes** new information on North Pacific right whales, noting that such sightings were rare. It looks forward to receiving a fuller report of the sighting survey at the next meeting.

No update was available for the small stock of bowhead whales in the Sea of Okhotsk.

Moore *et al.* (2012) provided results of a year-long acoustic study of the Spitzbergen stock of bowhead whales from September 2008 to September 2009 in western Fram Strait (79°N, 5°W). The rate of bowhead whale call detection was high from September 2008 through May 2009, including calls detected on every day of the month from November through February when sea ice was 90-100% surface cover.

The Committee continues to **reiterate** its grave concern over these small stocks and **encourages** continued or expanded research on these small populations.

10.6.2 Work

The Committee's views on the workplan for these stocks are given under item 21.

10.7 Arabian Sea humpback whales

10.7.1 Review intersession progress

The Scientific Committee has in the past (most recently in IWC, 2012m), recommended further research to help address the serious conservation status of the Arabian Sea humpback whale which is recognized as an isolated resident sub-population of humpbacks with an estimated population size of 82 (95% CI 60-111; Cerchio *et al.*, 2008; Minton *et al.*, 2011).

SC/64/SH30 provided details of surveys, shore-based observations, and passive acoustic monitoring conducted in Oman during October 2011-March 2012. A total of 36 humpback whales was encountered, 33 of which were photographed and 16 were newly identified individuals. No feeding was observed in the southern survey site and there were nearly three times fewer whales encountered this year. Differences in relative density and feeding may be due to annual fluctuations in food availability as a result of variable oceanographic conditions. Three mother-calf pairs were recorded in Oman during 2011 - 2012, one of which entered the newly operational multi-purpose Port of Duqm. These are the first documented records of humpback whale calves in Oman since 2000. Two mortalities were recorded in January and April 2012. An adult female floating at sea was photographed by local fishermen and a juvenile that stranded live on a remote stretch of shoreline and was subsequently buried by the local municipal authority before scientific investigation could be conducted.

Observations of severe entanglement scarring, as well as coastal road development, operation of a large new port at Duqm, and the planned inauguration of several fast ferry routes through known humpback whale habitat are cause for concern. Efforts are underway to highlight the population's conservation needs with local, national and regional governments as well as the general public, and progress is being made toward the formation of a network of researchers and managers responsible for the design and implementation of a Conservation Management Plan, as recommended last year (IWC, 2012f, p.25).

The Committee expresses **concern** over the relatively large number of strandings from this small population (9 over a 12-year period). Given its endangered status under the IUCN red list and the potential for growth of unregulated whale watching in the region, the Committee **recommends** that whalewatching vessel operator training workshops should be conducted with a view to promoting best practice for whalewatching and to support the need for development of whalewatching guidelines (see Item 23.

The Committee further noted plans to produce an updated mark-recapture estimate of population size. It **reiterates** its earlier recommendation (see International Whaling Commission, 2011), regular abundance surveys to be repeated on a regular basis, with assistance in planning and analysis from relevant experts.

10.7.2 The development of a CMP

The Committee has previously noted that this population is a likely candidate for an IWC Conservation Management Plan (CMP). An intersessional working group was formed at last year's IWC meeting to facilitate this process in accordance with the guidelines adopted last year by the Commission (IWC, 2012b). A key component of any plan is that it is supported by a broad range of stakeholders including range state governments. The Committee welcomes the progress that has been made in assembling the documentation required to submit a proposal to the IWC for a candidate CMP. It strongly **recommends** that discussions between scientists and

relevant range state governments continue to further progress the CMP process.

10.7.3 Work plan
The Committees views on the workplan for BRG are given under Item 21.

10.8 Cruises

10.8.1 The IWC-POWER programme

10.8.1.1 PLANNING THE IWC-POWER[14] PROGRAMME

The Scientific Committee has been discussing the objectives and priorities of the IWC POWER programme since 2009 (e.g. IWC, 2012t) and this culminated in the discussions given in IWC (2012l).

The Committee and the Commission agreed the long-term objectives for the programme in IWC (2012l).

> 'The programme will provide information to allow determination of the status of populations (and thus stock structure is inherently important) of large whales that are found in North Pacific waters and provide the necessary scientific background for appropriate conservation and management actions. The programme will primarily contribute information on abundance and trends in abundance of populations of large whales and try to identify the causes of any trends should these occur. The programme will learn from both the successes and weaknesses of past national and international programmes and cruises, including the IDCR/SOWER programme.'

(IWC, 2012t) provided an extensive review of current knowledge in the region, and a list of medium-term priorities by species for the programme was developed.

SC/64/Rep1 presents the report of a meeting of the Technical Advisory Group (TAG) established last year. The report builds upon the extensive work already undertaken to provide an overall strategy and detailed 5-year plan for the IWC POWER programme, including statistical power calculations. The TAGshop initially focused on methodological issues to investigate distribution, abundance and trends. It made a number of practical recommendations for visual methods (SC/64/Rep1, Item 3.1) regarding survey mode, track design, and angle and distance experiments. Initial power analyses suggest the need for increased future effort (at present only one vessel is available) to be able to detect trends. The results of the short-term programme (see below) will allow improved power analyses and a better determination of required effort for the medium-long-term. Other techniques examined included mark recapture and acoustic methods and recommendations for further investigative and collaborative work were made. It also examined past data to investigate the amount of effort required to obtain photo-IDs and biopsy samples; this information is valuable for both short- and medium-term planning.

After reviewing the available information, an integrated short-term strategy (for the years up to 2015) was developed in light of the medium-long-term objectives (SC/64/Rep1, item 7.1). The objective is to complete an initial survey of the remaining poorly covered areas (SC/64/Rep1, fig 1) to facilitate choice of appropriate survey blocks and strata for a long-term monitoring plan along with the essential undertaking of a more specific power analysis of the effort required to detect trends in abundance should they occur.

The TAG also made recommendations on the need for improved data collection systems, archiving of all kinds of data collected during the programme and a mechanism to ensure prompt collaborative analyses of the data collected (SC/64/Rep1, item 6). A detailed proposal for how to address these issues will be made at the 2013 Annual Meeting.

The Committee welcomes this report and **endorses** its recommendations. Noting the valuable contributions already made by Japan, Korea, the USA and Australia, it **strongly encourages** range states and others to consider more active participation in the IWC-POWER programme.

10.8.1.2 REPORT ON THE 2011 IWC-POWER CRUISE

The 2nd annual IWC-POWER survey was successfully conducted from 11 July to 8 September 2011 in the eastern North Pacific (north of 40°N, south of the Alaskan Peninsula, between 170°W and 150°W) using the Japanese Research Vessel, the *Yushin-Maru No.3*. The cruise had five main objectives:

(a) to provide information for the proposed future in-depth assessment of sei whales in terms of both abundance and stock structure;
(b) to provide information relevant to *Implementation Reviews* of whales (e.g. common minke whales) in terms of both abundance and stock structure;
(c) to provide baseline information on distribution and abundance for a poorly known area for several large whale species/populations, including those that were known to have been depleted in the past, but whose status is unclear;
(d) to provide biopsy samples and photo-identification photos to contribute to discussions of stock structure for several large whale species/populations, including those that were known to have been depleted in the past but whose status is unclear; and
(e) to provide essential information for the intersessional workshop to plan for a medium-long term international programme in the North Pacific.

[14] North **P**acific **O**cean **W**hale and **E**cosystem **R**esearch programme

Plans for the cruise were endorsed by the Committee (IWC, 2011) and the Committee agrees that it was duly conducted following the guidelines of the Committee.

On behalf of the Committee, Kato thanked the Cruise Leader, researchers, captain and crew for completing the second cruise of the POWER programme. The Government of the USA had granted permission for the vessel to survey in its waters, greatly contributing to the success of the cruise. The Government of Japan generously provided the vessel and crew for the survey.

Recognising the tremendous effort and expense in conducting the IWC-POWER survey, the Committee was yet again disappointed that potentially valuable data on stock structure was not able to have been collected as it had not been possible to resolve CITES permit issues regarding collection of biopsy samples collected outside of Japanese waters. The Committee **strongly recommends** that these issues are resolved. In planning for the 2013 survey, Hiruma reported that some initial progress on this front was made, and would continue. He hoped to be able to report a positive outcome to ongoing talks between the governments of Japan and USA in the near future. Brownell explained that the Japanese research vessel with biopsy samples collected on the high seas can enter and exit the US EEZ without a CITES permit, but biopsy samples cannot yet be collected in the USA.

10.8.1.3 THE 2012 IWC-POWER CRUISE

SC/64/Rep 7 presented the report of the detailed planning meeting for the 2012 IWC-POWER cruise that had been endorsed last year (IWC, 2012l). The cruise will take place north of 40ºN to the North American coast between 140°W and 135°W. The vessel kindly supplied by Japan will depart on 13 July 2012. The Committee **endorses** the report and looks forward to receiving the report of this cruise next year.

10.8.1.4 PLANS FOR THE 2013 IWC-POWER CRUISE

SC/64/O7 presented the research plan for the fourth survey in the IWC-POWER programme. The research area will be from the area from 160º-135ºW, between 30º- 40 ºN latitude. The plan was drawn up following guidelines agreed at the 2010 and 2011 Tokyo Planning Meetings (SC/63/Rep5 and SC/64/Rep1) and in light of the objectives developed in SC/64/Rep1. The cruise will collect line transect data, to estimate abundance, and biopsy/photo-id data. Biopsy sampling will be undertaken on priority species (sei, fin, right, blue and humpback whales) and on other species on an opportunistic basis. Some dedicated research time will also be allocated to photo-identification and/or video-taping of fin, right, blue and humpback whales. Final planning will take place at a planning workshop to be held in Tokyo in October 2012.

The Committee thanks the Government of Japan for its generous offer of providing a vessel for this survey.

10.8.2 Other North Pacific cruises (and see Item 6)

10.8.2.1 REPORT OF JAPANESE CETACEAN SIGHTING SURVEYS IN THE NORTH PACIFIC IN 2011

Three systematic dedicated cetacean sighting surveys were conducted in 2011 by Japan (ICR) as a part of JARPNII to examine the distribution and abundance of large whales in the Western North Pacific. The total searching distance was 4,060.3 n.miles. The sei whale was the main species sighted. The plans for these surveys were endorsed in the last year (IWC, 2012f) and the surveys were conducted as planned (SC/64/O6).

10.8.2.2 PLANS FOR JAPANESE CETACEAN SIGHTING SURVEYS IN THE NORTH PACIFIC IN 2012

SC/64/IA6 reports on plans for three systematic dedicated sighting surveys by Japan (ICR) as a part of JARPNII in the North Pacific in 2012, the first of which is currently underway. The main objective is to examine the distribution and estimate the abundance of common minke and Bryde's whales for the management and conservation purposes. Distance and angle estimation experiments will be conducted on all crises. Biopsy skin samples of blue, fin, humpback and right whales will be collected on an opportunistic basis. Photo-identification experiments on blue, right and humpback whales will be also conducted opportunistically. Reports of the three sighting surveys will be submitted to the 2013 Annual Meeting.

10.8.3 Cruises in the Antarctic Ocean

10.8.3.1 PROGRESS ON IDCR-SOWER CRUISES PUBLICATIONS

An intersessional email correspondence group (IWC, 2012s, Annex R) worked by correspondence and also met at this meeting. Its terms of reference were to consider:

(a) updating the IWC website; and
(b) creating a special volume of the Journal of Cetacean Research and Management.

Plans are already underway with respect to (a) including inclusion of photographs, video, acoustic recordings and links to key publications and reports. Pertaining to (b), the Group prepared a proposed outline for the volume, with suggested authors/lead persons for each topic identified (see Annex G).

The Committee endorses the approach proposed. It agrees to the appointment of Bannister to lead the creation of the commemorative volume. An Editorial Board was nominated and tasked with responsibility for the volume's preparation.

The Committee **agrees** that the work contributing to the volume would be greatly facilitated by the preparation of some standard sighting datasets (for species other

than Antarctic minke whales). The Secretariat kindly agreed to prepare such datasets from DESS in collaboration with knowledgeable scientists.

10.8.3.2 REPORT OF THE 2011/12 CETACEAN SIGHTING SURVEY IN THE ANTARCTIC

Plans for a dedicated sighting survey in the Antarctic in the 2011/12 austral summer season were presented last year and subsequently endorsed by the Committee (IWC, 2012f). The research vessels *Yushin-Maru No 2* and *Yushin-Maru No 3* were to survey in Area IIIE, Area IV and western part of Area V. The survey methods were to be the same as in IWC-SOWER surveys, and trackline design was improved to provide approximately uniform coverage probability. Furthermore, the planned sighting procedure was in accordance with the guidelines agreed by the Scientific Committee (IWC, 2012v). Unfortunately no research activity could be conducted due to external violent interference by an anti-whaling group (SC/64/IA8).

The Committee **expresses regret** that these actions had prevented the sighting survey from being conducted as reportedly planned. Following the cessation of the IDCR/SOWER programme in 2009, these surveys now provide the only dedicated cetacean sighting data in this region of the Southern Ocean that might be used for abundance estimation, and as such are extremely valuable to the work of the Scientific Committee.

10.8.3.3 PLANS FOR CETACEAN SIGHTING SURVEYS IN THE ANTARCTIC IN THE 2012/13 SEASON

A systematic two-vessel sighting survey for abundance estimation is planned in the Antarctic in the 2012/2013 season (SC/64/IA7) as part of JARPA II. The research area is south of 60°S in the Antarctic, in the eastern part of Area III, throughout Area IV and in the western part of Area V, between 35°E and 175°E from December 2012 to March 2013. Details of the cruise, which also incorporates biopsy sampling and photo-identification work are incorporated in Annex G, Item 6.5. The cruise report will be prepared by researchers and submitted to next year's annual meeting.

The Committee reviewed and endorses the plans for the proposed sightings survey. Noting the insight gained in SC/64/Rep4 on internally-estimated cue rates, it suggests that efforts be taken to ensure accurate times of sightings in IO mode, so that delayed and simultaneous duplicates could be more readily distinguished. The Committee **agrees** that this will be useful for estimating abundance from these data, and also invited any further suggestions for improved survey protocols from the developers of the methods described in SC/64/IA2 and SC/64/IA13, based on lessons learned in completing their analyses.

10.9 Progress towards an in-depth assessment of North Pacific sei whales

SC/64/IA11 presented an abundance estimate of North Pacific sei whales using data from the 2011 IWC-POWER cruise. Standard line transect methodology was applied to estimate abundance, assuming $g(0)=1$. In order to examine the robustness of the abundance estimate to alternative stratification options and detection functions, a sensitivity analysis was conducted. The abundance estimate for the surveyed area in the eastern North Pacific (north of 40°N, south of Alaskan Peninsula, between 170°W and 150°W), was 6,587 (CV=0.420). When data from recent cruises become available, a revised abundance estimate for North Pacific sei whales will be presented using the IWC-POWER sighting data from the period 2010-2012.

The Committee also received the report of the inter-sessional working group that had been appointed last year to prepare for the assessment. The group saw no impediment to conducting the In-Depth Assessment (IDA) as planned in 2013. It is anticipated that analyses of sei whale sightings from the POWER surveys through 2012 will be available for the assessment. The IDA will not address the question of suitability of data for use in the RMP.

Work on the historical catch series has proceeded. Allison has received new data on Canadian historic catches that is being entered into the IWC database. The findings of a new analysis of Soviet North Pacific catch records are also being incorporated. Sei whale catches in the IWC database are higher than the true catches because protected species like fin and humpbacks were reported as sei whales.

The Committee was informed that Mizroch and Ohsumi have recently analysed a sample of Japanese coastal whaling log books, and found that the catches of sei and Bryde's whales are differentiated in the log books, while this is not the case in the IWC individual catch data base, although the total numbers agree. The Committee **recommends** that this work be extended, in collaboration with Allison, to cover the years for which the IWC and Japanese figures differ. The Committee also **recommends** that the Secretariat be requested to consolidate other historical catch series for this species, and together with the Working group, being collating all available information in order to complete this assessment.

The Committee **recommends** that the sei whale IDA proceed as planned at the 2013 Annual Meeting. An intersessional steering group was appointed to oversee preparations (Annex Q).

11. STOCK DEFINITION

This agenda item was established in 2000, when a Working Group was established (IWC, 2001c). This year, updated Terms of Reference were adopted by the Working Group to reflect the evolving needs of the Committee (Appendix 2, Annex I). Continuing its

original purpose, the Working Group will develop a reference glossary of stock related terms, to aid consistent definition of 'stocks' in a management context for the Committee (see 11.4). The Working Group will also continue to develop guidelines for preparation and analysis of genetic data within an IWC context (see 11.1), and software that evaluates the management utility of various population genetic analyses (see 11.3). A major change stems from the Committee's request for the Working Group to discuss high-priority Committee papers related to population structure. The Working Group will now provide the Committee with feedback and recommendations concerning stock structure related methods and analyses used in those papers (see 11.2). The Report of the Working Group is given as Annex I.

11.1 Guidelines for DNA data quality and genetic analyses

Two sets of reference guidelines have been developed and endorsed by the Committee (IWC, 2009e) and form 'living documents' that can be updated as necessary. The first set addresses DNA validation and systematic quality control in genetic studies (SC/64/SD2). The second set provides guidelines for some of the more common types of statistical analyses of genetic data used in IWC contexts, and contains examples of management problems that are regularly faced by the Committee. Substantial progress on these latter guidelines was made during a small workshop in April, and this document will now be completed intersessionally (see Item 11.5). Both guidelines will also be published in the peer-reviewed literature.

11.2 Statistical and genetic issues related to stock definition

A number of stock related papers were discussed by the sub-group at the request of the following sub-committees and Working Groups: Revised Management Procedure (Annex D), Aboriginal Whaling Management Procedure (Annex E), Pre-Implementation Review of Western North Pacific Common Minke Whales (Annex D1), and Other Southern Hemisphere Whale Stocks (Annex H). Technical comments on these papers are given in Annex I.

Some general comments were made which are relevant to many papers submitted to the Scientific Committee. Firstly the Committee noted that uncertainty around point estimates is not always considered and urged that, where available, confidence intervals should always be reported in order that precision of estimates can be evaluated. Secondly, failure to reject a hypothesis, e.g. panmixia, is not equivalent to support for that hypothesis; strong statements of support should not be given to any null hypothesis that has not been rejected. Thirdly, there is often inconsistent treatment and interpretation of the genetic differentiation metric 'FST' amongst papers. Simplistic interpretations of this statistic should be avoided, such as conversion into migration rates, as these can misinform management scenarios.

The Committee **agrees** to compile results from past RMP trials of various species intersessionally, in order to try to identify where there were 'tipping points' in inter-population migration rates which made significant differences to trial outcomes, i.e. at what level does migration make a difference for each species? Such information may help to better define the parameter space over which inter-population migration rates are informative to management. This work will be presented at the 2013 Annual Meeting (see 11.5) and can be carried out in conjunction with projects being undertaken by the sub-committee on the RMP and the SWG on the AWMP (see Annexes D and E respectively).

11.3 Progress on the Testing of Spatial Structure Models (TOSSM)

The aim of TOSSM (IWC, 2007a) is to facilitate comparative performance testing of population structure methods intended for use in conservation planning. From an IWC perspective, the TOSSM software package allows evaluation of methods for detection of genetic structure, in terms of how well the methods can be used to set spatial boundaries for management. It is available for all to use and simulated datasets exist for three of the five stock-structure Archetypes previously proposed by the Committee (IWC, 2010c, p.51).

TOSSM is also a flexible simulation tool for investigating how certain observed genetic phenomena might arise among animals such as whales whose life histories are not well described by classical genetic theory. A practical example of this is provided by the Pacific Coast Feeding Group (PCFG) of eastern gray whales (see Annex E), which appears to be genetically different from the northern Aleutian feeding ground, yet also receives immigrants from it (which would be expected to influence observed genetic differentiation). Simulation testing of various immigration scenarios in the TOSSM framework was carried out in SC/64/AWMP4 (Annex E). The Committee welcomes this paper and noted its value in exploring the range of scenarios compatible with the observed differentiation, as it investigates a range of factors, including the degree and timing of isolation and effective population size of the PCFG. The results have informed the current *Implementation Review* of gray whales (Annex E, Item 2.2.2). Some longer term work items were suggested for this study: (1) to incorporate a minimum female calving interval into the most realistic (9-stage) life history model; (2) to report results using summary statistics that are as independent as possible (and therefore provide multiple checks on the similarity

between the simulations and the observed data); and (3) to identify research needs for future field surveys in order to improve current parameterisation of the models.

11.4 Terminology and unit-to-conserve

Defining and standardising the terminology used to discuss 'stock issues' remains a long standing objective of the Working Group, in order to help the Committee report on these issues according to a common reference of terms. A suite of definitions for Committee terms such as 'population', 'subpopulation', 'stock', 'sub-stock' and 'management unit' was provided in SC/64/SD3 as a first effort to build a 'living' glossary of stock related terms, with reference to past discussions within the Working Group and to terminology applied in other management contexts. This glossary will be developed intersessionally by members of the Committee, who will also try to come up with a series of agreed criteria for classifying population units by these terms, with reference to their usage in other management and conservation contexts (see Item 11.5).

11.5 Workplan

The Committee's view of the workplan for SD is given under Item 21.

12. ENVIRONMENTAL CONCERNS (E)

The Commission and the Scientific Committee have increasingly taken an interest in the possible environmental threats to cetaceans. In 1993, the Commission adopted resolutions on research on the environment and whale stocks and on the preservation of the marine environment (IWC, 1994a; 1994b). A number of resolutions on this topic have been passed subsequently (e.g. IWC, 1996; 1997a; 1998; 1999a; 1999b; 2001b). As a result, the Scientific Committee formalised its work on environmental threats in 1997 by establishing a standing working group that has met every year since then. Its report this year is given as Annex K.

12.1 State of the cetacean environment report (SOCER)

SOCER provides an annual update, requested by the Commission, on: (a) environmental matters that potentially affect cetaceans and (b) developments in cetacean populations/species that reflect environmental issues. It is tailored for a non-scientific audience. The 2012 SOCER (SC/64/E2) was restricted to the Indian Ocean as the regional focus, due in part to reduced funding. A primary source of information was the International Indian Ocean Cetacean Symposium, held in 2009 on the Maldives[15]. Overall, the awareness of environment-related threats to cetaceans is high in the region, but implementation and control measures are poor. However, this provides an opportunity to introduce best practices, state-of-the-art procedures for critical issues such as fisheries interactions, ship strikes, whalewatching, and new, well-thought-out Marine Protected Areas.

During discussion, it was noted that marine research in the Indian Ocean region is focused in a few locations, despite having expanded over the past five years. Cetacean, or indeed environmental, research is scant or absent in many areas and there are few peer-reviewed reports from the region. The Committee was pleased to learn that the next issue of JCRM (published this month) contains 15 peer-reviewed papers from the Indian Ocean.

Highlighting specific issues in the region, there are clearly 'hotspots' in terms of pollution, fisheries by-catch and environmental degradation (e.g. Arabian Gulf). Reports of mass mortality events (152 small cetaceans in Iran in Sept 2007, spinner dolphins and striped dolphins in two events, and 200-250 pantropical spotted dolphins in Pakistan in March 2009) on the northern coast of the Indian Ocean are particularly concerning because these three species do not usually mass strand in these numbers and the latter event occurred the day after the commencement of a multi-national naval exercise (AMAN 09) in Pakistan waters.

Next year the focus of the SOCER will be the Atlantic Ocean region and the SOCER editors request Committee members provide input, preferably in the form of pdf files, of papers published between 2011 and 2013.

12.2 Pollution

POLLUTION 2000+ is a long standing programme of the Committee. Three goals were identified at the IWC Intersessional POLLUTION 2000+ Phase II Workshop (IWC, 2011):

(1) develop integrated modelling approaches and risk assessment framework for evaluating the cause and effect relationship between pollutant exposures and cetacean populations;

(2) identify data needs and available datasets or case studies that would be appropriate for the models that are exposure driven, source driven or effects driven; and

(3) develop a prioritisation framework to evaluate the broad number of environmental pollutants.

12.2.1 Update on POLLUTION 2000+ Phase II progress

At the intersessional POLLUTION 2000+ Phase II workshop held in 2010(IWC, 2011d), four objectives for the cetacean pollutant exposure and risk assessment modelling component were agreed: (1) improve the existing concentration-response function for PCB-related reproductive effects in cetaceans (completed in

[15] www.mrc.gov.mv

2011); (2) derive additional concentration-response functions to address other endpoints (e.g., survival, fecundity) in relation to PCB exposure; (3) integrate improved concentration response components into a population risk model (individually-based model) for two case study species: bottlenose dolphin and humpback whale (completed in 2011); and (4) implement a concentration-response component for at least one additional contaminant of concern. The authors of SC/64/E5, funded by the IWC, investigated how contaminant-induced effects on immune function could be incorporated into the existing individual-based population framework constructed to assess the impact of polychlorinated biphenyls (PCBs) on cetacean populations (Objective 2).

By determining how the blubber PCB annual accumulation rates relate to concentrations in breeding females, comparisons with empirical data can be made and predictions about effects on various populations formulated. For example, based on the current blubber PCB concentrations determined in breeding females from two bottlenose dolphin populations in Sarasota Bay and St Joseph Bay, Florida, the model predicts that these populations would remain stable or increase slightly over the 50 –100 year timescales projected. Conversely, the bottlenose dolphin population in Brunswick, Georgia, where PCB levels in breeding females are 10 times higher, is predicted to decline over the same period without external population inputs through immigration.

In the future, impacts on other populations and species, such as humpback whales from the Gulf of Maine will be investigated (e.g., Hall *et al.*, 2011), as additional contaminant data for females become available. In addition, future developments of this model will include a sensitivity analysis; incorporation of a bioaccumulation model to estimate blubber concentrations for populations or species in which only levels in prey are known; and making the model available online with a user-friendly interface.

During discussion (Annex K), it was noted that body condition of cetaceans may have a significant effect on susceptibility to impacts from contaminant exposure. For example, body condition could affect immune function independently so when food is limited and animals are in poor condition this will further affect their ability to fight off pathogens. Furthermore, if PCBs are released from the blubber during periods of increased energy demand then more may be bioavailable. Although the current model does not account for body condition, the final phase of the project will incorporate a toxicokinetic model that will include body condition parameters, similar to an approach taken by Hickie *et al.* (1999).

The Committee **recognises** that cetaceans are exposed to a mixture of environmental contaminants. It **suggests** that, if possible, mixtures of contaminants should be added to the model. Due to the extremely high levels of PCBs measured the bottlenose dolphins in Brunswick, Georgia, USA, the Committee **strongly recommends** the continued monitoring of this population. The Committee **commends** the authors for the most recent results from the IWC's POLLUTION 2000+ programme and **strongly supports** their continued work to develop the necessary tools for analyses of pollutant exposure risk to cetaceans.

12.2.2 Oil Spill Impacts

12.2.2.1 UPDATE ON RESPONSE TO DEEPWATER HORIZON OIL SPILL IN THE GULF OF MEXICO

An update on the 2010 Deepwater Horizon (DWH) oil spill in the Gulf of Mexico was provided, where the injury assessment for cetaceans continues. The Natural Resource Damage Assessment (NRDA), a formal process in the USA to assess damages to natural resources, has included photo-identification, remote biopsy, live capture health assessments, and evaluation of stranding data for common bottlenose dolphins in nearshore waters. Analyses of tissue, blood, and urine samples from cetaceans in the Gulf of Mexico for PAHs and PAH metabolites have also continued, as outlined in the NRDA plans.[16]

In addition to the NRDA, an Unusual Mortality Event (UME) is ongoing in the northern Gulf of Mexico principally involving bottlenose dolphins [17]. The UME involved 745 cetacean strandings in the Northern Gulf of Mexico from 1 February 2010-10 June 2012, which started before the DWH oil spill. The historical average (2002–2009) for this area is 74 dolphins per year. The vast majority (95%) of stranded dolphins have been found dead; however, 35 stranded alive and seven were taken to facilities for rehabilitation. The UME is still ongoing, however stranding rates in the Northern Gulf in April and May 2012 were near-average.

Although it is typical to see strandings of dolphins less than 115cm (perinates) in the spring, there was a marked increase in strandings of this age class in spring 2011. Of these perinatal dolphin strandings, most were found to have died *in utero*. Twelve of 51 cases targeted for testing were positive for *Brucella,* and 8 cases were confirmed to have died of brucellosis. Compared to 2011, the number of stranded perinatal dolphins was lower during the spring of 2012. Three additional cetacean studies related to the DWH spill are underway in the Gulf of Mexico, including two passive acoustic surveys and one tagging study of sperm whales.

[16] http://www.gulfspillrestoration.noaa.gov .
[17] http://www.nmfs.noaa.gov/pr/health/mmume/cetacean_gulfofmexico2010.htm

The Committee **commends** this research related to the DWH oil spill and **strongly recommends** continued investigations into the impacts of the DWH oil spill on cetaceans, including exposure to oil spill related contaminants, biomarker investigations and health assessments. Furthermore, it **encourages** the early and full reporting of the findings of DWH studies into the public domain.

12.2.2.2 CAPACITY BUILDING REGARDING OIL SPILL IMPACTS ON CETACEANS

In 2011, the Committee agreed that there was significant need and interest in cross-training between the oil spill and marine mammal communities and it has established an intersessional e-mail group to evaluate the possibilities for such training (IWC, 2012o). As part of an effort to better understand and be prepared for oil spills and their impacts on marine mammals particularly cetaceans, workshops and planning exercises are underway or have taken place including: (1) an oil spill response workshop held at the International Conference on Marine Mammal Protected Areas (ICCMMPA)[18] and (2) dissemination of information and data on marine mammals at international meetings on oil spill response or with oil spill responders.

The ICCMMPA workshop included presentations from the Regional Marine Pollution Emergency Information and Training Centre (REMPEITC) in the Wider Caribbean Region and the Oiled Wildlife Care Network, industry, oil spill responders, and marine mammal scientists and managers. A number of recommendations developed at the workshop were reviewed and found similar in nature to those discussed last year (IWC, 2012o), in particular the desirability of companies, agencies, stakeholders and international organisations to work in cooperation with marine mammal specialists on oil spill response plans.

In discussion, the Committee noted that some response plans that are currently under development, especially those related to the Arctic, focus on identifying sensitive areas for marine mammals. However, in most areas, important baseline data are lacking and the Committee **recommends** that these data gaps be filled. It also **recommends** that oil spill response efforts throughout the world should include pelagic as well as coastal areas; further information on current capacities and mechanisms of oil spill recovery will be valuable. Last year, the Committee noted that a review of the capacity for oil spill response in the Arctic was an urgent priority in the aftermath of the DWH oil spill (IWC, 2012o). The Committee **agrees** that the recommendations from the 2011 MMPA workshop in Martinique will provide guidance on oil spill prevention and response in the Arctic at the upcoming intersessional Arctic Anthropogenic Impacts Workshop (see Item 12.5.3).

12.2.3 Other pollution related issues

Fossi provided information on Mediterranean odontocetes exposed to environmental stressors, in particular to persistent organic pollutants, emerging contaminants, polycyclic aromatic hydrocarbons and trace elements. In Panti et al. (2011), the response of 'gene expression biomarkers' was evaluated in Mediterranean striped dolphin in three sampling areas: the Pelagos Sanctuary (Ligurian Sea), the Ionian Sea, and the Strait of Gibraltar. The mRNA levels of five putative biomarker genes were measured for the first time by quantitative real-time PCR in cetacean skin biopsies. Striped dolphins from the Pelagos Sanctuary are more exposed to ecotoxicological hazard than those inhabiting the Ionian Sea and the Strait of Gibraltar. This evidence focuses attention on the potential risk to cetaceans inhabiting the largest pelagic MPA in Europe and the Committee **stresses** the importance of effective and long-term management of MPAs in order to preserve species in their habitats.

The sources of these contaminants in the study areas are unknown. The Committee **recommends** that the sources be identified, particularly for animals within the Pelagos Sanctuary, to enable the development and implementation of mitigation measures.

In 2005, the Conservation Committee agreed that a research program to address the issue of inedible 'stinky' gray whales caught by the Chukotkan aboriginal subsistence hunters should be established (IWC, 2006a). This year, the Committee examined IWC/64/CC10, which presented information on the various chemical compounds measured in tissues of malodorous ('stinky') and clean gray whales collected from 2005 through 2011. These included polycyclic aromatic hydrocarbons (PAHs), persistent organochlorines, benzene derivatives and chlorinated PAHs. The authors commented that the odorous carbonyl compounds measured in tissues of 'stinky' whales may be a result of slow metabolism of petroleum hydrocarbons that occur in the Pacific Ocean. They also noted concentrations of persistent organochlorines in the gray whale tissues were low or not detected (DDT).

It was noted (Annex F) that the finding of non-detectable DDTs is in contrast to the finding of measurable DDT levels in gray whale calves and mothers sampled in the lagoons in the Baja California region reported in SC/64/E4. Differences in DDT levels among these gray whales are most likely due to differences in contaminant levels on their feeding grounds although levels are generally low. The Committee **emphasises** that a clearer indication of which samples were 'stinky' and which samples were controls would make the information provided easier to

[18] http://second.icmmpa.org

interpret. Due to the lack of clarity in this regard (SC/64/CC10), no new conclusions could be drawn regarding 'stinky'gray whales. The Committee **reiterates** its previous **recommendations** (e.g. IWC, 2006c; 2007e; 2008f; IWC, 2009f) that futher efforts be made to determine the cause of the 'stinky whale condition.

12.3 CERD (Cetacean Emerging and Resurging Disease)

In 2007, the Committee recognised the need for increased research and standardised reporting in a wide range of disciplines dealing with cetacean health (IWC, 2008f), which led to the creation of the Cetacean Resurging and Emerging Disease (CERD) Working Group.

12.3.1 Update from CERD Working Group

An update to the CERD Work Plan agreed last year (IWC, 2012p) was presented. This workplan included: (i) identification of regional and national experts/points of contact via Steering Committee membership; (ii) creation of a listserve and a website; (iii) creation of a Framework Document; and (iv) identification of and contact with organizations synergistic with the goals of CERD. The CERD working group (WG) made significant progress on all tasks, except on the Framework Document, where work is now underway to better define the long-term vision and goals for the CERD working group.

12.3.2 Progress on CERD Website

The CERD website is being developed in two phases. The first phase focuses on large cetacean species and relies on a 'consultation and sharing' approach. The second phase is intended to include all cetacean species and incorporate a potential 'reporting' role. This website will have 'public' and 'registered user' levels. The public level will provide basic information on diseases in cetaceans, as well as access to selected discussion forum content. Registered users will have full access to the site, including in-depth information on cetacean disease, as well as to discussion forums and posting ability. On the main page, a 'map it' feature will allow registered users to record geographic locations of disease incidents, while a 'current events' header will alert website visitors to recent events in cetacean disease and facilitate international communication. Links will be provided for quick access to discussion boards that can be shared with groups focused on other topics such as pollution, ship strikes and marine debris.

It was noted that researchers examining photographs on the website may be able to distinguish between wounds from entanglements, ship strikes or marine debris and this discussion underlined the overlap among these areas. The Committee **agrees** that it will be useful to incorporate standardised tissue collection protocols on the CERD website. The Committee thanked the CERD WG and the Secretariat for their efforts on developing the website and **encourages** continued development of this tool.

12.3.3 Other disease related issues

SC/64/E1 presented the results of a study of six *Morbillivirus*-infected cetaceans stranded along the Italian coastline between 2009 and 2011. The authors concluded that: (1) *Morbillivirus* infection continues to represent a major threat to cetacean health and conservation in the Mediterranean Sea with an increasingly expanding 'host range' of the virus; and (2) the cases of morbilliviral infection characterized by an apparently exclusive involvement of the animal's brain tissues are a matter of concern, both from the conservation and from the comparative pathology standpoints, thereby underscoring the role of cetaceans as models for the study of their human neurological disease counterparts.

Discussion (Annex K) focused on the types of tests and assays performed on these animals and the need for increased surveillance for neurologic diseases in cetaceans. The Committee welcomed this study and **encourages** further studies on these pathogens in cetaceans.

The Committee also noted that there was worldwide press coverage over the recent (February - May) unusual mortality event (UME) of about 900 dead long-beaked common dolphins, Delphinus capensis, in Peru, but based on these press reports there remains considerable uncertainty about the cause of this UME. However, no scientific reports were available on this UME for the SC to review, but the SC looks forward to receiving reports on the UME next year.

In SC/64/E4 preliminary results were presented on contaminant levels (Organochlorine Compounds - OCs,) and biomarkers from biopsies in the San Ignacio Lagoon (Mexico). These preliminary data reveal an accumulation of OCs in gray whale calves resulting from the lactational transfer of these compounds from their mothers. Exposure to OCs (such as DDTs) at early life stages may have toxic impacts on their developing endocrine, immune and neural systems. The paper was discussed fully in Annex K.

The Committee welcomed this paper, noting its relevance to the IWC's POLLUTION 2000+ programme and **encourages** continued studies.

SC/64/E8 provided a review of diseases and microorganisms, as well as the public health and conservation impacts from cetaceans that stranded in Costa Rica during 2004-2011. Humans and cetaceans affected by marine *Brucella* can develop severe disease such as neurobrucellosis and osteomyelitis, and the authors concluded that conservation policies should support research that investigates incidence,

prevalence, geographic distribution and host range of *Brucella* infection in cetaceans. The paper is discussed fully in Annex K.

The Committee **welcomes** this paper, noting that data obtained from studies such as this are part of 'The One Health' concept - a worldwide strategy for expanding interdisciplinary collaborations and communications in all aspects of health care for humans, animals and the environment[19]. The Committee recognised *Brucella* as an important zoonotic pathogen and **encourages** additional research on this disease agent.

12.4 Anthropogenic sound

In 2010, the Committee reviewed evidence of masking of cetacean calls from anthropogenic sound, with an emphasis on low-frequency sounds (< 1 kHz) from commercial shipping and airguns used during seismic surveys (IWC, 2011g). It had recommended that: (i) the masking potential of anthropogenic sources be quantified and acoustic measurements be standardised; and (ii) IWC member governments work to develop a quantitative approach for assessing cumulative impacts of anthropogenic sound on cetaceans.

12.4.1 Mitigation of effects of anthropogenic sound on cetaceans

US federal regulations require scientists and representatives of offshore industries to acquire incidental harassment authorizations for activities that may disturb marine mammals, but the potential impacts of sound are often considered on a project-by-project basis in isolation from one another. This precludes meaningful analysis of cumulative impacts from multiple sources. In response to consideration of offshore industrial activities in the Alaskan Arctic, Moore *et al.* (2012) proposed a three-step assessment framework based development of *acoustic habitats*, which constitute the aggregate sound field from multiple sources compiled at spatial and temporal scales consistent with the ecology of Arctic marine mammals. Assessment framework steps include: (i) the development of acoustic habitat maps depicting anticipated sound fields from multiple sources; (ii) an overlay of acoustic-habitat maps with marine mammal seasonal distribution and density maps to identify areas or periods of concern and data gaps; (iii) development of precautionary measures to protect marine mammals from potential impact and a prioritisation of data gaps and research needed to address those gaps.

In the US, the Cetaceans and Sound (CetSound) project is now working toward mapping products envisioned in the first two steps of this framework[20]. The CetSound project consists of two working groups convened to develop mapping tools: the Underwater Sound-field Mapping (SoundMap) and the Cetacean Density and Distribution Mapping (CetMap). The overarching objective of the SoundMap group is to create maps depicting the temporal, spatial, and spectral characteristics of both chronic (e.g., shipping) and episodic (e.g., seismic survey) underwater noise. The overarching objective of the CetMap group is to create regional cetacean density and distribution maps that are time- and species-specific, using survey data and models that estimate density using predictive environmental factors. To augment the more quantitative density mapping and provide additional context for impact analyses, the CetMap group is also identifying known areas of specific importance for cetaceans, such as reproductive areas, feeding areas, migratory corridors, and areas in which small or resident populations are concentrated. The Committee **commends** the initial development of these powerful mapping tools, **endorses** this work and **strongly recommends** support for further development and improvement of these tools.

The Committee also **welcomes** the information on work being undertaken regarding noise by IUCN's Western Gray Whale Advisory Group and especially its Noise Task Force[21] (see Annex F, Appendix X).

12.4.2 Other anthropogenic sound related issues

Underwater noise from commercial shipping is chronic (IWC, 2011g). The IMO has established a correspondence group (CG) to develop non-mandatory guidelines to address noise from commercial ships; the IWC Secretariat participates in this group (IWC/64/4G). The IMO CG will finish the first draft of their report by the end of 2012 and it will be presented to the IMO in early 2013. The Committee **commends** the continued discussions between the IMO and IWC regarding efforts to reduce noise of newly built vessels. Further, it noted the importance of identifying ship acoustic signatures and **encourages** the collection of these data, as well as the coupling of this information with the appropriate automatic identification system data.

At past meetings, the Committee has received updates on the development of a modelling effort to determine the population consequences of acoustic disturbance (PCAD) on marine mammals initially proposed by the US National Research Council in 2005. In 2009, the US Office of Naval Research supported a Working Group whose objectives included building a formal mathematical structure for the framework, which led to key adaptations to the original framework, including the incorporation of other sources of disturbance, physiological change and the use of health as the primary metric through which changes in individuals can potentially impact the population. Combined, this led to the framework being renamed the population consequences of disturbance (PCoD). The SWG noted

[19] http://www.onehealthinitiative.com/index.php and http://www.oie.int/en/

[20] http://cetsound.noaa.gov/index.html

[21] http://www.iucn.org/wgwap/wgwap/task_forces/

that PCoD is a significant improvement on the PCAD model. Although the current model focuses on single stressors, accumulative effects, behavioural responses and other factors (e.g., acoustic masking) that could potentially affect health could also be added to the model. The SWG **strongly encourages** further work on this model and looks forward to progress updates.

12.5 Climate Change

12.5.1 Progress on recommendations from the 2nd Climate Change Workshop

At the 2nd Climate Change workshop (IWC, 2010i), three themes were recommended with regard to the study of cetaceans in the Arctic: (i) single species-regional contrast; (ii) trophic comparison; and (iii) distribution shift. With regard to the first theme, results of passive acoustic sampling in 2008-09 provided a means to compare seasonal patterns in call detection from bowhead whales in the B-C-B and Spitzbergen stocks, providing a contrast in seasonal occurrence for this species between the Atlantic and Pacific sectors of the High Arctic (Moore et al. 2012b). Details of this work are discussed in Annex K.

As also discussed in Annex K, an overview of a new programme was received which was called the Synthesis Of Arctic Research (SOAR). It is a US-based activity, which aims to bring together a multidisciplinary group of Arctic scientists and Alaskan coastal community representatives to explore and integrate information from completed and ongoing marine research in the Pacific Arctic sector[22]. While SOAR is not focussed specifically on cetaceans, eight projects under its auspices will focus on aspects of beluga and bowhead whale ecology, which are related to the three study themes of the 2nd Climate Change Workshop.

The Committee **welcomes** these updates on cetacean-related science in Arctic waters, **endorses** the work undertaken thus far and requests future updates.

12.5.2 Small cetacean restricted habitats Working Group

Building upon the work of an intersessional working group to further recommendations made at the IWC Climate Change Workshop on Small Cetaceans in 2010 (IWC, 2012u), the Committee **agrees** to the following definition:

The spatial extent of the range occupied by these populations may vary by orders of magnitude, but one or more of the following conditions apply: (i) the species/population has narrow habitat requirements; (ii) the habitat is bounded by physiographic or oceanographic barriers; and (iii) other suitable habitat which the population might be able to access is unavailable because it is occupied by competitors. The first two conditions might apply to fixed populations, such as the vaquita - the third condition in particular requires further consideration and development. These conditions may also apply to populations of large whales (e.g. fin whales in the Mediterranean Sea and the Gulf of California) and it was agreed that large whales would be considered in future discussions on this topic.

The Committee **welcomes** this effort to further advance our understanding of the potential impacts of climate change in cetaceans. However, it also **urges** caution with regard to which populations and species should be focused upon with respect to climate change, so as not to detract from efforts to address more imminent threats and stressors such as bycatch. Creating a list of species or populations to which this definition might apply was suggested as one way to further develop the topic. The Committee also noted the importance of integrating and considering the findings of climate change-related analyses that have been conducted for other marine mammal species (e.g. polar bears and ice seals) when considering the issue for cetaceans.

12.5.3 Planning for intersessional Arctic Anthropogenic Impacts Workshop

In 2010, the Commission asked the Committee to develop an agenda for a workshop on Arctic Anthropogenic Impacts on Cetaceans (IWC, 2011a). Last year, a draft agenda was completed and a steering group formed (IWC, 2012q) to further develop a plan for the workshop. A revised agenda that focused on anthropogenic activities related to oil and gas exploration, commercial shipping and tourism was developed intersessionally. The Committee noted that the workshop agenda should be expanded to include consideration of other anthropogenic activities such as commercial fishing and scientific research. Given rapid environmental changes and increasing human activities in the Arctic, the Committee **encourages** the continued development of an Arctic Anthropogenic Impacts workshop focused on climate change, but **strongly recommends** that it:

(1) carefully define the geographical area to be addressed;
(2) focus only on Arctic cetacean species (i.e., bowhead whales, white whales, and narwhals);
(3) consider a broad suite of anthropogenic activities; e.g., oil and gas development, commercial fishing, commercial shipping, tourism, continental shelf mapping and scientific studies;
(4) specifically include possible impacts from underwater sounds, spilled oil, dispersants, invasive species and discharges (including dumping of ballast water) related to exploratory drilling and shipping;
(5) include a discussion about assessing the cumulative and synergistic impacts of anthropogenic activities.

[22] http://www.arctic.noaa.gov/soar/

The topic of anthropogenic impacts to cetaceans in the Arctic is broad and complex and the Committee **recommends** that the process should involve an initial scientific workshop followed by a more inclusive Commission meeting that addresses management and policy aspects of Arctic Anthropogenic Impacts on Cetaceans. It is anticipated that final specification for the scope, agenda and schedule for the workshop will be undertaken jointly by the workshop steering group and representatives of the IWC and Secretariat.

12.5.4 Other climate change related issues

The IMO is working to develop a mandatory Polar Code to manage the increases in ship traffic in Arctic and Antarctic waters anticipated with the reduction of sea ice associated with climate change (IWC/64/4). The Polar Code work is coordinated by the sub-committee on Ship Design and Equipment, as is the work regarding ship quieting (see item 9.2). The IWC's endorsement of noise reduction goals (i.e., 3dB in 10 years; 10 dB in 30 years) advanced at an international workshop on shipping noise and marine mammals (Wright and Okeanos Foundation for the Sea, 2008) were re-iterated in a document entitled *Status on Implementation of the Arctic Marine Shipping Assessment 2009 Report Recommendations*, available on the Arctic Council website[23]. The Committee **welcomes** this information, **reiterates its endorsement** of noise reduction goals and looks forward to continued collaborations between the IWC and the IMO on this topic.

12.6 Interactions between MREDs and cetaceans

Given information and a review provided last year, the Committee had endorsed a proposal for a workshop on interactions between marine renewable developments (MREDs) and cetaceans.

That workshop was held immediately prior to the present Annual Meeting and its report, 'Marine Renewable Developments and Cetaceans Worldwide' is given as SC/64/Rep6.

Simmonds presented the report and noted that a variety of MREDs are now being deployed worldwide, with the highest concentrations in the Northern Hemisphere, especially in northern Europe. The three main forms of MREDs at this time are: (i) wind farms; (ii) tidal-stream driven devices; and (iii) wave energy converters. Each of these, as well as their supporting infrastructure, has the potential for interaction with cetaceans during the construction, operation and decommissioning phases (Simmonds *et al.*, 2010).

The workshop received detailed reports on the current state of development and management of marine renewable energy in waters of Germany, the United Kingdom, Belgium and the USA, including trans-boundary issues now arising in the busy waters of Europe (SC/64/Rep 6, fig. 1). The workshop focused on the three main types of MREDs; and considered potential impact to cetaceans on aspects of 'supporting infrastructure' for MREDs. A number of papers and websites informed discussions throughout the workshop (Rep 7 Appendix 2); of particular use was a special synthesis of the work on MREDs conducted by ICES (Murphy *et al.*, 2012).

The Committee noted that MREDs may well play a major role in the mitigation of climate change, which may profoundly affect cetacean populations as discussed at prior climate change workshops (IWC, 1997b; 2010i). The Committee thanked Simmonds for the successful Workshop. In particular it **endorses** the Workshop's conclusions and recommendations (see especially SC/64/Rep6, item 5). These are briefly summarised below.

1. Strategy to minimise risk

Risks from both lethal and sub-lethal effects can be minimised via a series of actions: the collection, collation and analysis of appropriate baseline cetacean data and appropriate industrial data will allow the identification and quantification of threats and their potential implications for conservation objectives. All stakeholders need to be involved from the outset such that impacts from all factors are considered, ensuring that appropriate mitigation measures and associated monitoring programmes are developed. Suitable scientific evaluation and compliance mechanisms are needed to ensure that mitigation and monitoring are adequate.

2. Broad management

Governments, managers and other stakeholders need to co-operate in strategic planning for MREDs taking into account the trans-boundary nature of cetaceans. Uncertainties over the level of impacts require a staged approach to developments taking into account lessons learned from other developments and other human activities that affect cetaceans, in order to be adequately precautionary. IWC member governments can assist in encouraging the development of international collaboration in this regard, and in particular, they can assist in emphasising the importance of incorporating consideration of cetaceans from an early stage and the value of following the broad strategy and principles outlined in the Workshop report and summarised in Fig. 3.

3. 'Fundamental' research

International collaboration will be required to determine population structure, status, distribution and procedures for assessing impacts. The Committee can assist with design and evaluation of population and impact assessments. While there are established methods for assessing lethal takes, data on the effects of (sub-lethal) stressors on cetaceans are also needed.

[23] http:arcticcouncil.gov/pame/amsa/

4. Evaluation of threats
All lethal and non-lethal impacts of human activities should be considered in an integrated manner, e.g. using modelling approaches that take into account the cumulative impacts from all threats when evaluating whether conservation objectives are likely to be met.

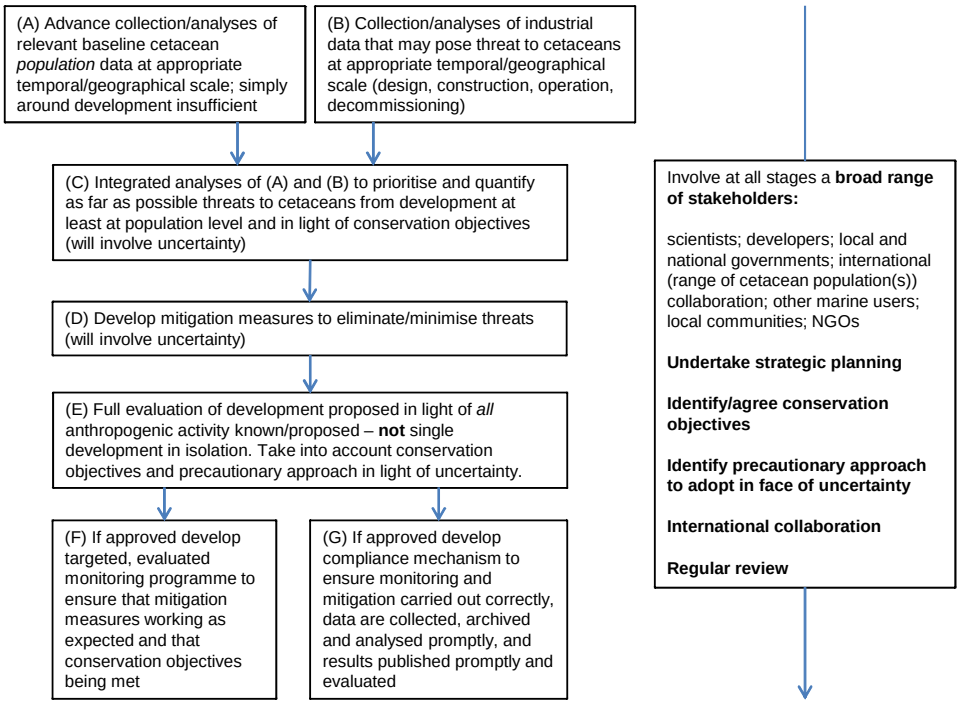

Fig. 3. Simplified schematic summary of a general strategy and principles to minimise environmental threats posed by MREDs. Some stages will occur in parallel and will involve feedback. See report for details

The Committee has considerable expertise in developing management frameworks and testing their performance against specified objectives.

5. Monitoring
Monitoring should be designed carefully, to assess impacts against pre-determined conservation objectives and to measure the efficacy of any mitigation measures that are implemented.

6. Data sharing and the future role of the IWC Scientific Committee in the consideration of MREDs
Improved information and data-sharing were identified as key and the Workshop encouraged the Committee to continue to act as a forum to review the development of MREDs and their implications for cetaceans, including promoting the sharing of data. Countries were encouraged to help in this by providing appropriate information.

In addition to the workshop report, the Committee received information from two papers on the topic of interactions between cetaceans and MREDs focused on waters offshore Scotland (SC/64/E3) and a preliminary assessment of the effectiveness of small Marine Protected Areas (MPAs) to protect dolphins offshore Wales (SC/64/E6). It also received an update on Chilean renewable energy projects (SC/64/E12) and noted that consideration should be given on the impacts of coastal wind farms, particularly in regions that support critical habitats for cetaceans. The Committee strongly **recommends** urgent development of environmental impact studies in this area of Chile and urges that a precautionary approach should be used with regard to critical cetacean habitats.

The Committee also **agrees** that there is an urgent need to develop or improve effective noise mitigation measures or quieter foundation installation methods, as noted in past reviews of anthropogenic sound (e.g. IWC, 2010f; IWC, 2012o).

12.7 Other habitat related issues
Primary papers submitted on topics related to other habitat related issues, included potential impacts of marine debris, cumulative impacts and results of a large-scale aerial survey programme in the French tropical EEZ.

12.7.1 Cetaceans and marine debris

In addition to receiving five papers on the topic of marine debris (SC/64/E7, E10, E13, E15, FI 10), the SWG received the results from an intersessional working group (Debris WG) that had considered the issue of both ingestion and entanglement of cetaceans in marine debris. The intersessional group offered the following conclusions and recommendations:

(1) Marine debris is a growing concern for marine wildlife in general, but its interactions with cetaceans are poorly understood.
(2) To better evaluate the potential impacts of marine debris on cetaceans and to provide a forum where relevant data can submitted it, a workshop on marine debris and cetaceans should be convened.
(3) The primary aim of this workshop would be to determine how to best investigate quantitatively the ways in which marine debris is affecting cetaceans and how best to monitor and mitigate for these effects. The workshop could also consider how best to develop a centralised database to collate cases of debris interactions, including the development of standardised criteria for data to allow more certain identification of the types of debris and the interactions involved.

Two key issues fundamental to assessing impact of marine debris on cetaceans were identified: (1) how to distinguish cetaceans that have died in active fishing gear versus those entangled in debris (including abandoned, lost, discarded - or 'ghost' -fishing gear) and the need to identify the 'worst culprit' types of fishing gear causing entanglement; and (2) how to investigate the potential accumulation of debris in the deep sea feeding areas of beaked and sperm whales. In addition, more effort is needed to investigate the impacts of microplastics on cetaceans, including baleen whales, which potentially ingest micro-litter by filtrating feeding (see Fossi *et al.*, 2012).

The Committee **recommends** that a workshop on marine debris and cetaceans be held (Annex K, Appendix 3) noting also its relevance to the Working Group on Bycatch with regard to entanglement issues (see Item 7.8). A number of potential data sources for data on marine debris were identified including those of international bodies such as CCAMLR and well as national and local bodies in several countries. SC/64/Rep1 noted the work being undertaken in by the USA, Korea and Japan and the Steering Group for the IWC-POWER cruises who are investigating how those cruises can contribute to international efforts to gather information on marine debris (see also Annex G).

12.7.2 Issues related to the March 2011 tsunami in the NW Pacific

Concerns have been raised with regard to increased marine debris transport to the eastern Pacific Ocean, as well as radioactive contamination of marine debris a result of the 2011 tsunami in Japan. Modelling efforts estimate that the bulk of the debris related to this event is probably dispersed north of the Main Hawaiian Islands and east of Midway Atoll.[24] Furthermore, as predicted by these modelling efforts, some buoyant debris reached the east Pacific coast from Oregon to Alaska during winter 2011-2012 and continues to occur in the region. It is highly unlikely that debris transported from Japan to the eastern North Pacific poses a radioactive risk. However, transport of non-native, invasive species or pathogenic microorganisms on tsunami-released debris could occur and pose a threat to eastern Pacific coastal ecosystems. Details of potential impacts of the tsunami released marine debris on marine mammals and the potential increase in either ingested marine debris or risk of entanglement are summarised in Annex K. Discussion of some Japanese work related to the effects of the tsunami on the marine ecosystem also occurs under Item 17.

12.7.3 Cumulative impacts of anthropogenic activities

SC/64/E11 reported on cumulative impacts of several anthropogenic activities on cetaceans. While there are a number of quantitative processes for assessing the combined impacts of multiple stressors being developed, some are active and used in management. For example, five actions to mitigate cumulative impacts were developed during the permit cycle of the Greenland Bureau of Minerals and Petroleum for the mitigation of cetacean exposures to disturbance from seismic surveys, as given in Annex K.

The Committee **welcomes** information on efforts to develop effective tools to address concerns regarding cumulative impacts of anthropogenic activities on cetaceans. It was noted that the effects of climate change on marine ecosystems may compound the cumulative impacts of anthropogenic stressors, such as chemical pollutants and noise.

12.7.4 REMMOA aerial surveys in the French EEA

The Committee received an update of the REMMOA project (Mannocci *et al.*, ; SC64/E14), aimed at providing maps of hot spots for pelagic megafauna in the French tropical EEZ and some EEZ of neighbouring countries. The long-term objective of the REMMOA surveys are to establish a baseline of information on cetaceans and other pelagic megafauna diversity and relative abundance and to build up a monitoring strategy to be implemented in the future. Mannocci *et al.* () present analyses of the Caribbean-Guiana survey where the aim of the study was to document top predator communities in terms of encounter rates, composition, abundance and spatial distribution and to compare them between these two contrasting ecosystems. SC/64/E14 presented the analysis of the southwest Indian Ocean survey with a focus on comparing cetacean and other pelagic

[24] http://marinedebris.noaa.gov/info/japanfaqs.html

megafauna communities in areas characterized by contrasted oceanographic conditions. The Committee **welcomes** these updates and **encourages** the results of their work to be presented next year.

12.8 Work plan

The Committee expressed its great appreciation to Moore for her superb guidance and chairing of the SWG over the 5-year period of her service as Chair.

The Committee discussions of the Workplan developed in Annex K is given under Item 23.

13. ECOSYSTEM MODELLING

The Ecosystem Modelling Working Group was first convened in 2007 (IWC, 2008e). It is tasked with informing the Committee on relevant aspects of the nature and extent of the ecological relationships between whales and the ecosystems in which they live. This advice is important to a number of other responsibilities of the Committee and the Commission has stated their interest in such work in a number of resolutions (IWC, 1999a; 2001b; 2002).

The Working Group's topics to address at this year's meeting were:

(1) review of ecosystem modelling efforts undertaken outside the IWC;
(2) explore how ecosystem models contribute to developing scenarios for simulation testing of the RMP; and
(3) review of other issues relevant to ecosystem modeling within the Committee

The report of the Working Group on Ecosystem Modelling is given as Annex K1.

13.1 Review of ecosystem modelling efforts undertaken outside the IWC

13.1.1 Ecosystem modelling in the context of ecosystem-based fisheries management

SC/64/EM1 outlined several ecological questions relevant to whale populations that can be addressed by ecosystem models. These included: What species and fisheries can potentially compete with whale feeding? How would one evaluate the potential magnitude of such competition? What are the potential, indirect food web effects on whales? What are the ecosystem tradeoffs that most warrant evaluation? What are the best scenarios (to model) to mitigate any of these concerns? How well do such (simulated) scenarios perform? The author also provided a review of the major classes of ecosystem model being employed globally in an ecosystem-based management context, provided a map of ecosystem models as they relate to these and similar questions, and described how global best practices are being adopted in the use of these ecosystem models. A key message was that the choice of model depends strongly on the questions being addressed. It is probably better to start with the simple multi-species models (with few components) or extended single-species models. The more complex multi-species models, food-web models or whole-system models are more suited to addressing broader questions.

SC/64/EM2 reported on efforts to place initial quantitative bounds on consumption estimates for a suite of marine mammals in the Northeast US Large Marine Ecosystem, including baleen whales, odontocetes and seals. Daily individual consumption rates were compiled from the literature and explored with sensitivity analyses to derive feasible ranges for each species which then could be raised to annual population-level consumption based on existing population abundance estimates. The results indicated that marine mammal consumption in this region might be similar in magnitude to commercial fishery landings for small pelagic and groundfish prey groups, although previous studies have indicated that targeted sizes may differ. Marine mammals probably consume as much prey as finfish predators, thus meriting continued evaluation despite the inherently wide confidence intervals of their consumption estimates.

The Committee **welcomes** this information, noting that with the move toward ecosystem-based management, consumption by marine mammals warrants inclusion as a source of natural mortality in assessments of mammal prey stocks. It also noted that reference points for marine mammal management, such Optimum Sustainable Production, had yet to be suitably defined in a multi-species context.

13.1.2 Ecosystem models of the effect on predators of fishing forage fish

Recent studies (Cury *et al.*, 2008; Fulton *et al.*, 2011; Pikitch *et al.*, 2012) have addressed the effects of exploitation of forage fish on their predators in several ecosystems, indicating that fishing of forage fish down to their MSY level can have major impacts on predators, including birds and marine mammals. In view of the importance of this issue to cetaceans, the Committee **agrees** that this should be a priority topic for next year.

13.1.3 Status update on NAMMCO ecosystem modelling

At last year's meeting, the Committee received an update on NAMMCO's initiative to implement a series ecosystem modelling exercises in the Barents Sea and the waters around Iceland. This year, the Committee was informed that the efforts have been delayed due to a lack of funding. However, the Committee remains interested in receiving information on these exercises as it becomes available.

13.2 Explore how ecosystem models contribute to developing scenarios for simulation testing of the RMP

Recent discussions in the sub-committee on the RMP (e.g. IWC, 2011e) on variation of *r* and *K* values in the face of environmental variability has shown that it can be useful to try to model the effects of food availability more explicitly, because this can have implications for the effects of prey abundance on whale population dynamics. The Committee **emphasises** the value of implementing this in small steps rather than going immediately to complex models and **agrees** that consideration of simple models of whales and prey should be a priority issue for next year.

13.3 Review of other issues relevant to ecosystem modelling within the committee

13.3.1 Update on Antarctic minke whale body condition analyses

Last year, the Committee discussed issues regarding the statistical significance of a decline (of about 0.2mm per year) in mean blubber thickness of Antarctic minke whales over the 18-year JARPA period reported by Konishi *et al.* (2008). The issues had been raised by De La Mare (2011), who found that the methods used by (Konishi *et al.*, 2008) could result in spurious apparent significance of trends because the nature of the sampling process and the associated components of the variance structure of the data were not taken into account. A reanalysis of the data at last year's meeting by Skaug (2012) using mixed-effect regression models to account for some of the additional variance structure resulted in a much higher variance of the estimated trend, but the point estimate changed little, and the estimated trend was still significant. Given the relevance of body condition indices to its work, the Committee agreed that further analysis of the data was warranted to determine: (i) whether the models fitted so far captured all the main features of the data; and (ii) whether the estimate of trend (whose confidence limits using the best fitting model ranged from near zero to values that could be of appreciable biological significance) could be made more precise. The Committee requested, *inter alia*, results from analysing the two sexes separately and the inclusion of slopes by latitudinal band as a random effect. It also suggested that the authors of De La Mare (2011) and of Konishi *et al.* (2008), apply for access to the data under Procedure B of the Data Availability Agreement, so that further analyses of these data could be reviewed by the Committee this year.

This year, de la Mare reported that he had applied for access to data through the Data Access Group but that a mutually satisfactory agreement was not reached. The generic data access questions raised in this case is discussed under Item 24. Pastene noted that Japan had offered to make available all data that had been requested by the Committee last year under the conditions of Procedure B (see Attachment B of SC/64/SCP1). De la Mare responded that conditions attached to the offer were in his opinion not in accordance with Data Access Agreement Protocol B and so was unacceptable.

In SC/64/EM3, he also presented an analysis of sex ratio and female length at 50% maturity using the JARPA data available in the IWC's catch database that showed unlikely trends and much higher levels of variability than would be expected in these parameters from a biological population. He noted that this indicated the presence of 'lurking variables' that had important effects on the dependent variable but that were not included in the predictor variables under consideration. Similar adverse effects could be present in the analyses of body condition described above, with possible sources of unaccounted variance including inter-annual variability in the locations and dates on which whales were taken, the spatial distributions of one or more biological populations and the co-effects of seasonality by sex and reproductive state. Using a statistical simulation of catches along random transects, SC/64/EM3 further showed that standard errors calculated using individual animals as the sample size underestimates the true variability because of spatial/temporal pseudo-replication, and that transects are the basic sampling units, not the individual catches.

There was considerable discussion of SC/64/EM3 and the implications for inferences on biological parameters derived from JARPA data. Some members emphasised that failing to estimate the variance associated with random transect placement means that the variances in the analyses of biological parameters will be underestimated such that hypothesis tests will be invalid. They further noted that the reported catch locations in the IWC database show that clearly identifiable transects that can be treated as replicates have not been realised and where transects are identifiable they have not been traversed in random time order. Consequently these members considered that the conditions for the appropriate analysis of the data have not been met.

Other members considered that non-independence can be accounted for by using jack-knife methods, as was done during last year's meeting with the blubber thickness data, using one year as the jack-knifing unit (IWC, 2012n). This approach showed that while the estimated SE increased from 0.0225 to 0.0836 on the regression slope (-0.213 mm/year), the slope estimate itself did not change and thus was still significantly different from zero at the 5% level. This jack-knife result should, according to these members, take care of concerns about dependence between observations. In addition, as mentioned above, mixed-effects models were also applied during last year's meeting to account for some of the additional variance structure resulting in a best model (based on the AIC criterion) with a

slope of -0.19 mm/year and SE = 0.07; (Skaug, 2012 pp. 259-62). In discussion, these members understood de la Mare to have claimed that these results did not take care of all possibilities for statistical dependence between whales (e.g. whales sampled on the same track line), but they considered it highly unlikely that such dependence could be so large as to destroy the findings of negative trends in blubber thickness, fat weight, girth or weight of stomach contents.

The Committee noted that valid conclusions can often be drawn from non-random samples as long as this is accounted for in the analysis. It further **recommends** that the authors of Konishi *et al.* (2008) investigate independence issues by using mixed-effects models with track line as a random effect to address the concerns raised above. These authors will consider carrying out such analyses before next year's meeting.

13.3.2 Other issues

A decline in energy storage in Antarctic minke whales over almost two decades (Konishi *et al.*, 2008) suggests that food availability may have been declining recently. To test this hypothesis, at this year's meeting Konishi presented a paper (Konishi *et al.*, in review) that examined whether there was any annual trend in the stomach contents of the whales using catch data from 20 seasons in JARPA and JARPA II (1990/91-2009/10). Results from linear mixed-effects analyses showed a 39% (95% CI 3.2-47.3%) decrease in the weight of stomach contents over the 20 years. A similar pattern was found in both males and females, except in the case of females sampled at higher latitude (particularly in the Ross Sea), suggesting a decrease in the availability of Antarctic krill for Antarctic minke whales in the lower latitudinal range of the JARPA/JARPA II research area. However, prey availability has not changed in the Ross Sea, where both Antarctic krill (*Euphausia superba*) and ice krill (*E. crystallorophias*) are available. The decrease in Antarctic krill availability could be due to environmental changes or to an increase in the abundance of other krill-feeding predators. The latter appears more likely, given the rapid recovery of the humpback whale in the area and the fact that humpback whales are not found in the Ross Sea, where no change in prey availability was observed for minke whales.

There was considerable discussion of this paper, focusing on two main areas:

(1) statistical issues, similar in nature to those discussed above with respect to the blubber thickness analysis, in particular as to whether the analysis takes account of all components of variance and whether the statistical significance of the apparent trends is reliable; and
(2) the biological issues associated with the relationship between stomach fullness and food intake and between stomach fullness and prey availability.

With respect to the statistical issues, members repeated many of the points summarised above with respect to the blubber thickness analysis and made a number of suggestions regarding additional statistical treatment of the data (see Annex K1). The Committee **recommends** that these analyses be conducted if possible.

With respect to the biological issues, some members noted the importance of considering the stomach evacuation rate and its relationship to the timing of feeding. The strong decline in mean stomach contents over the day, as shown in the results, is indicative that most feeding is occurring at night. It is possible to envisage a situation where high food abundance would lead to whales being satiated relatively early in the night, such that by the next day the stomachs are not very full. Conversely, during periods of lower food abundance, feeding may be spread over a longer period, such that more food tends to be found in the stomach during the day. Thus, the direction of the relationship between food availability or intake and observed stomach content weight is not obvious *a priori*. In response, other members draw attention to information such as the negative trend in blubber thickness, which supported the lower food availability hypothesis. Data collected during JARPA on the freshness of food in the forestomach may provide further information on the timing of feeding, and the Committee **recommends** that these data be analysed.

The Committee **agrees** that for an understanding of the possible relationships between food intake and stomach fullness, analyses of the consequences of the diurnal patterns of food intake should be reported. Furthermore, alternative models for stomach evacuation (such as linear and exponential models) should be examined. The Committee **agrees** to keep the issue on the agenda for next year and encouraged submissions on this issue.

13.4 Review new information on ecosystem model skill assessment

No new information was available for discussion on this topic.

14. SMALL CETACEANS (SM)

The Committee has been discussing issues related to small cetaceans since the mid-1970s (IWC, 1976). Despite the differences of views over competency (IWC, 1993), the Commission has agreed that the Committee should continue to consider this item (IWC, 1995c).

14.1. Review status of ziphiids whales in the North Pacific and northern Indian Ocean

The last worldwide assessment on the status of ziphiids was in 1988 (IWC, 1989). Last year the Committee reviewed the status of ziphiids in the North Atlantic and adjacent waters (IWC, 2012, Annex L). At this meeting, the priority is to review the status of the ten beaked whale species in the North Pacific and Northern Indian Ocean (Table 1). Considerable information was submitted for the review and details can be found Annex L (see Table 1 for agenda items). Only a general overview is given here.

Table 1

Ziphiids in the the North Pacific and Northern Indian Ocean

Name	Distribution	Item in Annex L
Cuvier's (*Ziphius cavirostris*)	worldwide except polar waters	3.1
Blainville's (*Mesoplodon densirostris*)	tropical and warm-temperate waters worldwide	3.5
Baird's (*Berardius bairdii*)	cold-temperate waters of the North Pacific	3.2
Hubbs' (*Mesoplodon carlhubbsi*)	cold-temperate waters of the North Pacific	3.4
Stejneger's (*Mesoplodon stejnegeri*)	cold-temperate waters of the North Pacific	3.9
pygmy (*Mesoplodon peruvianus*)	mainly in the Eastern Tropical Pacific (ETP)	3.8
Perrin's (*Mesoplodon perrini*)	Poorly known – few California specimens	3.7
Ginkgo-toothed (*Mesoplodon ginkgodens*)	Poorly known - tropical and warm-temperate Indian and Pacific	3.6
Longman's (*Indopacetus pacificus*)	Poorly known - tropical and warm-temperate Indian and Pacific	3.3
Deraniyagala's (unidentified *Mesoplodon* taxon)	Poorly known - tropical and warm-temperate Indian and Pacific	3.10

SC/64/SM 21 analysed passive archival acoustic data from across the North Pacific. Species-specific frequency modulated (FM) echolocation pulses made by Baird's, Blainville's, Cuvier's, Longman's and Deraniyagala's beaked whales at Palmyra Atoll, have been recorded and described, with visual confirmation of species identity. The species-specific features appear to be consistent within all sequences labelled to signal type level, making possible the discrimination of species. It was agreed that Cross Seamount was a good site to identify ginkgo-toothed beaked whale call signatures.

The Committee **welcomes** the report on the spatio-temporal distribution of species-specific acoustic echolocation signals of beaked whales in the North Pacific. Future research using visual sightings with biopsies in conjunction with acoustic recordings will be necessary to link several species and signal types.

SC/64/SM11 provided estimates of abundance and trends for Baird's beaked whale, Cuvier's beaked whale and Mesoplodon spp. in the California Current from 1991-2008 using a Bayesian hierarchical modelling approach. The analysis indicated declining abundance for Cuvier's (2.9% per year) and *Mesoplodon* spp. (7.0% per year) in the study area but no evidence of a trend for Baird's beaked whales.

The Committee **agrees** that these results should be interpreted cautiously given the variability in ocean conditions in the region since the early 1990s. In the 1990s, both *M. stejnegeri* and *M. carlhubbsi* occurred as far south as San Diego, but since the late 1990s, previously rare warm-water ziphiids appear to have moved into the area which is thought to be near the northern end of their range. An analysis of the pattern of strandings of Ziphius along the US west coast might be informative for evaluating the apparent decline suggested in SC/64/SM11.

SC/64/SM13 summarised records of five documented ziphiid species in the EEZ of Costa Rica. There are only a few scattered records of all species except Cuvier's beaked whale, which is sighted relatively frequently, and *Mesoplodon* sp. A (almost certainly *M. peruvianus*), which could mean Costa Rican waters are a significant part of the range of this poorly known mesoplodont.

14.1.1. Cuvier's beaked whale (Ziphius cavirostris)

SC/64/SM34 reviewed current knowledge of Cuvier's beaked whale in the North Pacific and northern Indian Ocean. It occurs in deep waters worldwide and ranges from equatorial tropical to cold-temperate waters in the North Pacific, north to the Gulf of Alaska, along the Aleutian and Commander Islands in the Bering and Okhotsk Seas. It is commonly found where the steep continental slope occurs close to shore, such as around the Hawaiian Islands, San Clemente Island (California), Isla de Guadalupe (Mexico – see SC/64/SM18) and the Aleutian Islands.

Few estimates of density or abundance are available, primarily due to the rarity and difficulty of detecting and identifying beaked whales. In addition large-scale cetacean abundance surveys are often focused in areas such as continental shelf waters where beaked whales usually do not occur.

14.1.1.1. CONCLUSIONS AND OTHER CONSIDERATIONS OF STATUS

Cuvier's beaked whale is classified in the IUCN Red List as of Least Concern. Abundance estimates are available only for the Eastern Tropical Pacific, the Hawaii EEZ and the west coast of the USA (to 300 n.miles offshore). Numbers in the California Current appear to have declined in recent years. Some anthropogenic mortality is known from fisheries in waters off California and Japan and probably occurs elsewhere (e.g. in driftnet fisheries off Mexico). This

species is vulnerable to noise produced by naval sonar and seismic research. Research priority should be given to understanding population trends off California and studying population structure. The Committee **agrees** that there is no basis for revising the status of Cuvier's beaked whale at the species or population level at this time.

14.1.2. Baird's beaked whale (Berardius bairdii)

Reviews of published (and some unpublished) information on Baird's beaked whales in the North Pacific were provided in SC/64/SM 8 and by Brownell and Allen. Additional information on distribution and abundance was provided in SC/64/SM5, SM11 and SM21 and by Wade.

Baird's beaked whale is endemic to the cold temperate waters of the North Pacific. It appears to be more abundant in the western than the eastern part of the basin despite the long history of exploitation in the west and relatively little exploitation in the east.

SC/64/SM5 reported on a study of Baird's beaked whales at the Commander Islands in the western Bering Sea. Baird's beaked whales were found within about 12 km of the coast, and mostly on the continental slope at depths of 100-1000m (maximum depth at sighting about 3000m). A total of 78 individuals was identified. Photo-identification confirmed associations over several years and the authors suggested that Baird's beaked whales live in a fission-fusion society. Evidence of killer whale predation was provided. More than half of the whales had marks the authors attributed to fishing gear and 3/75 had scars of possible anthropogenic origin, one apparently from harpooning.

Wade provided information on Baird' beaked whale sightings (n=25) made during nine killer whale surveys in nearshore waters of the Aleutian Islands, between 2001 and 2010. Baird's beaked whales were seen on every survey, generally close to the continental shelf edge break, in deeper waters on the continental slope. The extent of predation by killer whales on beaked whales might be considerable and ongoing stable fatty acid analyses may elucidate the importance of beaked whales in their diet.

14.1.2.1. LIFE HISTORY PARAMETERS

There are considerable data on life history parameters obtained from carcasses of whales taken on the Chiba ground and processed at the Wadaura station in the 1975 and 1985-1987 summer seasons (Kasuya *et al.*, 1997). This information has been interpreted assuming annual deposition of tooth growth layers (Kasuya, 1977). Full details are given in Annex L, section 3.2.4.

14.1.2.2. ABUNDANCE AND TRENDS

Abundance estimates for Baird's beaked whales are given in Table 2 and section 3.2.5. of Annex L.

14.1.2.3. TAKES INCLUDING BYCATCH

Baird's beaked whales have been hunted by hand harpoon in Japan since around 1600 and by Norwegian type whaling since 1907. Kasuya (2011) reviewed published information on the Baird's beaked whale fishery in the Chiba Prefecture.

Recent catch statistics by Japanese small-type whaling are summarised in Annex L, Table 3. Official statistics since 1932, except 1943-1946, are given in Annex L Appendix 2. The reported statistics for the 1950s may be unreliable because of the likely inclusion of illegally caught and misreported sperm whales at Wadaura, Chiba between 1959 and 1974 (Kasuya, 2011). Similarly, illegal catches of sperm whales by small-type whalers in Ayukawa on the Pacific coast of northern Honshu (Kondo and Kasuya, 2002) may have been reported as Baird's beaked whales, thus contributing to the surprisingly high numbers of the latter reported in the catch statistics in the 1950s and 1960s. The reported annual take of Baird's beaked whales in Japan (mostly along the Pacific coast) ranged between 107 and 322 during the period 1950-1969 (3,896 animals in 20 years).

The number of catcher boats operating for Baird's beaked whales off Chiba has been regulated by the prefectural government since 1920. The government introduced a licensing system to the small-type whale fishery in 1947 to limit the total number of boats operating. A voluntary quota system was introduced for Baird's beaked whales in 1983. The initial quota of 40 has since been increased to 66 (Annex L, Table 3). In 1985, the Committee noted (IWC, 1986) that such a catch level represents about 1% of the estimated population size but was unable to determine whether this was sustainable. To investigate this question further it was agreed that studies on school structure would be desirable (IWC, 1986) - see above regarding the study in the Commander Islands. The Government of Japan has increased the quota several times and whaling operations have expanded since the late 1990s into the Sea of Japan (Appendix 1 and Tables 3 in Annex L).

In the eastern Pacific, small numbers of Baird's beaked whales were taken by whaling stations in California (15) and British Columbia (29) between 1956 and 1970 (Rice, 1974).

Five cases of stranded Baird's beaked whales in Japan were categorised as incidental fishery takes (Table 4 in Annex L).

14.1.2.4. OTHER ACTUAL AND POTENTIAL THREATS

High concentrations of mercury, HDBPs and/or PCBs have been found in this species (Endo et al., 2003, 2005; Haraguchi et al., 2006; also see SC/64/SM3). Concern has been raised since the accidents at Fukushima No1 nuclear power plant but there is no

evidence yet for exposure of Baird's beaked whales. Their range is mainly to the north of Fukushima.

14.1.2.5. CONCLUSIONS AND OTHER CONSIDERATIONS OF STATUS

The species is classified in the IUCN Red List as Data Deficient. Abundance estimates for the US west coast reported in SC/64/SM11 showed no trend for the period 1991-2008. The three populations off Japan have been assessed as Rare by the Japan Fisheries Agency and Mammalogical Society of Japan. The Committee **agrees** that there is no basis for revising the status of the Baird's beaked whale at the species or population level at this time.

The Committee **recommends** the following:

(1) it is especially important to clarify population structure and geographical boundaries of the stocks off Japan, particularly as long as hunting continues there.
(2) improved and updated abundance estimates are needed for each population, and trends in abundance should be assessed. These needs particularly apply to exploited stocks.
(3) better understanding is needed of the movements of animals from the respective stocks into and out of the three sea areas of Japan (Sea of Japan, Sea of Okhotsk, Pacific coast).
(4) the study in the Commander Islands (SC/64/SM5) should be expanded to include biopsy sampling for determination of sex and paternity and maternity in order to support studies of social and population structure, as well as satellite tagging to learn about movements and stock relations;
(5) the limited information suggests a peculiar life history and social structure-it is uncertain whether the characteristics of Baird's beaked whales are common, rare or even unique among the Ziphiidae, but further studies such as those recently initiated in the Commander and Aleutian Islands are encouraged to continue.

14.1.3. Longman's beaked whale (Indopacetus pacificus)

Published information on this species was reviewed in SC/64/SM26. It is probably endemic to tropical waters of the Indian and Pacific Oceans. The west- and southernmost record is Natal, South Africa, the northernmost is Hakodate, Hokkaido, Japan, and the easternmost is Maui, Hawaii.

Two stranded specimens in northeastern Taiwan on 22 July 2005, provided the first genetic and external morphological descriptions in the western Pacific (SC/64/SM32).

14.1.3.1. CONCLUSIONS AND OTHER CONSIDERATIONS OF STATUS

Longman's beaked whale is classified in the IUCN Red List as Data Deficient. The Committee **agrees** that there is no basis for revising the status of Longman's beaked whale at either the species or population level as no abundance estimates are available, except around the Hawaiian Islands, and there is no information on trends. The species is best known from the western North Pacific. Some anthropogenic mortality is known to have occurred in fisheries around Sri Lanka and strandings in Taiwan may have been associated with naval activities. Ingestion of plastic debris and exposure to morbillivirus are also of concern.

No high-priority research needs were identified but efforts are needed to better document the species' overall range, especially in the Indian Ocean. Continued efforts are encouraged to investigate and sample stranded animals at every opportunity following standardised protocols for beaked whale necropsy. Necropsy results should be made available in the literature and in relevant publicly accessible databases as quickly as possible.

14.1.4. Hubbs' beaked whale (Mesoplodon carlhubbsi)

SC/64/SM 27 reviewed published information on Hubbs' beaked whale from the seas around Japan and from North America (<60 records). It is endemic to the North Pacific and found in cold temperate currents off Japan and along the west coast of the United States and southern British Columbia, Canada. It has rarely been reported at sea.

14.1.4.1. CONCLUSIONS AND OTHER CONSIDERATIONS OF STATUS

Hubbs' beaked whale is classified in the IUCN Red List as Data Deficient. The Committee **agrees** that there is no basis for revising the status of Hubbs' beaked whale at either the species or population level. Some concern was expressed at the apparent decline of mesoplodonts off the U.S. west coast (SC/64/SM11) as this probably includes Hubbs' beaked whales. No species-specific abundance estimates are available. Some anthropogenic mortality is known to occur in fisheries off both Japan and the USA and these whales may be vulnerable to anthropogenic noise from naval sonar and seismic research.

The Committee **agrees** that priority should be given to studies of possible population differences between Japan and the USA (genetics primarily but also external and internal parasites and cookie-cutter sharks scars). Acoustic studies (e.g. SC/64/SM21) may help to better determine the range of Hubbs' beaked whale, if a species-specific signal is found.

14.1.5. Blainville's beaked whale (Mesoplodon densirostris)

Published information on this species (primarily from strandings) was reviewed in SC/64/SM33. This has the most extensive distribution of any *Mesoplodon*. Its acoustic signal type (the same as in the North Atlantic) was the predominant signal type in the Pacific Islands region (SC/64/SM21). It is found in tropical and warm temperate waters of all oceans, including deep offshore waters, tropical oceanic archipelagos and continental or insular coasts bordered by warm waters. There are no records from polar or other high latitude regions. It is reported infrequently at sea, and positive field identification can be difficult unless key diagnostic characters of the head are observed.

14.1.5.1. CONCLUSIONS AND OTHER CONSIDERATIONS OF STATUS

Blainville's beaked whale is classified in the IUCN Red List as Data Deficient. The Committee **agrees** that there is no basis for revising the status of Blainville's beaked whale at either the species or population level. Some anthropogenic mortality is known to occur in fisheries off both Japan and the USA and this species may also be vulnerable to anthropogenic noise from naval sonar and seismic research.

In addition to the general recommendations under item 3.12, the Committee **recommends** expanded photo-identification and tagging efforts in Hawaii to monitor movement patterns (seasonal as well as ranges) to determine whether there is site fidelity to specific types of habitat.

14.1.6. Ginkgo-toothed beaked whale (Mesoplodon ginkgodens)

There is only limited information on this species which is found in warm temperate and tropical waters of the Pacific and westward into the Indian Ocean. It is classified in the IUCN Red List as Data Deficient. The Committee **agrees** that there is no basis for revising the status of ginkgo-toothed beaked at either the species or population level. No abundance estimates exist. Some anthropogenic mortality is known from fisheries in at least Japan, Sri Lanka, Taiwan and Micronesia, and from anthropogenic noise from naval sonar (Wang and Yang, 2006 JCRM). It is important to confirm the species identifications of all available specimens because a number have been misidentified in the past. Its status and abundance in its apparent 'hotspot' around southern Japan and Taiwan should be investigated.

14.1.7. Perrin's beaked whale (Mesoplodon perrini)

IWC/64/SM30 reviewed the existing information on Perrin's beaked whale. Very little is known about this species that was described in 2002 by Dalebout *et al.* (2002) based on five stranded specimens from south and central California – it remains known only from strandings in California and may have the most restricted range of any species of Mespolodon. Many or most of the unidentified mesoplodonts observed in ship surveys off California (SC/64/SM11) may be Perrin's beaked whales.

The species is classified in the IUCN Red List as Data Deficient. The Committee **agrees** that there is no basis for revising the status of Perrin's beaked at either the species or population level. As with all of the beaked whales, Perrin's beaked whales are probably at risk from anthropogenic noise produced by military sonar and seismic surveys as well as to fishery bycatch in areas of overlap. There is a need is to determine distribution and abundance in the eastern North Pacific including opportunistic biopsy sampling and correlated acoustic sampling.

14.1.8. Pygmy beaked whale (Mesoplodon peruvianus)

IWC/64/SM30 reviewed the existing information on pygmy beaked whales, which appear to be endemic to the eastern tropical Pacific. Most sightings are from the 'Eastern Pacific Warm Pool', an area with sea surface temperatures >27.5°C (Fiedler and Talley, 2006). It may be particularly abundant in the southern Gulf of California, Mexico (e.g. Ferguson *et al.*, 2006). There are a few records from Mexico (Urban-R, 2010) and it may be relatively common off Costa Rica (SC/64/SM13). The northernmost record is Moss Landing, California, the southernmost record in the eastern Pacific is from northern Chile (Sanino *et al.*, 2007) and the only record outside the eastern Pacific was from South Island, New Zealand (Baker and van Helden, 1999). Whether this latter specimen is indicative of a wider distribution for this species, or just an errant individual, is uncertain.

14.1.8.1. CONCLUSIONS AND OTHER CONSIDERATIONS OF STATUS

This species seems be fairly common within its range (Ferguson and Barlow, 2001). It is classified in the IUCN Red List as Data Deficient. The Committee **agrees** that there is no basis for revising the status of pygmy beaked whale at either the species or population level given the sparseness of information. Confirmation is needed that *Mesoplodon* sp. A is M. *peruvianus*; while biopsy samples (male) seem unlikely, a colour-pattern description of a freshly stranded adult male M. *peruvianus* would suffice. The southern Gulf of Californias seem to be a promising region for either of these events.

14.1.9. Stejneger's beaked whale (Mesoplodon stejnegeri)

IWC/64/SM25 reviewed information on this species, mainly from waters around Japan but including data from North America. It is endemic to the cold temperate North Pacific and has not been reported from any of the central Pacific islands. Four mass strandings occurred in Kuluk Bay, Alaska between 1975 and 1989

(Walker and Hanson, 1999). It is the most commonly stranded ziphiid in Japan although rare on the Pacific coast of Japan (Brownell *et al.*, 2004). Park (1999) reported five strandings and two incidental catches along the east coast of South Korea (35° to 38°N).

The presence of cookie-cutter shark bites present on animals around the Aleutian Islands but not the Sea of Japan, suggest some population structure in the central and western North Pacific. Brownell *et al.* (2004) suggest that the northern Sea of Japan should be considered as a provisional management unit.

14.1.9.1. CONCLUSIONS AND OTHER CONSIDERATIONS OF STATUS

Stejneger's beaked whale is classified in the IUCN Red List as Data Deficient. The Committee **agrees** that there is no basis for revising the status of Stejneger's beaked whale at either the species or population level. No species-specific abundance estimates are available. Some anthropogenic mortality is known to occur in fisheries off both Japan and the USA and at least one case of a ship strike has been confirmed. The mass strandings in the Aleutian Islands were suspected of being related to naval sonar.

In addition to the general recommendations under Item 14.1.11, the Committee **recommends** regular and extensive sample collection from stranded or bycaught specimens (especially off Japan) in order to better understand the species' ecology, life history and vulnerability to threats. Genetic research is needed to determine whether western and eastern populations can be differentiated. Better understanding of its biology and abundance in the apparent 'hot spot' in the Sea of Japan off Honshu could be accomplished by (i) strengthening the stranding programme in order to collect specimens in fresher condition, (ii) acoustic monitoring and (iii) small-scale surveys to assess abundance.

14.1.10. Deraniyagala's beaked whale

SC/64/SM3 presented new genetic and morphological data supporting the recognition of a previously described but unnamed Mesoplodon in the tropical Indo-Pacific. Genetic identification has related new specimens, including those initially described by Baker *et al.* (2007), to a type specimen in Colombo, Sri Lanka described as *M. hotaula*, in 1963. Known from at least seven specimens it is genetically distinct but closely related to (and possibly conspecific with) *M. ginkgodens.* Its distribution seems to be tropical in both the Indian and Pacific Oceans. SC/64/SM3 argued that available evidence was sufficient to accept the revised taxon as a new subspecies of *M. ginkgodens* and that further characterisation could result in the resurrection of M. hotaula Deraniyagala, 1963 as a full species. The Committee suggested the provisional common name 'Deraniyagala's beaked whale' for this taxon, in recognition of the original description.

Further genetic investigation, including biopsy sampling of live animals, is required to clarify the systematics and taxonomy. Visual and acoustic reports from around Palmyra Atoll have been attributed to this new taxon (see SC/64/SM21) and this area clearly provides the opportunity to collect fresh tissue samples for genome-level analyses.

SC/64/SM4 reported on the species identity and local use of Deraniyagala's beaked whales (and Blainville's and Cuvier's beaked whales) in the Gilbert Islands, Republic of Kiribati. This investigation, conducted with the help of government agencies, visited several of the outer Gilbert Islands in June-July 2009 and collected bones and artefacts.

It is important to obtain new specimen material from oceanic islands and atolls in the central tropical Pacific and and to confirming the identities and provenances of existing museum specimens attributed to *M. ginkgodens*. Consideration should be given to the possibility that there are island-associated nearshore populations that are geographically and demographically isolated or semi-isolated from offshore populations of both Deraniyagala's beaked whales and ginkgo-toothed beaked whales, as is the case with Blainville's beaked whales.

Almost nothing is known about overall distribution, population structure, life history, abundance or takes of Deraniyagala's beaked whales, with the exception of those in Kiribati (SC/64/SM4). The five beaked whales strandings from Palmyra Atoll and Kingman Reef between 2002 and 2007 is high for such a small area and high compared to the number of beaked whale strandings reported on other Pacific Islands.

14.1.10.1. CONCLUSIONS AND OTHER CONSIDERATIONS OF STATUS

No IUCN Red List has been made for Deraiyagala's beaked whale at either the species or population level. The Committee **agrees** that there was insufficient data to assess this status at either the species of population level. The Committee expressed concern about the apparently high numbers of strandings around Palmyra Atoll in recent years. Deraniyagala's beaked whales are probably vulnerable to sound from naval sonar and seismic research, similar to other beaked whales. Assuming that the beaked whale recorded both acoustically and visually around Palmyra Atoll is Deraniyagala's beaked whale, the first priority is to make this determination genetically.

14.1.11. Common issues and threats

14.1.11.1 MILITARY SONAR AND OTHER NOISE SOURCES

Evidence of gas bubble lesions (gas embolism) and fat embolism have been reported at necropsy in beaked whales from atypical mass stranding events (MSEs),

which were coincidental with nearby use of mid-frequency sonar (Fernandez *et al.*, 2004). Exposure to sonar may alter the behaviour and/or physiology of beaked whales, potentially resulting in decompression sickness (DCS) in some circumstances.

Bernaldo de Quirós and Fernandez Rodriguez (2011) studied gas presence and composition in order to compare decompression vs. decomposition gases present at necropsy. Bubbles alone cannot be used to determine cause of death and it is important to differentiate between gas embolism and putrefaction gases. They recommended scoring gas bubble presence and sampling bubbles for gas composition analysis within 24 hours, but preferably within 12 hours, to minimise the masking effects of putrefaction gases.

The Committee **recommends** that groups working on mass strandings make all reasonable efforts to examine dead animals within 12 hours (or at most 24 hours) after death. Response teams should, if at all possible, include a veterinarian, a veterinary pathologist or a responder with experience in necropsy and sample collection. Routine necropsy protocols should include examination of bubbles present in tissues, scoring relative prevalence and sampling for gas composition analysis, particularly to detect and describe intravascular and peri-renal subcapsular emphysema bubbles.

The Committee took note of the latest investigations of MSEs in the Canary Islands, Spain associated with the use of naval sonar (Fernandez *et al.*, 2004). No further atypical MSEs have occurred since international naval exercises ended in 2004 following a recommendation of the parliament of the European Union and a Spanish government resolution banning the use of military sonar around the Canary Islands. This supports the inference that the atypical MSEs before the ban were caused by mid-frequency sonar.

Noting the ample evidence about the vulnerability of beaked whales to military sonar and seismic surveys and the potential for impacts at the population level (including not only animals that strand and are detected but also the potentially large number that die at sea and do not strand), the Committee strongly recommends that military exercises and seismic surveys should avoid areas of important habitat for beaked whales; that further effort should be made to mitigate their impacts; and that further efforts should be made to identify such areas (MacLeod and Mitchell, 2006; Cañadas, IWC/63/SM10).

The Committee also reiterates two previous recommendations.

(1) The continuation and expansion of studies of how anthropogenic noise, especially from naval sonar and seismic survey airguns, affects ziphiids. These should include efforts to determine if and how vulnerability differs between species, habitat types, animal activities (e.g. travelling, foraging) etc.

(2) Collaborative arrangements with military and industry authorities should be made to ensure researchers have advance notice of sonar exercises, seismic surveys and other activities so that the possibility of beaked whale stranding events can be anticipated with enhanced beach surveillance etc.

14.1.11.2. MARINE DEBRIS

Available data from the North Pacific and northern Indian Ocean (IWC/64/E10; Simmonds in press) indicates that beaked whales may be especially vulnerable to the ingestion of plastics and other marine debris; this can cause pathology and mortality. The population-level and long-term implications of the ingestion of plastic debris are unknown. The Committee **recommends** that this issue is further investigated via the collection, collation and analyses of relevant data from around the world concerning ingestion rates, debris types and associated pathology. It also **recommends** that standardised protocols are developed for pathology investigations. Consideration should also be given to investigating marine debris accumulation and associated processes in areas of important habitat for small cetaceans.

14.1.11.3 GENERAL RECOMMENDATIONS

The Committee **recommends** that for all North Pacific and northern Indian Ocean ziphiid species, further efforts are made to define population structure, delineate population boundaries, obtain estimates of abundance and identify and rank threats. Attention should be given to populations known or suspected to be small and/or exploited. The available evidence suggests that most ziphiid species occupy relatively narrow ecological niches and occur as local, largely isolated groups, which should be regarded as putative subpopulations (in the IUCN Red List sense).

The Committee **recommends** that more effort be made to investigate and validate methods of estimating population size for ziphiids, including those that incorporate passive acoustics for application in areas where the local species are acoustically distinguishable. Further data are needed to adjust density estimates from line transect surveys to account for visibility bias (given that these deep-diving whales spend relatively little time at the surface and species are difficult to distinguish) and for responsive movement. Consideration should also be given to interrupting line transect surveys (closing mode) in order to obtain photographs and biopsies as a way of reducing the 'unidentified ziphiid' component of abundance estimates.

Initial efforts have been made to map high-use areas for ziphiids on a global scale (MacLeod and Mitchell,

2006) to provide guidance for mitigation measures to reduce the risks from naval sonar and seismic survey operations. However, a more detailed examination is needed of these 'hotspots', including fine-scaled habitat characterisation and predictive habitat modelling. The Committee **recommends** that collaborative efforts similar to those described last year in SC/63/SM10 be made by the relevant scientists and research groups in the North Pacific and Northern Indian Ocean where anthropogenic sound is considered a problem.

Ziphiids are at risk of entangling in nets, especially pelagic driftnets, which tend to be deployed in or near their habitat. They are also known to get hooked or entangled in longline gear. The Committee **recommends** that methods be developed and applied to estimate fishery-related mortality, giving special attention to areas where there is direct evidence of incidental mortality as well as to areas where driftnetting and longlining operations overlap known concentrations of ziphiids.

Evidence of beaked whale population decline along the North American coast (SC/64/SM11) raised concern that beaked whales, and particularly resident populations, may be negatively affected by large-scale environmental change. The Committee **recommends** efforts be devoted to understanding impacts of changes in habitat on the distribution and abundance of beaked whales. This could involve pursuing an improved understanding of beaked whale feeding ecology and deep-water oceanographic processes as well as prey-community dynamics.

The Committee further **recommends** broad-scale collaborations to generate integrated results from analyses of genetic material, photograph collections and survey data. Particularly for *Mesoplodon* species, biopsies should be obtained from live animals to verify species identification. This is especially important for females and young males. Efforts are also needed to validate acoustic signatures of *Mesoplodon* species by collecting biopsies (and good photographs) along with acoustic recordings at sea.

14.2. Report on the voluntary fund for small cetacean conservation research

14.2.1. Status of the voluntary fund for small cetacean conservation research

In 2009, Australia made a generous donation toward the IWC Small Cetacean Conservation Research Fund of about £250,000 which enabled eight grant awards to research and conservation projects on small cetaceans (IWC, 2012r). At the Commission meeting in 2011 and during the interessional period, France, Italy, the United Kingdom and a number of NGOs provided extra funding of £73,000 which allowed: (i) the full funding of the two remaining projects recommended by the Committee in 2011; (ii) support for invited participants in 2011 and 2012; and (iii) a chance to start rebuilding the Fund. The Committee **thanks** the above governments and the NGOs for their generous contributions to the fund and hopes that the next Conservation Committee and Commission meetings will generate new funding that will allow another call for projects by the end of 2012.

14.2.2. Review on Progress on Funded Projects

The Committee reviewed brief project reports on five of the nine projects selected in 2011 (Annex 2) and received more extensive reports on three of them, which are presented in Annex L (Solomon Islands, in this section; franciscana, Item 14.3.3; Atlantic humpback dolphin, Item 14.3.5).

SC/64/SM23 presented preliminary results of an assessment of dolphins in the Solomon Islands where there is a long history of exploiting dolphins through traditional drive-hunts. More recently, the Indo-Pacific bottlenose dolphin (Tursiops aduncus), has been live-captured for export, with a current annual export quota of 50. This Committee as well as several intergovernmental bodies (CITES, CMS, IUCN, SPREP) have expressed concern in the past about the potential conservation implications of these removals.

The Committee expresses its appreciation for this work and acknowledges the constructive involvement of the Solomon Islands Fisheries and Environment ministries in collaborating and providing support. The preliminary results reinforce previously expressed concerns regarding the sustainability of past and ongoing live-capture removals of *T. aduncus* from what appear to be small island-associated populations. The Committee **encourages** the authorities responsible for conservation management (e.g. under CITES) to carefully consider the information from this study. It recommends that efforts to integrate the current and historical photo-identification catalogues be pursued as a priority.

14.3. Progress on previous recommendations

14.3.1. Vaquita

The Committee has expressed its grave concern over the status of this species and its continuing decline over many years. Last year, the Committee was informed about the pilot phase of implementation of an acoustic monitoring programme to track future changes in vaquita abundance in the Upper Gulf of California (IWC, 2012w). SC/64/SM19 provided further information on the implementation of the scheme in the first full sampling season. An overall loss rate of 44% of the detectors resulted in data being available for 38 sampling sites within the refuge. Deployment of buoys is the only way to obtain year-round information so an alternative method of deployment that reduces loss must be found. An analysis of the acoustic encounter rates in 2008 (0.74 encounters/day, CV 0.44) compared to those from the current study in 2011 (0.58 encounters/day, CV 0.05) is indicative of further

decline of the population since 2008, i.e. when strategies to reduce fishing effort by the Federal Government were already being implemented.

Jaramillo-Legorreta noted that redeployment of the array in late spring of 2012 was delayed because the presence of 87 boats fishing illegally within the refuge at that time presented too great a risk of loss of equipment; deployment was underway at the time of the Committee meeting.

The subcommittee considered the report[25] of the fourth Meeting of the International Committee for the Recovery of Vaquita (CIRVA) held in Ensenada, Mexico from 20-23 February 2012. The role of CIRVA has been recognised by the Government of Mexico in the agreement for the creation of the Vaquita Protection Refuge and in the current federal Action Program for the Conservation of Vaquita (PACE-Vaquita). Hence, the recommendations of CIRVA are important in terms of driving recovery actions. The report notes that the population has continued to decline, with an estimated reduction of nearly 60% between 1997 and 2008 and possibly as few as 220 porpoises remaining in 2008 (CIRVA, 2012). The report is discussed in detail in Annex L.

CIRVA's assessment of progress is that switch-out programmes (conversion to vaquita-safe gear) has been poor with only a very small proportion of the total fleet using such gear. Fishermen using such alternative trawl gear would have great difficulty operating safely in the middle of the large gillnet fleet. A working group has been engaged in a public process to amend the Mexican Official Standard 002-PESCA that regulates shrimp fishing. A three-year process beginning in 2013-14 to ban shrimp gillnets and exchange them for the new small artisanal trawl net design has been approved but not yet published in the Federal Register.

Details on CIRVA recommendations are given in Annex L and the Committee **strongly endorses** the CIRVA recommendations.

At last year's meeting the Committee concluded, as it has in several previous meetings, that the only reliable solution for vaquita conservation is to eliminate vaquita by-catch by replacing gillnets with alternative fishing gear. In a detailed recommendation, the Committee strongly supported robust gear trials to assess alternative gear effectiveness and economic viability (IWC, 2012r).

The Committee again **reiterates its extreme concern** for the status of this species and, as stated in 2011 (IWC, 2012r), **reaffirms** that the only reliable approach for saving the species is to eliminate vaquita bycatch by removing entangling gear from areas where the animals occur. It **strongly recommends** that, if extinction is to be avoided, all gillnets should be removed from the upper Gulf of California immediately. This is in accord with the Committee's strong recommendation made in 2009 (IWC, 2012f, p.66) regarding the extinction of the vaquita.

In light of reports on the successful development of an alternative shrimp trawl and the CIRVA recommendations summarised in Annex L, the Committee also **recommends** that vaquita conservation efforts focus on:

(1) expedited approval and adoption of the small shrimp trawls as an alternative to gillnets and prohibition of shrimp fishing with gillnets throughout the entire range of the vaquita;
(2) continued research on technologies to replace gillnetting for finfish or otherwise to remove all gillnets from the vaquita's entire range.

In this regard the Committee **notes** the ongoing project funded under the Voluntary Fund for Small Cetacean Conservation Research "Supporting the assessment of alternative fishing gears for replacing gillnets that cause bycatch of vaquita (*Phocoena sinus*) in the Upper Gulf of California, Mexico" and **looks forward** to a progress report at next year's meeting.

14.3.2. Harbour porpoise

In 2001, the Committee acknowledged the efforts by ASCOBANS to address serious harbour porpoise bycatch problems in the Baltic, Kattegat/Belt and North Sea areas and encouraged further efforts in that regard (IWC, 2010g). Since then, the ASCOBANS Jastarnia Group has met and considered new analyses of survey and bycatch data, which have had the effect of reinforcing and increasing concern about sustainability of bycatch as well as other factors potentially affecting the porpoise populations in the region, including declines in availability of prey, ship traffic, construction work, seabed exploitation, contaminants, and diseases.

The Committee remains concerned about the status of harbour porpoises in the western Baltic, the Belt Seas and the Kattegat ('Gap' area, also known as Belt Sea stock according to the ASCOBANS Jastarnia Group). Although the abundance estimates for harbour porpoises from SCANS and SCANS II were almost identical for the wider North Sea area, there was a southward shift in density distribution of porpoises between SCANS and SCANS II. However, there are indications of a possible decline in abundance in the Gap area. Bycatch is the major source of anthropogenic mortality and should be monitored and mitigated. EC Regulation 812/2004 does not adequately protect harbour porpoises from bycatches in this area because it requires bycatch monitoring only on boats > 15m and pinger use only on boats >12m.

In the current state of scientific uncertainty, the Committee looks forward to receiving the results of a

[25] http://www.iucn-csg.org/index.php/downloads/

planned dedicated shipboard survey to be conducted in the Gap area in the summer of 2012 with the intention of obtaining a new abundance estimate.

The Committee recommends with regard to the Gap area to:

(1) assess porpoise bycatch levels;
(2) monitor porpoise abundance on a regular basis;
(3) introduce measures to mitigate bycatch and other anthropogenic mortality;
(4) monitor the health status of the porpoises;
(5) ensure all bycaught and stranded animals are reported and delivered to qualified institutions for necropsy and sampling;
(6) implement the recovery plan for harbour porpoises which is currently being developed by ASCOBANS for the Gap area.

The Committee also repeats its longstanding concern regarding the critically endangered harbour porpoise population in the inner Baltic ('Baltic proper') and encourages all possible efforts to eliminate the bycatch there and address other factors that may be preventing this very small population's recovery. The current process of developing management plans for Special Areas of Conservation under the European Habitats Directive, offers a concrete chance to implement monitoring and mitigation as foreseen by the Jastarnia Plan. The Committee urges that effective monitoring and mitigation measures focusing on harbour porpoises be included in such national management plans.

14.3.3. Franciscana

SC/64/SM17 describes results of a project conducted with funding from the IWC Small Cetacean Conservation Fund. The main goal of the study was to assess distribution and obtain an abundance estimate of franciscanas inhabiting the region known as Franciscana Management Area I (FMA I), as recommended in IWC (2004). In December 2011 and January 2012, design-based aerial surveys were conducted to assess distribution and to estimate abundance of franciscanas in FMA I. The fully corrected abundance estimate was 1,998 (CV=0.48, 95% CI: 796-5,013). The most recent (2001-2002) estimate of incidental mortality in FMA I (Di Beneditto, 2003) corresponds to 5.5% of the estimated population size presented here. This indicates high and unsustainable bycatch if current mortality is similar to that in the early 2000s.

The Instituto Chico Mendes para a Conservacao da Biodiversidade (ICMBio) is the government agency responsible for establishing management and conservation strategies for endangered species in Brazil. In 2010, ICMBio published the 'National Action Plan for the Conservation of the Franciscana' (Di Beneditto et al., 2010) and made a series of general recommendations for research and monitoring (summarised in Annex L) which the Committee endorsed.

The Committee further recommends the following with respect to FMA 1

(1) Additional aerial surveys with increased sampling effort in order to:
  a) produce more robust (lower CVs, estimates for the northern range of FMA I) population estimates;
  b) further assess distribution (e.g. offshore limits, discontinuity);
  c) evaluate potential habitats that could be protected (e.g. by one or more no-take zones, marine protected areas) to improve conservation.
(1) Resume systematic and long-term by-catch monitoring in northern Rio de Janeiro and Espírito Santo, in order to produce more up-to-date mortality estimates.
(2) Studies be conducted to assess areas within the range of the species where other human activities could pose a threat to the long-term viability of franciscanas in FMA I.

Melcon *et al.* (2012) illustrated the potential for the use of autonomous acoustic detectors or towed arrays designed specifically for the identification of porpoise-like signals (e.g. C-PODs or A-tags) in franciscana research.

14.3.4. Narwhal and white whale

Bjørge reported on progress towards organising and convening a proposed global review of the monodontids (IWC, 2012 p. 279). The NAMMCO Secretariat has indicated interest in organising and convening such a review jointly with the IWC Scientific Committee and the inter-sessional correspondence group has identified a list of scientists interested in attending from four of the five range states (Norway, United States, Canada, Russia). Broader involvement of other scientific groups and individual scientists for a range-wide workshop or symposium on monodontid science may be appropriate. The involvement of groups as disparate as oceanaria and environmental NGOs as co-conveners might bring greater organisational motivation and financial resources to support such a workshop or symposium. The Committee recommends that a steering committee (Bjørge, Reeves, Suydam, a scientist from Canada, Donovan and Mario Aquarone from NAMMCO Secretariat) be established to meet intersessionally to discuss these issues and report back at next year's meeting.

14.3.5. Atlantic humpback dolphin

SC/64/SM22 presents a brief update on the project funded by the IWC Small Cetacean Conservation Research Fund for Atlantic humpback dolphins in

Gabon and Congo. There have been some challenges and shifts in focus and priorities over the last year, given boat failures and the discovery of a significant bycatch problem in Congo. As the project is ongoing, more complete reporting will be provided next year. The Committee thanks the authors for this preliminary report and expressed its appreciation for their perseverance in the face of the difficult challenges faced to date in this research.

14.3.6. River dolphins

IWC (2001) recommended that 'scientists with appropriate theoretical and/or analytical skills should be directly involved in river cetacean studies, so that surveys result in statistically robust estimates of abundance'. In 2002, two biologists and two statisticians led a pilot survey (line and strip transect data and some photo-ID data) of boto (*Inia geoffrensis*) and tucuxi (*Sotalia fluviatilis*) in portions of the Amazon in Colombia and Peru (IWC 2003). SC/64/SM24 revisited this dataset and reported on preliminary analyses. Participants drew attention to the existence of both older and more recent abundance estimates for the study area and suggested that a three-way comparison of abundance estimates would be of great value. The Committee expresses its appreciation to the Government of Brazil for supporting a proposed PhD studentship to work on this issue.

14.3.6.1. BOTO AND TUCUXI

Two largely sympatric endemic cetaceans, the tucuxi and the boto, inhabit the Amazon basin and both are increasingly killed for use as bait in the piracatinga (*Calophysus macropterus*) fishery (see IWC, 2007; 2008; 2009; 2012). Catches in this fishery, primarily for export to Colombian markets but also for sale in domestic markets, have increased in Brazil in recent years. Alves et al. (in press) reported on an interview study with fishermen and traders, to elucidate interactions between fishermen and river dolphins, including the occurrence of illegal, indiscriminate killing and growing trade in dolphin carcasses. In the view of fishermen, botos damage gear, steal (and also probably damage) catches. Botos are negatively portrayed in numerous traditional Amazonian folk myths and superstitions. These factors make them extremely unwanted or even hated and they are considered as pests. Now they have also become an economic resource as bait in the increasing piracatinga fishery. Addional information suggests that the true extent of the area of the piracatinga fishery and the area of direct takes is unclear, although the reported expansion of the piracatinga market and fishing effort add to concerns regarding the impacts on dolphins.

As previously noted (IWC, 2001), the population status of botos and tucuxis has been assessed in only relatively small portions of their Amazonian range. The Committee reiterates its serious concerns with the potential population implications of the intentional killing of botos and tucuxis for use as bait in the piracatinga fishery. It welcomes the information provided at this year's meeting but notes that the true extent of this exploitation throughout Amazonia is poorly understood. It also emphasises that this relatively new and rapidly growing problem is in addition to other historical and ongoing threats to these dolphins, e.g. from incidental mortality in fisheries, vessel traffic, construction of hydroelectric dams, mining and other development.

In view of these concerns and the information gaps, the Committee recommends the organisation of an international scientific workshop involving scientists and managers from the range states, with the goals of addressing research and conservation priorities, standardising methodologies and planning long-term strategies. The following specific topics could be discussed at the workshop:

(1) geographic and temporal extent of the piracatinga fisheries and associated dolphin use;
(2) methods to assess abundance and mortality (rapid assessment as well as longer-term approaches);
(3) improved understanding of dolphin movements and habitat use (including population structure) ;
(4) ways to reduce (or preferably eliminate) the pressure on dolphin populations from exploitation as bait for the piracatinga fishery.

The Committee agrees that the status of the boto and tucuxi should be added as a recurrent item on its agenda.

14.3.6.2. INDUS RIVER DOLPHIN

WWF-Pakistan hosted the Indus River Dolphin Conservation Strategy Planning Workshop in Lahore (Pakistan) last April. The objective was to lay the groundwork for development of a ten-year strategic action plan for conservation of endangered Indus River dolphins (*Platanista gangetica minor*), which are restricted to the Indus River system in Pakistan. Details can be found in Annex L, section 5.6.2.

14.3.6.3. MEKONG RIVER POPULATION OF IRRAWADDY DOLPHINS

A Mekong Irrawaddy Dolphin Conservation Workshop was held in Kratie, (Cambodia) last January. The workshop was jointly hosted by the Commission for Dolphin Conservation and Development of Mekong River Dolphin Ecotourism, the Fisheries Administration of the Ministry of Agriculture, Forestry and Fisheries, and the World Wide Fund for Nature – Cambodia. Participants reviewed the available evidence on possible causes of mortality of Irrawaddy dolphins in the Mekong in particular, the high and as-yet-unexplained level of calf mortality. Details can be found in Annex L, section 5.6.3.

All freshwater populations of Irrawaddy dolphins (*Orcaella brevirostris*) are listed on the IUCN Red List as Critically Endangered. The Mekong River population is estimated at 85 individuals (95% CI 78-91), excluding young calves (Ryan et al. 2011) with recruitment close to zero. Although births occur, few animals survive to adulthood. The available information, suggests a slow decline (2.2%/year during the study period). If confirmed, the current population composition has serious implications for the long-term viability of the Mekong River population.

Last year, the Committee expressed grave concern about the rapid and at least partially unexplained decline of this riverine population. Unfortunately, the high mortality of young calves has continued as has the occasional mortality of adults from entanglement. The Committee **recognises** and **commends** Cambodian government agencies and WWF-Cambodia for making serious, concerted efforts since the last meeting to diagnose the cause(s) of calf mortality and further reduce the risk of entanglement. The Kratie Declaration[26] is a major step forward and the Committee recommended that it be fully implemented as quickly and as effectively as possible.

14.3.7. Killer whales

The Committee was pleased to receive information on the first photo-ID catalogue of killer whales in Adélie Land, East Antarctica (SC64/SM6) as discussed in Annex L. This catalogue will be augmented in coming years and made available for regional matching and for a global Antarctic killer whale catalogue.

14.3.8. Clymene dolphin

The Committee was pleased to receive information a study underway on the first molecular characterisation of the Clymene dolphin (*Stenella clymene*) a recently rediscovered dolphin species. It has been suggested that the species could have had a hybrid origin, with *S. coeruleoalba* and *S. longirostris* acting as parental species (see Annex L).

14.4. Takes of Small Cetaceans

Annex L (Appendix 3) presents information on catches and associated quotas for small cetaceans from 1997-2010 obtained by Funahashi from the Japanese National Research Institute of Far Seas Fisheries website. The Secretariat developed the summary of catches of small cetaceans in 2009-2011 from this year's national Progress Reports.

The importance of these reports was noted, but concern was expressed that the Committee was not doing enough to take advantage of the significant information therein. The Committee **agrees** to explore intersessionally more specific terms of reference for evaluating direct take data, including the idea of developing case studies (e.g. assessing sustainability of bycatch in Europe) or other analyses from this information.

The Committee **thanks** Funahashi and the Secretariat for their work in compiling this information for the Scientific Committee each year and reiterated the importance of having complete and accurate catch and bycatch information and encourages all countries to submit data, appropriately qualified and annotated.

The Committee **expresses** its continuing concern about the lack of assessment of the exploited stock or stocks of killer whales in Greenland where reported catches were 14 in 2009 and 15 in 2010.

14.5. Local studies

SC/64/SM20 reported on the presence of long-beaked common dolphins in coastal waters of northern Colombia for the first time. These sightings extend the known range in the Caribbean, previously known primarily from the eastern Caribbean, some 700-800km.

Bolaños-Jiménez reported on: (1) work to gather records and sightings of killer whales in the Caribbean Sea and adjacent waters in collaboration with other North Atlantic killer whale studies and databases; (2) preliminary abundance estimates of Atlantic spotted and common bottlenose dolphins in the State of Aragua, central Venezuela, on the basis of mark-recapture models and photo-ID techniques as part of efforts to provide a stronger foundation for proper management and monitoring of dolphin-watching activities; and (3) new records of common dolphins in central-western Venezuela-common dolphins have recently been recorded on the Colombian side of the Guajira Peninsula (SC/64/SM20).

SC/64/BC2 reported on unusual strandings of two species of oceanic dolphins on the Pacific coast of Costa Rica. The first was a mass stranding of 38 rough-toothed dolphins in 2002, 34 of which were returned to the sea. The second was of an adult female Fraser's dolphin in 2006. Both strandings are the only ones known for each of these species in Costa Rica.

SC/64/SM10 reported on studies to identify critical habitats for coastal pantropical spotted dolphins in Golfo Dulce, Costa Rica, as the foundation of the design and implementation of Marine Spatial Planning and Marine Protected Areas. The current study investigates the underlying behavioural mechanisms that govern patterns of niche differentiation and the resulting conservation implications.

The Committee expresses its gratitude to the presenters of local research papers and noted that such work to establish baselines, distribution records, and habitat requirements is essential to addressing the concerns of the Committee.

[26] http://www.iucn-csg.org/wp-content/uploads/2010/03/Kratie-Declaration-signed-with-appendices-1.pdf

14.6 Hector's dolphins

Slooten reported on a number of recent findings and processes in New Zealand concerning Hector's dolphins. Bycatch in gillnet and trawl fisheries is the most serious threat to this endangered species. A substantial increase in survival rates (5.4%/yr) has been detected in one of the protected areas created to reduce the overlap between dolphins and these fishing methods (Gormley et al., 2012). The Banks Peninsula population was declining at approximately 6%/yr before 2008 and is now declining at about 1%/yr (Gormley et al., 2012; Slooten and Dawson, 2010). The population was predicted to recover if the boundaries of the protected areas were extended to the 100m depth contour. Slooten explained that the survival rate increase demonstrates that protected areas can work if (i) they are large enough and in the right place; (ii) key threats are managed by removing rather than displacing them; (iii) no new threats are added (e.g. in this example marine mining, tidal energy generation); and (iv) effective monitoring and enforcement is in place.

Bycatch in 'exemption' areas without protection measures, and in areas with incomplete protection, is causing continued population declines and population fragmentation (DOC and Mfish, 2007; (Davies *et al.*, 2008) Slooten and Dawson, 2010; SC/64/ProgRepNewZealand). Weak protection on the west coast of South Island, a lack of protection on the north coast of South Island and 'exemption' areas in other regions are slowing or preventing species recovery ((Davies *et al.*, 2008) Slooten and Dawson, 2010). There is also continued bycatch from illegal setnetting inside protected areas.

Full details are given in section 7.2 of Annex L.

The Committee expresses particular **concern** about the low abundance of Maui's dolphins (North Island subspecies of Hector's dolphin). The latest abundance estimate of 55 individuals over one year old (CV 0.15) was calculated from a genetic mark-recapture analysis (Hamner *et al.*, 2012).

The Committee **recommends** the immediate implementation of the proposal by the New Zealand Ministry for Primary Industries to extend the North Island protected area to approximately 80km south of the latest dolphin bycatch site (Maunganui Bluff to Hawera), offshore to the 100m depth contour, including the harbours, for gillnet and trawl fisheries. This would protect part of an area with high gillnet and trawl fishing effort between the North and South Islands. Further population fragmentation could be avoided by also protecting the north coast of the South Island, providing safe 'corridors' between North and South Island populations (Hamner *et al.*, 2012).

Adequate observer coverage across all inshore trawl and gillnet fisheries is important in order to obtain robust scientific data on continuing bycatch as a means of assessing the effectiveness of protection measures.

14.7. Workplan

The Committee's views on the workplan for the sub-committee on small cetaceans is given under Item 21.

The sub-committee reviewed its schedule of priority topics which currently includes:

(1) status of ziphiids in the Southern Hemisphere;
(2) systematics and population structure of *Tursiops*.

There is a need for extensive preparatory work for the proposed *Tursiops* review. Therefore the Committee agrees that the review of the systematics and population structure of *Tursiops* should be conducted in 2014 and an *ad hoc* group (Brownell, Perrin, Fortuna) was established to prepare for this. The Committee will need to carefully manage other agenda items to allow sufficient focus on the priority topics.

The Committee agrees that ziphiids of the Southern Hemisphere will be the priority topic at the 2013 Annual Meeting.

The Committee on small cetaceans intersessional group evaluating the feasibility of having the so-called 'marine bushmeat' issue as a future priority topic agreed on a number of attributes important for defining and delineating the issue (see Annex L). The Committee agrees to proceed with planning for a workshop characterised along the lines of 'poorly documented hunts of small cetaceans for food, bait or cash' although this may change somewhat at the discretion of the Convenor. It was emphasised that terminology and definitions as well as the scope and purpose of any workshop should be clarified to in advance. A steering group was established under Ritter (Annex Q).

15. WHALEWATCHING

The report of the sub-committee on whalewatching is given as Annex M. Scientific aspects of whalewatching have been discussed formally within the Committee since a Commission Resolution in 1994 (IWC, 1995b). The Commission also has a standard working group on whalewatching (IWC/64/CC6) that reports to the Conservation Committee (see Item 15.4.1).

15.1 Assess the impacts of whalewatching on cetaceans

SC/64/WW1 reviewed recent advances in whalewatching research. Steckenreuter *et al.* (2012a) investigated the impact of vessel interactions on the behaviour of a genetically distinct population of Indo-Pacific bottlenose dolphins; Steckenreuter *et al.* (2012b) examined the effectiveness of two Speed Restriction Zones (SRZs) in a dolphin-watching area;

and Harris *et al.* (2012) documented interactions between cruise ships and humpback whales at Glacier Bay National Park (GBNP) in Alaska. Summaries are presented in Annex M, item 5.

SC/64/WW2 reported on a resident population of bottlenose dolphins in Bocas del Toro, Panama, of 100-150 animals. Their predictability and site fidelity has encouraged the development of several dolphin-watching operations. Resolution ADM/ARAP No. 01 (2007) regulates whalewatching activities but few operators are well-informed about the regulations and their importance. This preliminary study found that group size and group presence decrease with increasing number of dolphin-watching boats, although this trend was not statistically significant and that overall, dolphins interacting with boats showed more avoidance behaviour. Future studies in the region will increase survey effort and include new data collection parameters to better characterise effects of dolphin-watching boats on these animals. Discussion and concerns expressed by some members of the sub-committee regarding SC/64/WW2 are detailed in Annex M, item 5.

The discussion further noted that one factor influencing the high volume of operators watching dolphins at the same time is that all operators have similar tour schedules. This results in competition among boat captains, little compliance with the regulations, and an increased risk of boat strikes (three dolphins were killed by dolphin watching boat strikes in 2011). The Committee **draws attention** to the need for developing strategies that minimise the impact of dolphin watching on the dolphin population, including staggering departure times to even out boat presence at any one time of day.

The Committee thanks the author for her presentation regarding a relevant situation in the host country and expressed concern regarding the intense and uncontrolled dolphin watching in Bocas Del Toro. The Committee **strongly recommends** that Panamanian authorities enforce the relevant whalewatching regulation (ADM/ARAP No. 01) and in particular promote adherence to requirements regarding boat number and approach speed and distances. It also **welcomes** the continuation of the Cooperative Agreement between Argentina and Panama to develop and conduct operator training workshops The Committee **recommends** continued research to monitor this dolphin population and the impacts of tourism on it.

SC/64/WW7 presented a controlled study on the swim-with-whale operations targeting humpback whales in Tonga. Up to five swimmers approached the whales while behaving in one of three ways: quietly slipping into the water and approaching at the surface making minimal noise; approaching whales at the surface making loud vigorous splashes; or, approaching whales with surface swimming and subsurface diving. The control treatment involved the boat approaching whales with no swimmers entering the water. The measure of disturbance was the time until the whales moved from their original location. Preliminary analyses suggest there was no significant difference between the quiet approach and the control, whereas there was a significantly shorter time to departure when the swimmers were loud and splashing, suggesting the management of swimmer behaviour could reduce the disturbance. Discussion is detailed in Annex M, item 5.

SC/64/WW3 presented a modelling approach to examine the potential effects of dolphin watching. Health was used to link individual behavioural changes to vital rates, since health can moderate survival and reproduction. Behaviours had a cost-benefit relationship with dolphin motivations (e.g. foraging reduces hunger), and health was linked to hunger to avoid biologically unrealistic variation. Trade-offs between motivations (e.g., hunger versus fear) then determines behaviour. Application to a bottlenose dolphin population in New Zealand found increased time foraging and decreased time resting leading to a negative shift in the population's health. A theoretical, larger population was then considered, looking at the potential loss of foraging time due to whalewatching vessels. Population-level impacts were dependent on population size and the intensity of whalewatching activities: larger populations required greater disturbance intensity to realise a population-level effect. These results highlight the need to consider whalewatching impacts and management at the population level. Short-term changes in behaviour can be significant, but do not automatically indicate a threat to the population's long-term health. Discussion and concerns over some aspects of SC/64/WW3 are detailed in Annex M, item 5.

The Committee **welcomes** the use of modelling to address the effects of whalewatching on cetaceans. It was suggested that Bocas del Toro, Panama, might be a location where this model could be tested.

15.2 Review whalewatching off Central America

SC/64/SH16 reported on whalewatching operations used as platforms of opportunity in Costa Rica, mainly offering trips to Marino Ballena National Park and Isla del Caño Biological Reserve, areas used by humpback whales during the winter. It was noted that this is a location where, without action, whalewatching could expand without sufficient oversight or control. It was suggested that this could be an important location for future focussed work to assess the development and evaluation of regulations, monitoring efficacy and compliance. The Committee **expresses** concern that whalewatching operators appear to target mothers and calves, especially as the season progresses.

A survey investigating whalewatching tourists' attitudes toward cetacean conservation issues was undertaken in Blackbird Caye, Turneffe Atoll, Belize in 2007 and 2008 (Patterson, 2011), an area that provides year-round habitat to approximately 200 coastal bottlenose dolphins. Two main types of whalewatching were identified: dedicated cetacean research and incidental cetacean watching. Information relevant to the Committee is detailed in Annex M, item 6.

Annex M, Appendix 2 presents information summarising the known whalewatching operators, areas and targeted species in Central America. All Central American countries have whalewatching activities, primarily concentrated in the Pacific, but only Costa Rica and Panama have organised their industries with tour operator associations. In the south Pacific coast of Costa Rica, workshops to train and certify operators in best practices are being held twice a year. In Panama, operator training started in 2006 and will continue this year. In Guatemala and Nicaragua, whalewatching operators are becoming organised. Belize, Honduras, and El Salvador do not yet have organised whalewatching operators or associations or whalewatching regulations.

The Committee **welcomes** the information provided in Annex M, Appendix 2. It was noted that more whalewatching may be occurring in the region, but it is likely to be incidental or opportunistic.

15.3 Reports from intersessional working groups

15.3.1 Large-scale whalewatching experiment (LaWE) steering group

The convenor for this intersessional correspondence group was unable to attend this year's meeting. A detailed progress report of this group's intersessional work is provided in the appendix of SC/64/WW6.

SC/64/WW6 introduced a meta-analysis to test for significant changes in speed, activity budget, inter-breath intervals and cetaceans' paths during whalewatching events. These changes could lead to increased energy expenditure and reduced foraging. In a call for participants, 10 ultimately provided data, after accounting for quality assurance and control procedures. A random effects model allowed for incorporation of heterogeneity due to moderators, such as study quality and body size. Only presence versus absence of vessels was modelled due to data limitations. Whalewatching activities had an impact in all studies, although the magnitude of the response varied. The only consistent response across species was path linearity and changes in resting behaviour. The only significant moderator was the effect of body size: smaller species and populations were less likely to rest in whalewatching vessels' presence. Researchers were receptive to suggested protocols meant to improve the quality of data collected.

15.3.2 LaWE budget development group

This intersessional group was unable to make progress. The convenor sought information on budget requirements from the LaWE principals, but did not receive sufficient information to develop a budgetary framework. The Committee **strongly recommends** that the principal researchers on the LaWE steering group provide concrete information on budget requirements to the convenor of the budget development intersessional group well before the next annual meeting, to allow this group's work to progress.

15.3.3 Online database for worldwide tracking of commercial whalewatching and associated data collection

Work continued intersessionally to develop a database to keep track of the details of whalewatching operations worldwide. The database developer is working towards putting the current version on the Commission's server for evaluation by the Committee.

15.3.4 Swim-with-whale operations

The questionnaire for operators (Rose *et al.*, 2007) was field-tested on three companies in the Dominican Republic in early 2012. Their responses indicated that the questionnaire was appropriate and sufficient to present more widely to operators. Further work will be undertaken intersessionally to distribute the questionnaire to more operators and report results at IWC 66. The Committee thanks Rachel Ford, who conducted the field test of the questionnaire and the Pacific Whale Foundation which funded Ford's trip to the Dominican Republic.

15.3.5 In-water interactions

The Committee discussed the issue of human-cetacean in-water interactions in the wild in 2011 and an intersessional correspondence group was established (see IWC 2012). In order to examine potential risks to both cetaceans *and* humans, key points will be to identify for whom these in-water interactions are dangerous and what is considered dangerous. Definitions are elaborated in Annex M, item 7. In its workplan, the group proposes to work on a comprehensive list of human cetacean in-water interactions, based on Scheer (2010), and to elaborate a list of areas and operations where in-water-interactions take place.

In discussion, the Committee noted that the Commission's Five Year Strategic Plan for Whalewatching (see Item 15.4.1) may not adequately account for swim-with-whale and in-water interactions as forms of whalewatching. The Committee **recommends** that the Commission address issues that arise uniquely from operations that allow customers to swim with or feed cetaceans. It was suggested that the Commission refer to the Committee's definitions of types of whalewatching, as reported in Parsons *et al.*

(2006), as well as the General Guidelines[27] as it progresses its work on whalewatching.

15.4. Other issues

15.4.1 Review scientific aspects of the Commission's Five Year Strategic Plan for Whalewatching

The Committee **agrees** that the goal of its review was to offer the Commission advice that will lead to results that benefit both the work of the Conservation Committee's SWG on whalewatching as well as the Scientific Committee's work. It was clarified that while the Committee focused its input on Objectives 1 (Research) and 2 (Assessment), all five objectives of the Strategic Plan could benefit from further cooperation between the two Committees, particularly in regards to elements such as regulatory frameworks, where this Committee could contribute expertise, data, and other work. The Committee again recognises the ambitious scale of the science-related work programme found in the Strategic Plan and noted that the Commission should consider which actions would require additional time to address (see Annex M, Appendix 3). A working group was convened to formulate the Committee's comments back to the Commission. The Committee **endorses** the results of their consultation, which can be found in Annex M, Appendix 3.

An intersessional correspondence group (Annex Q) was established to discuss and develop guiding principles per Action 1.1 in the Strategic Plan. Action 1.2 should be completed intersessionally, with results reported to the next meeting.

15.4.2 Consider information from platforms of opportunity of potential value to the Scientific Committee

The United Nations Environment Programme-Caribbean Environment Programme (UNEP-CEP), through the Specially Protected Areas and Wildlife Protocol and with the support of the National Environmental Authority of the Government of the Republic of Panama, convened a regional Workshop on marine mammal watching on 19-22 October 2011 in Panama City, Panama (Anon. 2011), bringing together marine mammal tour operators and government regulators from across the wider Caribbean region (WCR). The participants concluded that the data collected during marine mammal watching operations have the potential to answer questions about marine mammal populations in the WCR. Furthermore, these data should involve a network of collectors that cover larger field areas and archived so that they can be accessed and facilitate collaborations. Acknowledging the importance of standardised data, a template data form was developed. A copy of the proposed data form for the WCR may be found in Appendix V of the workshop report.

The Committee **welcomes** this report on UNEP-CEP's activities and encouraged the submission of work related to this initiative to future meetings (and see Item 15.4.3)

Sollfrank and Ritter () presented results from a study conducted on La Gomera (Canary Islands). Boat-based studies have been on-going for years, but little effort has been made to observe cetaceans systematically from land. This study demonstrated that it is possible to direct whalewatching boats to cetaceans spotted from land, allowing comprehensive and simultaneous data collection from land-based stations and boat-based platforms of opportunity. Land-based observations are the best way to monitor compliance with whalewatching regulations and to measure impacts from whalewatching vessels, as the presence of a research vessel does not influence operators or confound impact results.

M.E.E.R. (2012) laid out a model for a marine protected area for sustainable whalewatching in the Canary Islands. Almost 15 years of cetacean data collected exclusively on whalewatching vessels (platforms of opportunity) were used to elaborate a marine protected area (MPA) model. With anthropogenic threats increasing, the MPA model is especially designed for long-term development of whalewatching and other uses in a sustainable way. It is hoped that this report will contribute to the process of designating effectively managed marine protected areas within the European Union and elsewhere.

The Committee **welcomes** this presentation, as it represents the type of data most relevant to this agenda item and the work of the Committee as it can be applied toward science-based management decisions and actions.

SC/64/O12 reported on the situation in Samaná Bay, Dominican Republic, part of a national marine mammal sanctuary (along with the Navidad and Silver Banks). The Samaná Bay Boat Owners Association provides space aboard whalewatching vessels as platforms of opportunity. Data obtained over a period of 12 years were analysed to determine the spatial and temporal distribution of humpback whales in Samaná Bay. This information has played a vital role in the marine spatial planning of Samaná Bay and the creation of a conservation zone with restricted fisheries and tourism activities during the whale calving season. Details on the results of the study and discussion are found in Annex M, item 8.2

In particular given the expanding development of tourism in Samaná Bay, the Committee **recommends** that monitoring and research continue, especially in

[27] http://iwcoffice.org/conservation/wwguidelines.htm

light of the increasing number of cruise ships entering the bay during the calving season.

SC/64/SH16 reported that along the South Pacific coast of Costa Rica, whalewatching boats have been used as platforms of opportunity to collect data on distribution and behaviour of humpback whales from breeding stock G from 2009-2011. The results indicated a high number of mother-calf pairs and the use of coastal waters as a breeding ground. It was suggested that this location might be a good place to study the efficacy of a MPA by conducting research on the behaviour of animals inside and outside the MPA.

15.4.3 Review whalewatching guidelines and regulations

Carlson noted that the compendium of regulations and guidelines[28] on the Commission website was open, as always, to additions and updates. The Committee thanks Carlson for her committed work in this regard and **agrees** that the compendium is a valuable tool and should be continued. SC/64/WW5 analysed the compendium. The analyses, like the compendium, are intended as a reference, in this case to demonstrate both the diversity and similarities in existing rules. The Committee **agrees** that this analysis would also be a useful reference for the Commission and **recommends** that it also be posted on the Commission website.

The Committee reviewed the General Principles[29] and considers them robust. However, it **recommends** that they be renamed 'General Guidelines' (to avoid confusion with the term 'guiding principles'). It **agrees** to revisit them on a more regular basis to ensure they remain representative of 'best practices' and to address them under the standing agenda item on reviewing whalewatching guidelines and regulations.

SC/64/WW1 reviewed several studies that addressed whalewatching guidelines and regulations: Howes et al. (in press*)* investigated the effectiveness of the Ticonderoga Bay Sanctuary Zone to mitigate pressures of dolphin-swim operations on a small population of bottlenose dolphins*;* Alves et al. (2011) report on tourists swimming with and feeding Amazon river dolphins in Brazil; Ponnampalam (2011) collected baseline data on the nature of whalewatching in the Sultanate of Oman; and Pacheco *et al.* (2011) describe the success rate of sighting humpback whales from a marine wildlife-watching vessel operating in the coastal waters off northern Peru. Summaries are found in Annex M, item 8.3.

A product of the regional Workshop on marine mammal watching held in Panama (Anon., 2011) was the development of overarching principles and best practice guidelines for marine mammal watching in the WCR (UNEP-CEP, 2011a; 2011b). These principles and guidelines take into consideration pre-existing codes of conduct and regulations from countries within, and outside, the WCR and closely follow the steps and language used in the document *Pacific Islands Regional Guidelines for Whale and Dolphin Watching* (IFAW, 2008). All of the principles and guidelines developed for the WCR were agreed upon by the tour operators and regulators present at the workshop and may serve as the basis upon which each country's own codes of conduct and regulations may be developed.

Galletti reported that the Chilean Government enacted whalewatching regulations in 2012. Many of the recommendations made by the Scientific Committee in 2007 were included, such as a maximum 300m approach distance for blue whales and allowing only land-based whalewatching for critically endangered southern right whales. Regulations will be translated into English and submitted for the compendium. The Committee **welcomes** this news.

15.4.4 Review of collision risks to cetaceans from whalewatching vessels

No new information was presented under this item.

15.4.5 Swim-with-whales operations

SC/64/WW1 presented information on swim-with programs: Mangott et al. 2011a, reported on swim-with dwarf minke whales on the Great Barrier Reef. The summary is found in Annex M, item 8.5. The Committee **reiterates its recommendation** from item 15.3.5.

15.4.6 Emerging whale watching industry in Oman

Oman's whalewatching industry has experienced gradual growth over the last 10 years, reflecting a steady increase in tourism and a growing awareness of cetacean fauna. The Arabian Sea humpback whale has recently become a target of opportunistic and unregulated whalewatching in southern Oman. The Committee has previously expressed concern over the status of this population which is discussed further under Item 10.7; unregulated whalewatching represents an additional potential threat to this population.

Existing, unofficial whalewatching guidelines in Oman are now over 10 years old. Progress has been made on updating these guidelines as well as gathering data on whalewatching operations, but further technical support is required to finalise the new guidelines as well as to assist with the training of operators.

The Committee **strongly recommends** that operator training workshops should be conducted with a view to promoting best practice for whalewatching and to aid the interpretation and implementation of revised whalewatching guidelines (and see Item 21).

15.5 Work plan

This is discussed under Item 21.

[28] www.iwcoffice.org/conservation/whalewatching.htm#regulations

[29] http://iwcoffice.org/conservation/wwguidelines.htm

15.6 Other matters

It was noted that the development of general data requirements on the effects of whalewatching would be valuable in situations where a country is considering whether it would be sustainable to increase the level of whalewatching (e.g., a proposed increase in whalewatching permits for Kaikoura, New Zealand). The concept of assessing 'whalewatching carrying capacity' is of interest in the management and scientific communities and the Committee **encourages** presentation of a paper outlining the situation in New Zealand at the next meeting of the Committee to facilitate its discussions of the broader issue.

16. DNA TESTING

The report of the Working Group on DNA is given as Annex N. This particular agenda item has been considered since 2000 in response to a Commission Resolution (IWC, 2000).

16.1 Review genetic methods for species, stock and individual identification

No documents were presented this year. The Committee encourages the preparation of technical documents on methods for species, stock and identification for discussion at the next year meeting (see also Item 16.5).

16.2 Review results of the amendments of sequences deposited in GenBank

During the first round of sequence assessment (IWC, 2009 pp. 347) some inconsistencies were found that appeared to be due to a lag in the taxonomy recognized by GenBank or uncertainty in taxonomic distinctions currently under investigation: 23 labelled as *Balaenoptera acutorostrata* in GenBank were identified as *B. bonaerensis*; 9 labeled as *B. edeni*; and 10 labeled as *Eubalaena glacialis* were identified as *E. australis* and *E. japonica*. The Committee had recommended notifying the original submitter about the inconsistency and encouraging an amendment to be made to the entry.

Following 2010/11 intersessional work, amendments were made for four cases of Bryde's whale and one case of minke whale, respectively (IWC, 2012 p 52). In view of the limited responses, the Committee had requested that an official letter be sent from the Secretariat requesting the submitters to make the amendments in Gen Bank. This was done for three scientists for which addresses were available, involving nine cases of right whale (one scientist), one case of right whale (one scientist) and one case of Bryde's whale (one scientist). Unfortunately no responses have yet been received and thus no amendments have been made in GenBank during the intersessional period.

In view of this, for the next period, the Committee **reiterates** its previous suggestion on the addition of a field in GenBank where comments on taxonomy updates of the entries can be made (IWC, 2012 p 52). The Committee **agrees** that Cipriano should make a request to GenBank and that he should inform the IWC Secretariat and the Convenor of the DNA Testing Group if a more formal request is required.

16.3 Collection and archiving of tissue samples from catches and by-catches

Last year, the Committee endorsed a new format for the updates of national DNA registers to assist with the review of such updates (IWC, 2012 p 53). The updates of the DNA registers by Japan, Norway and Iceland this year were based on this new format.

The collection of tissue samples in Japan is from special permit whaling in the North Pacific (JARPN-JARPN II) and Antarctic (JARPA-JARPA II), and from bycatches. It includes coverage for 1994-2011 (JARPN-JARPN II), 1987/88-2011/12 (JARPA-JARPA II). In the case of bycatches it includes coverage for 2001-2011 (see Appendix 2 of Annex N).

The collection of tissue samples in Norway is from the commercial catches of North Atlantic common minke whales. It includes coverage for the period 1994 to 2011 (see Appendix 3 of Annex N).

The collection of tissue samples in Iceland is from scientific whaling and from commercial catches. It includes coverage for 2003-2007 (permit whaling) and 2006-2011 (commercial whaling) (see Appendix 4 of Annex N).

16.4 Reference databases and standards for diagnostic registries

In the Japanese register, almost all common minke whale sampled by JARPN-JARPN II in 1994-2011 were screened for mtDNA and microsatellites. Almost all of minke whales bycaught in 2001-2010 were screened for mtDNA and microsatellites. For animals bycaught in 2011, the percentage for microsatellite is lower (77.8%). This lower percentage is a result of the loss of 26 samples after the 2011 tsunami in Japan (see Appendix 2 of Annex N).

Almost all Bryde's whales sampled by JARPN II in 2000-2011 were screened for mtDNA and microsatellites. Genetic work for mtDNA and microsatellite was completed for four whales bycaught in 2001-2010. Almost all sei whales sampled by JARPN II in 2002-2011 were screened for mtDNA and microsatellites (see Appendix 2 of Annex N).

Almost all sperm whales sampled by JARPN II in 2000-2010 were screened for mtDNA and microsatellites. The single animal sampled in 2011 was screened for mtDNA. Microsatellite work has not been completed yet. All sperm whales bycaught in 2001-

2010 were screened for mtDNA and microsatellites (see Appendix 2 of Annex N).

In the case of Antarctic minke whales, 16.5% and 92.3% of the whales sampled by JARPA in 1987/88-2004/05 were screened for mtDNA and microsatellites, respectively. Work for mtDNA is ongoing. Many of the samples of JARPA II (2005/06-2010/11) were lost after the 2011 tsunami in Japan. DNA work is ongoing on the recovered samples. For animals sampled in 2011/12, the mtDNA and microsatellite work has not yet been completed. For Antarctic fin whales, the 17 samples collected by JARPA II in 2005/06-2010/11 were screened for mtDNA and microsatellites. The DNA work on the single animal sampled in 2011/12 is ongoing (see Appendix 2 of Annex N).

All North Pacific humpback whales bycaught in 2001-2011 were screened for mtDNA and microsatellites. Two North Pacific right whales and three North Pacific fin whales bycaught from 2001-2010 were screened for both mtDNA and microsatellites (see Appendix 2 of Annex N).

Almost all samples in the Japanese DNA registry have been sexed (see Appendix 2 of Annex N).

A suggestion was made that the genetic data of bycaught humpback whales could be of utility for testing hypotheses on stock structure of this species in the western North Pacific.

In the Norwegian register, after discounting for duplicates, missing samples and laboratory problems, 100% of the North Atlantic common minke whale caught in 1997-2011 were screened for mtDNA and microsatellite (see Appendix 3 of Annex N). The Committee **commends** the analyses on quality control carried out on the Norwegian DNA register (Glover *et al.*, 2011).

In the Icelandic registry, all common minke whales sampled under scientific permit whaling in 2003-2007 were screened for mtDNA and microsatellites. The percentage for both markers is 6.1% for whales taken by commercial whaling in 2007-2010. The percentage is 3.5% for whales taken by commercial whaling in 2011. All fin whales caught by commercial whaling in 2006-2010 were screened for both mtDNA and microsatellites (see Appendix 4 of Annex N). A question was raised on the low percentage for the commercial samples of common minke whale. In response, Víkingsson noted that while not required by IWC rules or regulations, tissue samples had been collected for the DNA register from all animals caught in the Icelandic commercial hunt. The delay in the laboratory analyses of samples collected since 2007 is due to funding restrictions but these will be completed before the *Implementation Review* of North Atlantic common minke whales scheduled for 2014.

The Committee appreciates the efforts of Japan, Norway and Iceland in compiling and providing detailed information on their registries in the new format. The Committee **agrees** that the information provided in the new format facilitated greatly the annual review.

16.5 Work plan

The Committee **encourages** the submission of papers in response to requirements placed on the Committee by the IWC Resolution 1999-8 (IWC, 2000). Relevant information in documents submitted to other groups and sub-committees of the Committee will be reviewed next year. Results of the 'amendments' work on sequences deposited in GenBank will be reported next year.

17. SCIENTIFIC PERMITS

This Agenda Item was discussed by the Working Group on Special Permits in two late afternoon sessions to enable all Committee members who wished so to attend. Bjørge was elected Chair of the Working Group. Weller acted as Rapporteur, and the Working Group report has been directly incorporated here.

17.1 Review of results from existing permits

As in previous years, the Committee received short cruise reports on activities undertaken but spent relatively little time on discussion of the details. For long-term programmes the Committee has agreed that regular periodic detailed reviews (following 'Annex P') were more appropriate.

17.1.1 JARPN II

17.1.1.1 AUTHORS' SUMMARIES

SC/64/O3 presented the results of the 2011 Japanese Whale Research Program under Special Permit in the Western North Pacific-Second Phase (JARPN II) offshore component survey in sub-areas 7, 8 and 9 of the western North Pacific. There were three main research components: the whale sampling survey; the dedicated sighting survey; and the whale prey species survey. Two sighting/sampling vessels (SSVs), 1 research base vessel (NM whale sampling survey component), 1 whale prey survey vessel equipped with scientific echo sounder (PSV and 3 dedicated sighting vessels (SVs) were used. The whale sampling survey took place from 11 June to 5 September 2011. A total of 5,156 n. miles was surveyed in 76 days (by the SSVs and NM) sightings included, 53 common minke, 476 sei, 149 Bryde's, 295 sperm, 66 fin and 8 blue whales. A total of 49 common minke, 95 sei, 50 Bryde's and one sperm whale were sampled by the SSVs. Sampled whales were examined on board the research base vessel. In July, common minke whales fed mainly on Japanese anchovy near Syiriya, and they fed mainly on walleye pollock around east of Hokkaido. There were geographical changes of prey species of minke whales

in sub area 7. Sei whales fed mainly on copepods and Japanese anchovy from June to August in sub areas 8 and 9. Bryde's whales fed mainly on krill in sub area 7 in July. Dominant prey species in the stomach of the sperm whale included mid- and deep-water squid. The dedicated sighting surveys took place from 28 April to 6 June 2011 in sub areas 8 and 9. During 4,060 n. miles surveyed 3 common minke, 51 sei, 6 Bryde's, 116 sperm, 31 fin and 4 blue whales were sighted. The prey species survey was carried out from 13 to 28 June in 2011. In parts of sub areas 8 and 9 by the PSV. Its objective was to estimate sei whale habitat and prey preference in relation to oceanographic and prey environments as well as productivity in early summer. Data obtained in this research will be used to elucidate the role of whales in the marine ecosystem through the study of whale feeding ecology in the western North Pacific.

SC/64/O4 presented the results of the 2011 JARPN II -coastal component- survey in spring. Usually the coastal spring survey is carried out in the locality of Ayukawa. On March 11 2011 the Ayukawa town, including all research facilities of JARPN II there, was destroyed by a large earthquake and tsunami. For this reason, the 2011 spring coastal survey was conducted in Kushiro, from 25 April to 10 June, using three vessels. Sampling occurred within 50 n. miles from Kushiro port, and animals were landed at the JARPN II research station. A total of 3,867.4 n. miles was surveyed and 36 schools (43 individuals) of common minke whales were seen and 17 common minke whales were sampled. Average body length was 6.70 m (SD=0.84, *n*=9) for males and 6.29 m (SD=1.02, *n*=8) for females. Dominant forestomach prey species were walleye pollock (*Theragra chalcogramma*) throughout all of the survey period, and krill (*Euphausia pacifica*) that was observed less frequently. Walleye pollock is one of the most important food items for common minke whales in Kushiro in both spring and autumn seasons. Distribution of common minke whales appeared to differ between spring and autumn surveys in Kushiro, at least for some years.

SC/64/O5 outlined the results of the autumn survey of the JARPN II coastal component off Kushiro, northeast Japan (the sub-area 7CN) in 2011. The survey was conducted from 9 September to 30 October 2011, using four vessels. During 5,367.8 n. miles searched, 144 schools and 150 individual common minke whales were sighted and 60 whales were sampled. Average body length was 6.24 m (SD=1.06, *n*=35) for males and 6.05 m (SD=1.08, *n*=25) for females. Overall, 19 of the 35 males (54.3%) and 3 of the 25 females (12.0%) were sexually mature. The dominant forestomach prey species was Japanese anchovy (*Engraulis japonicas*) (61.7%), followed by walleye pollock (26.7%), and krill (8.3%). Pacific saury (*Cololabis saira*) and Japanese common squid (*Todarodes pacificus*) were not observed. The frequent sightings of whales in combination with the slightly higher ratio of mature and larger whales in the 2011 survey, as compared to the 2010 survey, as well as more whales comsuming Japanese anchovy suggested that the abundance and distribution of this prey item may have attracted whales to the coastal waters off Kushiro in autumn 2011. During the survey, no apparent impact due to the earthquake in March 2011 was detected in the distribution, density or catch composition of common minke whales. This implied that effect of the earthquake on the migration of common minke whales in the coastal waters off Kushiro might be negligible.

17.1.1.2 DISCUSSION

Following the cruise report presentations, there was some discussion of how the cruise tracks for the coastal survey off Kushiro were designed and if the intent was to obtain a representative sample or rather to increase the probability of encountering whales. The authors of SC/64/O5 explained that survey vessels used during the coastal component of the programme departed port each day following a number of predetermined lines with 15° radials that were selected on a daily basis after review of weather, oceanographic conditions and the distribution of whales. Survey tracks were concentrated relative to whale distribution and differed from standard line transect methods in that the first 30 n. miles were dedicated to survey search mode followed then by the vessels moving freely within the study area. In further discussion, the Working Group was reminded that at last years meeting it was suggested that whales taken during coastal operations be examined for radionuclides, especially caesium-137, for use in stock elucidation (IWC, 2012). The authors of SC/64/04 stated that one of the three objectives of the JARPN II programme was to monitor environmental pollutants in cetaceans and the marine ecosystem. Data collection for radionuclide assessment is being undertaken and data are available on the website of the Fisheries Agency of Japan.

17.1.2 JARPA II

17.1.2.1 AUTHORS' SUMMARY

SC/64/O2 presented the results of the 2011/12 survey of the Second Phase of the Japanese Whale Research Program under the Special Permit in the Antarctic (JARPA II). Two dedicated sighting vessels (SV), one sighting and sampling vessel (SSV) and one research base vessel engaged in the research for 66 days, from 1 January to 6 March 2012 in Areas V (130°E - 170°W) and VI West (VIW: 170°W - 145°W). Unfortunately, the research activities were interrupted several times by the violent sabotage activities of an anti-whaling group. The planned dedicated sighting survey had to be cancelled so that the vessels could undertake security tasks. The research activity of the SSV was also interrupted several times. The total search distance by the SSV of 3,040.5 n. miles, was approximately one-

third of the search distance in 'normal' years. Eight species including six baleen whales (blue, fin, sei, Antarctic minke, humpback and southern right whale) and two toothed whales (sperm and southern bottlenose whales) were seen. The most common species seen (284 schools, 684 individuals) was the Antarctic minke whale followed by the humpback (112 schools, 208 individuals) and fin whales (11 schools, 31 individuals). A total of 266 Antarctic minke whales (99 males and 167 females) and one fin whale (female) were sampled examined on the research base vessel. A total of five blue, six humpback and four southern right whales were photo-identified. Two biopsy samples were collected from humpback whales and four from southern right whales. In March, satellite tags were deployed on two southern right whales. Oceanographic surveys to investigate vertical sea temperature profiles were also implemented using XCTD. In summary (1) whale composition in the research area was stable compared to previous JARPA and JARPA II surveys in the same area; (2) the ice-free extent in Area VIW was substantially larger than in previous seasons; (3) high density areas of Antarctic minke whales were observed near the ice edge; (4) mature female Antarctic minke whales were dominant in the southern part of Area VIW (66.8%); and (5) Antarctic minke whales in the 'transition area between 130°E and 165°E' (area of stocks mixing), were successfully sampled.

17.1.2.2 DISCUSSION

Following the presentation of the 2011/12 JARPA II cruise report, it was noted that the lack of discussion did not imply there is agreement on the issue of scientific whaling under special permits. Differing views on this activity remain and the Working Group was referred to the statements made in Annex P1 and Annex P2.

17.1.3 Planning for a final review of results from Iceland - North Atlantic common minke whale

The results from the Icelandic programme on common minke whales will be subject to final review during the coming intersessional period. 'Annex P' (IWC, 2009) documents the review process. The only time this procedure has been used was to review the JARPN II Special Permit in 2009 (IWC, 2010a). While the process worked well in general (IWC, 2010b), improvements on some aspects of the implementation of the process have been agreed and are detailed in Annex P4 of last year's report (IWC, 2012 pp. 310-311). One change in implementing the 'Annex P' procedure (IWC, 2009) will be the presence of observers. The general outline of the workshop includes an initial session where a restricted number of scientists associated with the proposal will present results of their research and answer questions. Then the main part of the review workshop will be closed sessions where the expert panel evaluates the results. At the end of the workshop there will be a short open session where the expert panel can ask scientists associated with the proposal questions for clarification. Observers will be allowed to the open sessions. In light of these modifications, the timetable to be used for the Iceland and JARPA II reviews is presented in Table 3 of Annex P4 (IWC, 2012 pp. 310-311).

Vikingsson stated the Working Group that Iceland will meet the requirements of the time schedule of Annex P4 (IWC, 2012 pp. 310-311) for a review in 2013. The Working Group **agrees** that the review of results from Iceland will occur February/March 2013.

SC/64/SCP1 addressed the data availability under Procedure B of the Data Availability Agreement. A small group was set up to consider this document. The Committee agrees the clarifications to 'Annex P' (IWC 2009) included as Annex P3.

17.1.4 Planning for a periodic review of results from JARPA II

The Working Group **agrees** that the review of results from JARPA II will occur February/March 2014.

17.2 Review of new or continuing proposals

17.2.1 JARPA II

Japan reported that there was no plan to change the JARPA II programme.

17.2.2 JARPN II

Japan reported that there was no plan to change the JARPN II programme.

18. WHALE SANCTUARIES

The Committee received no new proposals for sanctuaries this year. The report of an international workshop on Marine Protected Areas (SC/61/O20) was discussed under Annexes K and M.

19. SORP

The Southern Ocean Research Partnership (SORP) was proposed by the Australian Government to the IWC in 2008 (IWC/60/16) with the aim of developing a multi-lateral, non-lethal scientific research programme to improve the coordinated and cooperative delivery of relevant scientific information to the IWC. The Partnership now includes ten countries: Argentina, Australia, Brazil, Chile, France, Germany, New Zealand, Norway, South Africa and the USA. A framework and set of objectives for SORP have been endorsed by the Committee (IWC, 2011) and six SORP research projects were endorsed last year (IWC, 2012). Progress of these research projects was reviewed this year. The IWC has a budget specifically related to the work of SORP established with a contribution from Australia in 2008 and supplemented by additional voluntary contributions from Australia and the USA in 2011. This budget is administered by the IWC Secretariat.

SORP was originally discussed in an open session, chaired by Gales and rapporteured by Bell. The report of that session is incorporated directly into the plenary report here.

The Committee noted that in April 2012, Bell was appointed the Southern Ocean Research Partnership coordinator replacing Childerhouse and Wadley was appointed the Antarctic Blue Whale Project coordinator.

19.1 Review of progress since IWC 63

SC/64/O13 summarised the progress of SORP since IWC63. Progress was made on the following major items:

(1) *Overall support and progress of the six SORP research projects* – progress reports for the 2011/12 period are available in SC/64/O13;
(2) *Provision of interim funding* – funding was provided for all six SORP projects to support research during 2011/12 (SC/63/SC-report);
(3) *Further development of the* SORP Antarctic Blue Whale Project *(formerly known as the SORP Year of the Whale Project)*;
(4) *Planning and implementation of collaborative SORP Antarctic blue whale expeditions* – two expeditions led by Australia were undertaken in the austral summer of 2011/12 (SC/64/SH11) to develop and test methodologies that will be employed during the SORP Antarctic Blue Whale Voyage planned for early 2013 (SC/64/SH13). Further development of acoustic methods (SC/64/SH12) and survey design (SC/64/SH10, SH14, SH26) was also undertaken;
(5) and *Completion of the core SORP project*: The Living Whales Symposium and Workshops, held in Chile in March 2012 (SC/64/O14).

These items are covered in more detail below. The Committee was **pleased** to note that SORP is being successfully implemented and **welcomes** the results.

19.1.1 SORP Antarctic Blue Whale Project

The title 'Antarctic Blue Whale Project' (ABWP) now replaces 'The Year of the Whale' (YOTW) to reflect the fact that the proposed research will require a multi-year, multi-platform, integrated and coordinated research effort. This became clear following discussions within the Committee and intersessionally, particularly given the extensive methodological development (SC/63/SH3; SC/63/SC-report Annex H; SC/64/SH10-14, SH26) reported. A single season effort is not an appropriate strategy to deliver an estimate of circumpolar abundance, given logistical constraints and the preferred sampling regime under a mark-recapture approach.

The specific objectives of this initiative are to:

(1) provide a circumpolar abundance estimate for Antarctic blue whales;
(2) improve understanding of Antarctic blue whale population structure;
(3) improve understanding of connectivity between blue whale feeding and breeding grounds;
(4) and to characterise foraging habitat of blue whales.

SC/64/O13, SH10-14 and SH26 were discussed in Annex H. The project was very well received as an investigation to determine the viability of ideas and methods. Gales welcomed the maturing ideas and methods under development and their implementation in the Southern Ocean during 2012/13. Results from the ABWP have been presented at international scientific meetings, including the International Polar Year conference in Montreal, April 2012.

The importance of SORP as a means to engender international cooperation was noted. There are encouraging signs that estimating the circumpolar abundance of blue whales will be possible.

19.1.2 Ways to expand Antarctic Blue Whale Project (ABWP) work

SC/64/O16 provided information about the South African Blue Whale Project (SABWP) and it was discussed in annex H. Despite evidence of recent increase, the population of Antarctic blue whales remains severely depleted from commercial whaling. Both the high concentrations of sightings of Antarctic blue whales in the 0-20° E sector of the Antarctic in recent years (IWC IDCR/SOWER and SOWER sighting records) and the high historic catches of some 12,000 probable Antarctic blue whales off the west coast of South Africa, Namibia and Angola prior to 1930, suggest that the southeastern Atlantic Ocean and neighbouring Southern Ocean region should provide exciting opportunities for research on Antarctic blue whales. The South African Blue Whale Project (SABWP) has been recently funded by the South African National Antarctic Programme (SANAP) and the National Research Foundation (NRF) to investigate the seasonality, distribution and relative abundance of this species in these areas with the long-term aim of determining relative abundance indices to measure the population trend. Research efforts will be concentrated in two regions; 67°S to the ice edge and 0-20°E region in summer, and off the south-western Cape coast in winter. Autonomous Acoustic Recorders (AARs) will be deployed in both the high and low latitude regions to determine distribution and seasonality patterns of this migratory species. Line-transect surveys (incorporating photo-identification, biopsy sampling and ship-based passive acoustic monitoring) will be carried out in the Antarctic region during summer to provide abundance and call-rate measurements for 'broadbrush' ground-truthing of Antarctic AAR data. Low–latitude AAR data will provide information on where and when to concentrate future research efforts off the south-

western Cape coast. Data from this voyage will contribute to the ABWP and other SORP projects. A proposal for one of the team to receive training in AAR deployment during a cruise off Greenland this summer (SC/64/O17) has been adopted.

Norway joined SORP two years ago. Norway may contribute to SORP in the following manner:

(1) Financially: upon provision and favourable review of a budget and research proposal from existing or new SORP projects, Norway would be willing to fund research. Norway does not have to be involved in the research proposal.
(2) In kind support: annually, Norway sends scientists on fishing vessels that work in the Southern Ocean, in 2012/13 primarily around the South Orkney Islands. Biannually, the Norwegian vessel R/V *G O Sars* operates in the Southern Ocean I.A. in the area around Bouvet Island. This is a dedicated research vessel that can be directed to other areas. It will next sail in 2013/14 (to be confirmed). Berths on these vessels could be made available to SORP researchers.
(3) Personnel: the expertise of Norwegian scientists could be provided for collaboration on SORP research projects.

Particular interest was expressed in contributing to the Antarctic Blue Whale Project.

The Committee **greatly welcomes** Norway's offer of monetary, in kind and personnel support for SORP and **agrees** that it will be resolved intersessionally how it will be managed and administered.

The Committee was informed of France's intention to use the R/V *l'Astrolabe* to carry out a photo-identification and sightings surveys of blue whales in Terre Adelié. Surveys will be carried out over the next two years and it is hoped it can be continued for up to four years. A marine science voyage is also being considered in the southern Indian Ocean, south of Kerguelen on the Marion Dufresne. It is hoped that time may be allocated on this to perform blue whale research but it is a highly competitive process.

The Committee was informed of Germany's intention to perform their fifth cetacean survey from January to mid-March 2013 in the western Weddell Sea. This will be a repeat of the 2006/7 survey. The aim is to relate krill abundance to hydrography and oceanography. Helicopters will be used as the survey platform.

The Committee was also informed of plans by the International Fund for Animal Welfare for a Southern Ocean voyage that may be able to contribute to the Antarctic Blue Whale Project through combined acoustic surveys and photo-identification.

It was noted that collaboration with the wider Antarctic community is underway with SCAR, COMNAP, IAATO and CCAMLR to pursue the objectives of the ABWP.

The Committee **encourages** international involvement in the SORP Antarctic Blue Whale Project in the form of research, ship time or personnel. The Committee also stressed the importance of standardised protocols and shared data access across a range of data types, and **encouraged** their adoption across international cetacean research programmes.

19.1.3 Killer whales in the Southern Ocean

The principal investigators once again participated as 'visiting scientists' on board the tour vessel M/V *National Geographic Explorer*, during four consecutive trips to the Antarctic Peninsula from 7 January to 15 February 2012; approximately 3000 photo-id images of over 200 individually-recognisable animals for future mark-recapture analyses were obtained; 2 skin biopsy samples were obtained (samples archived at SWFSC), and 3 individuals were satellite-tagged. Data are presented in the full project report in Annex 1 of SC/64/O13. Other tour ships operating in the Antarctic Peninsula area were also canvassed for killer whale photographs and thousands of images were obtained from over two dozen killer whale encounters. The principal investigators feel confident that within the next year or two they should have enough images to estimate population sizes for the three types of killer whales that are recognised in the Peninsula Area.

The Committee **commends** the work of the principal investigators.

The Committee was also informed of new killer whale photo-id data from the Institut Polaire Française (IPEV), CEtacés Terre Adélie project that is available for 35 individuals in Terre Adélie, eastern Antarctica (SC/64/SM6).

19.1.4 Foraging ecology and predator prey interactions of baleen whales and krill

During the funding period, significant progress was made towards the overall goal of understanding the foraging ecology and predator-prey interactions between baleen whales and krill in the waters around the Western Antarctic Peninsula. Analysis was completed describing the diving behaviour of humpback whales from suction-cup tags deployed in 2009 and 2010. These results were presented at numerous scientific meetings including the Biennial Conference on the Biology of Marine Mammals (Tampa, FL, November 2011), and the recent SORP workshop on non-lethal research techniques for studying cetaceans (Puerto Varas, Chile, March 2012). A full project report is included in Annex 1 of SC/64/O13.

The main findings of the project to date are summarised below:

(1) Humpback whales were found to feed almost exclusively during night-time hours in late autumn (May/June), spending daylight hours either resting or traveling. The initiation of feeding was often proceeded by deep exploratory dives that are hypothesised to sample the water column to determine where prey are distributed.
(2) Humpback whales appear to achieve or conform to ecological predictions of optimal foraging theory in two significant ways: By increasing the number of feeding lunges executed per dive with increased dive depth; and by targeting higher densities of krill as feeding depth increases
(3) While both of these findings are significant, the fact that the principal investigators have been able to quantify increases in prey density concurrent to whale feeding is novel. The information provided from this relationship will be a substantial component of the manuscripts that are currently in preparation to be submitted for peer review.
(4) Humpback whales vary the depth of their feeding in relation to the diel vertical movement of krill in the water column.

The Committee **welcomes** these results and **encourages** further work to enhance understanding of humpback whales that overwinter in Antarctica. Gales noted that additional satellite and datalogger work on humpback and minke whales was planned.

19.1.5 Oceania humpback whale mixing

The focus of this project has been on preparing for the proposed 2013 satellite tagging work at the Kermadec Islands and American Samoa (SC/63/O13). The Oceania humpback whale population estimate has been published (Constantine *et al.*, 2012) with a sex-specific POPAN super-population model, which accounted for residents and whales migrating through the survey areas, giving an estimate of 4329 whales (3345−5313) in 2005.

In the winter of 2011, satellite tagging work was undertaken in New Caledonia (Garrigue in collaboration with Zerbini and Clapham) adding to the 2007 (Garrigue *et al.,* 2010) and 2010 tagging efforts. The general trend observed was for the majority (~75%) of whales to head in a south-southeasterly direction once they left the New Caledonia breeding grounds. Some whales stopped at seamounts or other undersea geographic features along the way for varying lengths of time.

The Raoul Island (Kermadec group) single day four hour survey conducted between 0800 and 1200 hrs was conducted on the 8th October 2011. This adds to the previous three years of October surveys using a standard set of seven land-based locations (Potier, 2008; Brown, 2009; Brown, 2010)[30]. Previous whale-counts from these surveys have ranged from 62-153 whales and the 2011 survey counted 126 individual whales (Potier and Shanley, 2012)[30]. The consistently high number of humpback whales observed migrating past Raoul Island, peaking in October, confirms the Kermadec Islands as the southernmost location in Oceania with regular whale sightings and the ideal site to attach satellite tags as the whales migrate south. Constantine will visit the Kermadec Islands in August 2012 to consider this research site. Research in American Samoa conducted in the 2011 field season continued preparation for the planned satellite tagging in 2013.

Future work will focus on addressing two questions.

(1) What is the connection between the humpback whales from Area V feeding grounds and their migratory corridors and breeding grounds in Australia and Oceania?
(2) Do whales from Area V represent a single breeding ground or are they a mix of individuals from several distinct breeding grounds?

A full project report is included in Annex 1 of SC/64/O13.

19.1.6 Fin and blue whale acoustics

Understanding baleen whale distribution and abundance in the Antarctic, particularly blue and fin whales, is complicated by the pelagic distribution of both species, the difficulty of working in the Southern Ocean (SO) and the massive decline of both due to commercial whaling. After a half-century of protection, little is known about the present-day status of each species. Blue and fin whales are congeners that are the largest mammals on earth. Both occur in all oceans of the world with similar distribution patterns. In particular, each species occurs in high latitudes in the Southern Hemisphere. In the Antarctic, blue whales are generally thought to occur closer to the ice edge than fin whales. Blue whales are designated as different subspecies, i.e. Antarctic (*B.m. intermedia*) and pygmy types (*B.m. brevicauda*), and Chilean blue whales are also considered an unnamed subspecies, or at least a separate management unit. In the case of fin whales in the Southern Hemisphere, two subspecies have been considered: *B. physalus quoyi* for the Southern Ocean form and the pygmy fin, *B. p. patachonica* found in the northern parts of the Southern Hemisphere.

Both blue and fin whales were targets of commercial whaling, particularly from the early 1900's through the 1930's, leading to heavy depletion. Blue whales were protected internationally from whaling in 1966 and fin whales in 1985. At present, both species are listed as Endangered by the IUCN and there are no reliable population estimates for either species globally. A recent examination of almost 40 years of sighting data resulted in an estimate of 2,280 (CV = 0.36) Antarctic blue whales, which is less than 1% of the original

[30] Unpublished field reports

population (Branch 2007). There are no equivalent estimates for SH fin whales.

From 1978 to 2010 the IWC supported the annual IDCR/SOWER Antarctic cruises that consisted of three circumpolar sets of cruises over multiple years that focused primarily on minke whale abundance but that also provided an estimate of abundance for Antarctic blue whales (Branch *et al.* 2004). Only two of the recent cruises focused on fin whales (Ensor *et al.* 2006, 2007). Given the amount of effort, ship time, high risk of poor weather and cost of sighting cruises, it is unlikely that the tremendous shipboard effort of IDCR/SOWER will be repeated. In order to continue to monitor Antarctic blue and fin whales, the use of a network of long-term passive acoustic recorders has been proposed *in lieu* of dedicated circumpolar visual surveys.

Passive acoustic monitoring is a robust means of monitoring blue and fin whales in remote areas over long time periods, including around the Antarctic. The present analysis of all the available data shows the geographic and seasonal occurrence of blue and fin whales around the Antarctic. However the lack of overlap in the years and locations monitored, the differences among instruments and analysis methods used, underlines the need for coordinated effort. To best exploit passive acoustic data long term, a pan-Antarctic monitoring system needs to be put in place and maintained. Thus far there has been a positive response from many countries regarding this project. In the near term the principal investigators need to find the finances and continue instrument development to facilitate a coordinated research effort. Further a single method either for each species or for both needs to be adopted for analysing the data. A review of existing methods for estimating relative abundance from passive acoustic sensors demonstrates that the scientific question of interest will drive the analysis methods chosen. The principal investigators suggest that the Australian Marine Mammal Centre, based at the Australian Antarctic Division, Hobart, maintain a database of the metadata and data from hydrophones and make these freely available if possible.

Acoustic data from a single hydrophone present unique challenges to density estimation: to overcome these, the principal investigators need to improve their knowledge of call rate, acoustic behavior and source level of whales; detection distance and sound propagation (environmental parameters and ambient noise level). Methodology to estimate the density of whales from acoustic data is advancing rapidly and it is anticipated that if understanding of the parameters above is improved, density estimation using passive acoustic data will become the state of the art for monitoring Antarctic blue and fin whales. A full project report is included in Annex 1 of SC/64/O13.

The Committee **commends** the work of the principal investigators and it was noted that this project addresses the research priorities identified by SORP to meet the overall objectives of the IWC.

It was highlighted that it will provide valuable data for blue whales and may provide the only practical way to obtain data about fin whale abundance, information that the scientific community currently does not have. From this data it may be possible to estimate trends in blue and fin whale populations over decadal scales.

This work is closely aligned with the objectives of the Antarctic Blue Whale Project. It was also noted that that the global economic situation is very likely to reduce the amount of ship time available to researchers in the future, therefore the development of acoustic methods such as these are essential for continued, non-lethal cetacean research.

19.1.7 Living Whales Symposium and non-lethal research techniques workshops

SC/64/O14 summarised the Southern Ocean Research Partnership Symposium and Workshops entitled 'Living whales in the Southern Ocean: advances in methods for non-lethal cetacean research'.

The Symposium and accompanying workshops were held in Puerto Varas, Chile from 27-29th March 2012, to discuss recent advances in methods for non-lethal research on whales in the Southern Ocean. The Symposium was attended by 124 registered participants from 16 countries and was also live streamed on the web, allowing an 1,553 simultaneous viewers.

The first day was an open Symposium with invited experts who showcased new non-lethal research methods for whales in the Southern Hemisphere. The Symposium talks were divided across five sessions that covered an overview of the history of whaling, evolution of non-lethal techniques and the role of whales in Southern Ocean ecosystem. These were followed by sessions on molecular techniques, biologging, remote sensing and long-term non-lethal research. A PDF of the talks are already available[31] and the videos of each talk, in English and Spanish, will soon be available.

The Symposium was followed by two days of Workshops that covered specific research areas. The Workshops were each one day in duration and covered the following topics:

(1) health assessment of live cetaceans;
(2) advances in long term Satellite Tagging Techniques for Cetaceans;
(3) population dynamics and environmental variability; and
(4) estimation of diet and consumption rates from non-lethal methods.

[31] www.simposioballenas.cl

The workshop health assessment of live cetaceans reviewed several techniques obtained from blow samples, biopsy samples, collection of faeces, visual health assessment, photogrammetry, blow intervals and respiration rates, among others. The workshop identified two main aspects:

(1) health assessment data and studies should be integrated with population dynamics data, where possible; and
(2) integration of live animal health assessment with studies on dead and stranded animals, particularly within the same geographical region, is highly informative and should be a priority. The priority areas for further consideration in health assessment include nutritive stress and body condition; feeding and fasting or starvation state; skin lesions; stress; emerging issues and exposures; and particularly, standardisation of methodologies.

The workshop on large whale population dynamics and environmental variability explored which life history parameters can be connected with environmental variability and highlighted the need for researchers to collect data on body condition, mortality and reproductive output, among others. The workshop also evaluated different analytical and simulation techniques to incorporate environmental variability into population models and recognised the need of long term data sets to detect such effects. The workshop recommended that long-term studies, photo-identification and biopsy sampling be routinely collected and promoted the use of geochemical tracers (e.g. stable isotopes) and other 'eco-markers', including DNA, since this approach can help to identify foraging locations of populations.

The workshop advances in Long-Term Satellite Tagging Techniques for Cetaceans and their Application to Address Research Questions in the Southern Ocean reviewed advances on tag development and dedicated studies to address possible physical and physiological effects of satellite tags on cetaceans. The workshop highlighted that effort could be directed to minimise the size and diameter of body-penetrating satellite tags in order to minimise trauma of implant and water ingress and promoted the use of an alternative to body-penetrating tags, such as new designs with external electronics and a long anchoring system. It was agreed that new designs for cetacean tags ought to be developed and that priority should be given to accelerometer and dive/surface interval data and to the development of algorithms that can compress data for transmission via Argos. The workshop also recognised that some devices have the potential to cause considerable tissue damage and that studies on carcasses derived from incidental mortality should be conducted, as well as monitor tagged animals. Finally, the workshop highlighted the need to create awareness on the use of these techniques within local communities, regulatory agencies and the general public prior to tagging project.

The workshop on Estimation of Diet and Consumption Rates highlighted several techniques that might be used to achieve this difficult objective. Tagging studies could provide information about foraging effort, photogrammetric techniques about individual fitness and steroid-hormone samples (from faeces or biopsy) about reproductive status. Understanding interspecific differences in prey preference will help to predict how climate driven changes affect krill and, ultimately whales. The value of understanding how local oceanographic conditions and prey availability affect the foraging behaviour and distribution was highlighted. Also recognised was the need to improve understanding of foraging strategies, prey choices, feeding destinations, etc. and recommended the use of several dietary tracers, such as stable isotope analysis, and molecular techniques, for diet reconstruction alongside fecal sampling and fatty acid analysis.

In summary, the Symposium and Workshops were very successful. The event drew a large audience and the Symposium organisers recommend the use of live broadcast technologies alongside simultaneous translation as a means to reach a wider audience in future events. The workshops gave an excellent overview of existing and new research techniques and contributed enormously toward setting guidelines and prioritising research needs for improving our current scientific understanding and techniques.

The Symposium organisers and the SORP Scientific Steering Committee **thanked** the sponsors of the Symposium and Workshops: the Ministry of Foreign Affairs, Chile; the directorate of Maritime Territory and Merchant Marine of Chile; the Australian Government; the National Oceanic and Atmosphere Administration of the United States (NOAA); Oregon State University; the International Fund for Animal Welfare; the South Pacific Research Whale Consortium; Altavoz; and the Cetacean Conservation Center Chile. The Symposium and Workshops represent a completed Southern Ocean Research project. The full report can be found in SC/64/O14.

The Committee **thanks** the Symposium organisers, in particular Galletti, Baker and their teams for their work and congratulated them on their success. The usefulness of the Symposium and Workshops for improving current non-lethal techniques for cetacean research was stressed. It was noted that some of these will be applied to research to be conducted in the coming field season, e.g. by Argentinean researchers. It was also noted that useful recommendations came out of the Workshops with regard to research on climate change impacts on cetaceans, e.g. Southern right whales in the southwest Atlantic, in line with wider SORP objectives.

Table 10

SORP funding requests and allocations for 2012/13

Project	PI	Line item	Requested (GBP)	Allocated (GBP)
SABWP	Best	Travel	2,500	2,500
SORP 1: ABWP	Wadley	-	0	11,700
SORP 2: Killer whales	Pitman	Travel	2,235	2,235
		6 x wildlife computers on location-only tags	10,360	10,360
		6 Wildlife Computers depth and location tag	17,267	0
SORP 3: Baleen whales	Friedländer	Coordinator's salary[#]	13,430	0
SORP 4: Blue and fin whales	Stafford	Salary	7,963	7,963
		Support for coordination and development activities	15,926	15,926
		Steering Committee meeting[*]	4,778	0
SORP5: humpback whales	Constantine	Photo-ID and tissue sampling	9,548	9,548
		Project assistant[**]	6,376	6,376
		Steering Committee meeting[*]	3,819	0
SORP 6: Symposium	Baker/Galletti	-	0	0
Total requested 2012/13			94,202	
Total allocated 2012/12				**54,908**

[#] The Committee requested clarification of the use of the money requested for consideration intersessionally.

[*]No money was allocated to individual projects for Scientific Steering Committee meetings because of proposals to hold a SORP conference in 2013 (see workplan item 6).

[**] The principal investigators also requested 182,748 GBP to support research in 2013/14. It was noted that SORP cannot support such large requests for money. Therefore, the Committee **encourages** that SORP funds allocated for 2012/13 be used in part to allow the project assistant to write proposals for additional project funding.

19.2 Budget

The IWC has a budget specifically related to the work of SORP established with a contribution from Australia in 2008 and supplemented by additional voluntary contributions from Australia and the USA in 2011. This budget is administered by the IWC Secretariat.

19.2.1 Budget overview

Bell presented a summary of the SORP money spent to date and remaining funds. A total of 76,947 GBP remain unallocated and unspent. A figure of £37,730 GBP[32] remains in the SORP budget allocated but unspent.

19.2.2 Request for funds from projects

Table 10 summarises the requests for SORP funds received from existing SORP projects for 2012/1.

SC/64/O17 requested 2,500 GBP for the South African Blue Whale Project (SABWP; SC/64/O17) to support travel for one investigator, Meredith Thornton, from South Africa to Greenland to participate in a week-long cruise cruise in which five Autonomous Acoustic Recorders (AARs) will be deployed west of Disko Bay in August 2012. The cruise will be led by the Greenland Climate Research Centre and Applied Physics Laboratory of Washington University. The intention is that the investigator gain the necessary technical experience in deployment of AARs at sea, that otherwise might entail an experienced person accompanying a long supply voyage from Cape Town to the ice and back just for a few days' work. An official response from the organisers of the cruise has still not been received.

The Committee **approved** this request for funding.

Funding requests from existing core SORP research projects for 2012/13 are outlined in Table 10 alongside the agreed allocations.

19.2.3 Reallocation of funds

A small group was formed consisting of the SORP Scientific Committee and other interested parties to discuss reallocations of remaining SORP funds to projects in 2012/13.

A figure of £37,730 GBP remains in the SORP budget allocated but unspent. The Committee **agrees** that 11,700 GBP of this be reallocated to the Antarctic Blue Whale Project and the remaining 26,030 GBP be

[32] This figure has not been finalised because of possible outstanding invoices from the 2011/12 allocation to SORP Project 6:

rolled-over into the general SORP budget for reallocation in the future.

19.2.4 Allocation of funds
The Committee **agrees** to allocate SORP funds for 2012/13 as outlined in Table 10.

19.2.5 Seeking additional funding
Following the reallocations and 2012/13 allocations, £48,069 GBP will remain in the SORP budget administered by the IWC Secretariat.

The Committee **thanks** the Government of Australia and the USA for their generous contributions to the SORP and **encourages** support and voluntary contributions from other nations to ensure the continuation of this exciting initiative.

19.3 Requirements for formalising participation in SORP and development of new projects
The Committee is keen to promote continued and new involvement in SORP. Partners are **encouraged** to formalise their involvement in the form of a letter to the SORP Secretariat. If Partners require more formal protocols, such as a Memorandum of Understanding, this can be arranged by the SORP Secretariat. The Committee **encourages** the involvement of new and existing Partners in SORP scientific steering Committees, working groups and technical Committees.

19.4 Workplan
The Workplan is discussed under Item 21. The Committee **agrees** that data management and sharing was an important issue to consider. Gales reiterated the importance of workplan item 7.

20. RESARCH AND WORKSHOP PROPOSALS AND RESULTS

20.1 Review results from previously funded research proposals
Research results from previously funded proposals are dealt with under the relevant agenda items.

20.2 Review proposals for 2012/13
No unsolicited research proposals were received this year. Proposals for the voluntary fund for small cetaceans were discussed under Item 14.3 and those relating to SORP are discussed under Item 19.

Table 11 lists the proposed intersessional meetings and workshops. Financial implications and further details are dealt with under Item 23.

21. COMMITTEE PRIORITIES AND INITIAL AGENDA FOR THE 2013 MEETING

As in recent years and with the Scientific Committee's agreement, the Convenors met after the close of the Committee meeting and finalised the following basis for an initial agenda for the 2013 meeting. The same criteria as previous years were taken into account and this was based on the recommended work plans developed by sub-committees and the general discussion of these within the Committee. The Committee **recognises** that it is the Commission who establishes the Committee's overall priorities. Thus priorities may have to be reviewed in light of decisions made by the Commission. Items of lower priority on sub-committee agendas will only be discussed if time allows. Therefore, the Committee **stresse**s that papers considering anything other than priority topics will not be addressed at next year's meeting. This information will be included on the website when the information about document submission is published next year. Convenors will receive timely information on the titles of papers intended for the discussion within their gaps, and may contact authors if they believe the papers are unlikely to be discussed.

Table 11

Proposed workshops for the intersessional period

Subject	Agenda Item	Venue	Dates
Review of MSYR workshop and WNP common minke whale's Second Intersessional Workshop	5.1; 6.6	To Be Determined	late Feb-Apr 2013
AWMP Greenland hunt SLA development	8.3	Copenhagen, Denmark	3 days within 12-18 Dec 2012
Planning for the 2013 IWC-POWER cruise	10.8.1.3	Toyko, Japan	25-27 Oct 2012
Workshop on Arctic anthropogenic impacts on cetaceans	12.5.3	Anchorage, Alaska	late Feb - Mar 2013
Workshop on assessing the impacts of marine debris	12.7	location of SC meeting	4 day pre-meeting; mid May - mid Jun 2013
"Marine bushmeat" workshop	14.6	location of SC meeting	2 day pre-meeting; mid May - mid Jun 2013
Icelandic Special Permit expert panel review workshop	17.1.3	Reykjavik, Iceland	Feb-Mar 2013

Revised management procedure (RMP)
The following issues are high priority topics:

(1) Review new information on western North Pacific Bryde's whales

(2) Conduct an *Implementation Review* for North Atlantic fin whales starting during a pre-meeting before SC65 and continuing during the 2013 Annual Meeting

(3) Prepare for the 2014 *Implementation Review* for the North Atlantic minke whales

(4) Review information available for North Atlantic sei whales in the context of a *pre-implementation assessment*

Western North Pacific common minke whales
Complete *Implementation Review*(including hold intersessional workshop)

Bycatch group (BC)
The focus of the group will remain in estimating mortality due to bycatch and ship strikes. The work plan will include:

(1) reviewing progress in including information in online National Progress Reports,

(2) estimating risk and rates of bycatch and entanglement,

(4) development of methods to estimate mortality from ship strikes,

(5) continuing development and use of the international database of ship strikes,

(6) review of information on other sources of mortality.

Special Permit

(1) Review results of the expert workshop in the Icelandic special permit programme;

(2) Plan for expert workshop on JARPA II;

(3) Review new and existing proposals as appropriate

Bowhead, right and gray whales (BRG)
High priority items will include:
(1) perform the annual review of catch information and new scientific information for BCB stock of bowhead whales and eastern gray whales;

(2) review any new information on all stocks of right whales, especially results of assessments for southern right whales;

(3) review North Pacific gray whale stock structure and movement

(4) review any other new information on western and eastern North Pacific gray whales and other stocks of bowhead whales.

Environmental concerns (E)
(1) Receive the SOCER (focus: Atlantic Ocean)

(2) Pollution issues

(3) Cetacean Resurging & Emerging Diseases (CERD)

(4) Impacts of anthropogenic sound

(5) Climate change issues

(6) Marine debris and cetaceans (including report from the Marine Debris Workshop)

(7) Other habitat-related issues

7.1. (MREDs)

7.2. Cumulative impacts

(8) Unusual mortality events incl. Peru

Ecosystem modelling (EM)
(1) Modelling of the direct relationship between baleen whale populations and the abundance of their prey.

(2) Coordination with CCAMLR's Ecosystem Monitoring and Management Programme will also be sought on its efforts to advance krill-predator models.

Aboriginal subsistence whaling management procedure
(1) Highest priority will be to work towards the development of long-term SLAs for the Greenland hunts;

(a) Develop trial structures and operating models for the Greenland hunts of bowhead and humpback whales to be presented initially at an intersessional workshop

(b) Develop an AWMP/RMP-lite program to assist developers of *SLA*s for the Greenland hunts of fin and common minke whales;

(c) Review a full scientific paper on the work in Greenland related to the collection of information on conversion factors

(2) Present *Evaluation* and *Robustness Trial* results to the SWG of an *SLA* variant that corresponds exactly to the management plan proposed by the Makah Tribe to the US Government;

(3) Review a revised document on the probability of a gray whale that regularly feeds in the western North Pacific being taken in a Makah hunt;

(4) Review a document that provides advice on the development of *SLA*s and their evaluation

.
In-depth assessment (IA)
High priority will be given to:
(1) The development and application of the SCAA models to the agreed estimates and the most recent aging data.

(2) Further work examining reasons for the differences between estimates from CPII and CPIII.

(3) Further development of the IWC simulated datasets, specifically to

3.1 provide a testing framework for hazard probability models for internally-estimated cue rates from Antarctic minke whale schools

3.2 provide one realistic scenario for testing variance estimation.

Now that minke whale abundance estimates had been agreed, the main remaining issues are listed as follows:

(4) Modify the Hazard Probability model to cope better with real diving patterns,

(5) Improve remaining misfits, for example, to the way that the simultaneous/delayed duplicate fit changes with school size (linked to item 4 above).

(6) Embed refined Hazard Probability models into a spatial framework,

Lower priority items are:

(7) Data management

7.1Further validation of IDCR/SOWER data

7.2 Curation of experimental IDCR/SOWER data

7.3 Production of standard datasets for analyses of species other than Antarctic minke whales.

(8) Review of abundance estimation data collected during CPII and CPIII; their utility for estimating abundance of Antarctic minke whales; and review of data insights.

SORP

Workplan items include:

(1) establishment of ABWP management structure and Committee;

(2) establishment of intersessional technical committees for methodological development;

(3) refinement of the ABWP survey plan for the 2013 ABW voyage(s);

(4) development of uniform sampling protocols for ABW sampling and voyage(s);

(5) continuation of five ongoing SORP research projects;

(6) planning and implementation of an intersessional SORP conference prior to the next annual meeting;

(7) intersessional development of a paper on data management and legacy.

22. DATA PROCESSING AND COMPUTING NEEDS FOR 2011/12

The Committee agrees the requests for intersessional work by the Secretariat given in Table 12.

23. FUNDING REQUIREMENTS FOR 2012/13

Table 13 summarises the complete list of recommendations for funding made by the Committee. The total required to meet its preferred budget is £327,000. The Committee recommends all of these proposed expenditures to the Commission.

However, it understands that the projected amount available for funding is about £315,000. Following some initial suggestions produced by the Convenors group, the Committee therefore carefully reviewed the proposed full list, taking into account its work plan, priorities and the possibility that some of the work requiring funding could be postponed to a future year or years. Such considerations are difficult and the Committee stresses that projects for which it has had to suggest reduced funding are still important and valuable. Should the Commission be unable to fund the full list of items in Table 13 the Committee agrees that the final column given in the table represents a budget that will allow progress to be made by its sub-groups in its priority topics. Progress will not be possible in some important areas, as outlined below and the Committee strongly request that the Commission or individual member governments provide additional funding in these areas. The Committee strongly recommends that the Commission accepts its reduced budget of £315,000.

Table 12

Computing tasks/needs for 2012/13.

RMP – PREPARATIONS FOR I*MPLEMENTATION*
(1) Work with the Norwegian Computing Centre to modify the Norwegian CatchLimit program so that only standard FORTRAN-95 statements are used (Annex D Item 2.4)
(2) Work to specify and run additional trials for testing amendments to the *CLA* (Annex D Item 2.2)
(3) Work related to the *Implementation Review* for North Atlantic fin whales (Annex D Item 3.2)
(4) Run a full set of trials using the Norwegian 'CatchLimit' program for North Atlantic fin whales, Western North Pacific Bryde's whales; and North Atlantic minke whales and place the results on the IWC website (carried over from last year)
NPM
Complete conditioning of the North Pacific minke whale trials and run a full set of trials (Annex D1)
AWMP
Work arising from the proposed workshop (see Annex E Item 4)
IN-DEPTH ASSESSMENT
Prepare a catch series for North Pacific sei whales including incorporation of additional information from Japanese log book records and a new analysis of Soviet North Pacific catch records (see Annex G Item 7)
Validation of the 2011 POWER cruise data (see Annex G Item 8)
Complete validation of the 1995-97 blue whale cruise data and incorporate into the DESS database
WHALE STOCKS
Documentation of the catch data available for Antarctic minke whales in preparation for the *pre-implementation assessment* (see Item 10.1, carried over from last year).

A summary of each of the items is given below, by sub-committee or standing Working Group. Full details can be found under relevant Agenda Items and Annexes as given in Table 13.

Table 13

Budget requests (see text). Note that in addition, the budget request for SORP is given in Table10.

Title		Agenda Item	Full (£)	Reduced (£)
(1)	Development of an operating model for West Greenland humpback and bowhead whales	8. AWMP	5,000	5,000
(2)	Workshop on development of SLAs for Greenlandic hunts	8. AWMP	8,000	8,000
(3)	AWMP developers funds	8. AWMP	3,000	3,000
(4)	Ship strike database coordinator	7.8 Ship strikes	10,000	8,000
(5)	Right whale survey off of South Africa	10.5 SH right whales	21,730	21,730
(6)	Genomic diversity and phylogenetic relationships among right whales	10.6 N Pacific right whales	7,000	0
(7)	Photographic matching of gray whales	9.2 E Pacific gray whales	9,000	9,000
(8)	Contribution to the preparation of the State of the Cetacean Environment Report (SOCER)	12.1 SOCER	3,000	3,000
(9)	Pre-meeting workshop on assessing the impacts of marine debris	12.8 Habitat related issues	20,500	20,500
(10)	Develop simulation of Southern Hemisphere minke line transect data	10.1 Antarctic minke whales	9,000	5,000
(11)	IWC-POWER cruise	10.8.1 IWC-POWER cruise	60,754	60,754
(12)	Preparation for the application of the statistical catch-at-age assessment method for Southern hemisphere minke whales	10.1 Antarctic minke whales	4,000	4,000
(13)	"Second' intersessional workshop on the Implementation Review for wNP common minke whales	6.3 N Pacific common minke whale Implementation Review	20,000	18,500
(14)	Essential computing for RMP/NPM and AWMP	22. Data processing and computing needs	25,000	25,000
(15)	MSYR review workshop	5.1 MSY rates review	5,000	5,000
(16)	Review and guidelines for model-based and design-based line transect abundance estimates	5.7 Abundance estimates	5,000	5,000
(17)	Modeling of Southern Hemisphere humpback whale populations	10.2 SH humpback whales	3,000	3,000
(18)	Antarctic humpback whale catalogue	10.1 Antarctic minke whales	15,000	13,000
(19)	Photo matching of Antarctic blue whales	10.3 SH blue whales	3,000	3,000
(20)	Southern Hemisphere blue whale catalogue 2012/13	10.3 SH blue whales	3,000	3,000
(21)	Expert workshop for final review of Iceland's Special Permit programme on common minke whales	17.1 Review of existing scientific permits	30,000	24,000
(22)	Whale watching guidelines and operator training in Oman	10.7 Arabian Sea humpback whales	3,500	3,500
(23)	Invited Participants (IP's) funds	All	64,000	64,000
TOTAL			**337,484**	**314,984**

(1) DEVELOPMENT OF AN OPERATING MODEL FOR WEST GREENLAND HUMPBACK AND BOWHEAD WHALES

The Committee developed interim *Strike Limit Algorithms* (*SLA*s) for the minke, fin, humpback and bowhead whales off West Greenland. These *SLA*s need to be reviewed and perhaps revised, ideally by the 2017 Annual Meeting. Development of *SLA*s for the hunts of minke and fin whales can be coordinated with the *Implementation Reviews* for these whales which are being conducted by the RMP sub-committee. In contrast, the situations for humpback and bowhead whales are relatively straightforward (essentially

single-stock situations), but without a fully-specified and coded operating model progress on these cases will be limited. The first step in the process of developing *SLA*s is constructing an operating model and associated trials, and this project aims to make sufficient progress that an AWMP Workshop (in late 2012) could finalize trials and initiate testing.

The key activities covered by the proposal:

(1) Extend the single-stock gray whales trials so that trials can be conducted for humpback and bowhead whales.
(2) Outline a set of evaluation and robustness trials which could form the basis for the evaluation of *SLA*s for these two groups of whales.
(3) Present the trial specifications and results for (a) the interim *SLA*s and (b) an alternative *SLA* at an intersessional AWMP workshop.
(4) Develop an AWMP/RMP-lite to assist developers of *SLA*s for the cases of fin whales and common minke whales.

(2) WORKSHOP ON DEVELOPMENT OF SLAS FOR GREENLANDIC HUNTS

The existing interim safe procedure for the Greenlandic hunts agreed in 2008 (IWC, 2009) was agreed to be valid for up to quota blocks so up to 2018. The Committee has identified completion of the development of long-term *SLA*s for these hunts as high priority work. With the completion of the BCB bowhead and gray whale *Implementations* this year, the SWG on the AWMP will give highest priority to the Greenland work, particularly for the complex cases of common minke whales and fin whales. In addition to the proposal for work by Punt (Annex E, Appendix 6), to meet the proposed timeframe an intersessional Workshop is required. The objectives of the workshop are to: (1) to review the work undertaken by Punt to develop proposed operating models and trial structures for the relatively easy cases of the bowhead and humpback whale hunts with a view to finalising these at the 2013 Annual Meeting; and (2) review the work undertaken by Punt to develop simple (AWMP/RMP-lite programs) to facilitate initial work on developing potential *SLA*s to allow the development of SLAs for West Greenland fin and common minke whales in light of the current operating models used in RMP *Implementations*. The Workshop will be held in winter 2013 for four days in Copenhagen, Denmark and the costs are for the IPs travel.

(3) AWMP DEVELOPERS FUNDS

The developers fund has been invaluable in the work of *SLA* development and related essential tasks of the SWG. It has been agreed as a standing fund by the Commission. The primary development tasks facing the SWG are for the Greenlandic fisheries. As noted above these tasks are of high priority to the Committee and the Commission. The fund is essential to allow progress to be made. It now stands at £12,000 and a request of £3,000 is made to restore it to the initial target level of £15,000.

Bycatch and other human-induced mortality

(4) SHIP STRIKE DATABASE COORDINATOR

The ongoing development of the IWC ship strike database requires data gathering, communication with potential data providers and data management. The Working Group on Bycatch and Other Human Induced Mortality recommended a part-time post initially for 3 months a year to undertake the tasks described in Annex J. This includes:

(1) Identify national contact points, organisations or groups that hold data on ship strikes that have not been contributed to the database and facilitate and encourage contributing data to IWC database;
(2) Monitor and respond to emails addressed to the shipstrikes@iwcoffice.org email address, including reports of new incidents, giving feedback to data providers and dealing with requests for summary information from the database;
(3) Keep IWC ship strike web site pages up to date including updating publicly available summaries from the database;
(4) Develop and document a communication strategy;
(5) Provide an annual update to Scientific Committee;
(6) Data entry of new records including data presented in meeting papers and National Progress Reports at annual meetings of Scientific Committee;
(7) Work with data review group to ensure that all new records are appropriately reviewed including identification of potential duplicate reports;
(8) Further development of database handbook including criteria for determining whether ship strike was a cause of death. Ensure database documentation remains up to date;
(9) Maintain data base and data entry system, making adjustments as appropriate in response to user problems and suggestions.

Bowhead, right and gray whales

(5) RIGHT WHALE SURVEY OFF OF SOUTH AFRICA

The southern right whale population visiting the South African coastline (arguably the largest in the Southern Hemisphere) has been monitored annually by aerial surveys since 1971 and since 1979 by a photo-identification survey. The results have been presented to several meetings of the SC, such as the Buenos Aires workshop in September 2011, where four papers were presented (SC/S11/RW15, 16, 18, 29). Since its inception the photo-id surveys have concentrated on adult females with calves: the catalogue (2010) stands at 1,217 adult females, of which resighting rates average 70% annually, leading to very precise

estimates of population size and growth rate, adult survival rate, age at first parturition and juvenile female survival rate. The application of an individual-based model has now allowed estimation of the probability of females calving at various intervals (SC/64/BRG24), which can be correlated in turn with the occurrence of oceanographic anomalies to determine the influence of environmental variation on reproductive success. The project has been funded domestically almost since its inception and has just completed a 3-year funding cycle. Unfortunately an application to the South African National Antarctic Programme for renewed funding was rejected as being geographically inappropriate, so interim funding is being sought to enable the 2012 survey to take place while an application is made for a new cycle commencing in 2013. The survey is scheduled to take place in mid October. All images should be matched by 1 April 2013 and results ready for the 2013 SC meeting.

(6) GENOMIC DIVERSITY AND PHYLOGENETIC RELATIONSHIPS AMONG RIGHT WHALES

The investigators request supplemental funding, as described in SC/64/BRG15, to do the following:

(1) assess genetic diversity and estimate Nmin within the central North Pacific right whale population, represented by 27 individuals (including 3 from Russia), using complete mitochondrial genomes and sequence from 23 nuclear loci;
(2) compare mtDNA diversity in eastern North Pacific right whales with other oceanic populations based on complete mitochondrial genomes (16386 base pairs), rather than the limited resolution currently based on control region sequences (286 base pairs); and
(3) confirm reciprocal monophyly and phylogenetic relationships among right whale species using sequence from complete mitochondrial genomes and 23 nuclear loci.

The primary funding for this project, provided by the Pacific Life Foundation, has support the development of the primary datasets but this funding is now exhausted. This proposal seeks supplemental support for two months for a postdoctoral fellow to complete analysis of the primary dataset and estimation of N_{min} for the central population of the North Pacific right whale.

(7) PHOTOGRAPHIC MATCHING OF GRAY WHALES

Results regarding mixing of western (WNP) and eastern (ENP) gray whales illustrate the great conservation and management importance of a more comprehensive examination of gray whale movement patterns and population structure in the North Pacific. The committee noted that for such an effort to be successful it must be international and collaborative. To facilitate this, and noting the existing safeguards for collaborators provided under the Committee's Data Availability Agreement, it recommended that a collaborative Pacific-wide study be developed under the auspices of the IWC, recognizing that *inter alia* this will contribute to the Committee-endorsed Conservation Plan for Western North Pacific Gray Whales and incorporate previous recommendations made by the Committee. Such a study should involve collaborative analysis and sharing of existing data as well as the collection of new data (IWC, 2011). This is the second year of the project. The report of the results of the first year was presented in the document SC/64/BRG13 (Urbán et. al 2012). The funds requested for this year is to match gray whale photographs to photographs from Sakhalin and Kamchatka.

Environmental concerns

(8) CONTRIBUTION TO THE PREPARATION OF THE STATE OF THE CETACEAN ENVIRONMENT REPORT (SOCER)

SOCER is a long-standing effort to provide information to Commissioners and SC members on environmental matters that affect cetaceans in response to several Commission resolutions. The focus for 2012 will be on the Indian Ocean. Funds are for salaries, library services, and printing.

(9) PRE-MEETING WORKSHOP ON ASSESSING THE IMPACTS OF MARINE DEBRIS

In 2011, the IWC agreed to (1) endorse the Honolulu Commitment; (2) establish a standing item on marine debris on the Conservation Committee agenda and (3) request the Scientific Committee continue reviewing potential threats to cetaceans arising from marine debris. It is proposed that a workshop be held on marine debris and cetaceans where the primary aim is to develop tools that allow quantification of whether or how marine debris is affecting cetaceans and how best to monitor and mitigate for these effects.

The objectives of the workshop are to:

(1) Better understand the effects of debris interactions at an individual and population level;
(2) Identify and classify key types and sources of debris that contribute to entanglements, or are ingested by cetaceans and examine the mechanisms by which they arrive in the marine environment, with the goal of identifying possible mitigation measures;
(3) Design and develop a centralised database to collate cases of debris interactions to obtain more accurate estimates of the incidence of mortality and injuries, help detect trends over time and identify hotspots; and
(4) Contribute towards a quantitative assessment of the extent of the threats for cetaceans.

The report of the Workshop will, in addition to providing the analyses, review and recommendations

listed under Item 2 above, develop: (1) a series of research and conservation actions that will include a rationale, actions required and proposed responsible persons/groups; and (2) a two-year work plan to be considered. The report will be submitted to the IWC and made publicly available on their website. It is proposed to publish the results of the workshop in a peer-reviewed journal. Funds are to assist some of the expected 20 participants for a 4-day pre-meeting held before the 2013 Scientific Committee meeting.

In-depth assessments

(10) DEVELOP SIMULATION OF ANTARCTIC MINKE LINE TRANSECT DATA

This year an abundance estimate for Antarctic minke whales had been agreed upon. As discussed this estimate had to use externally-estimated cue rates from a small sample of Antarctic minke whales, though an internally estimated cue rate would be preferred to estimate a more accurate and perhaps precise estimate. However, additional methodological develop is needed to achieve this. To test these newly development methods, it was proposed to use simulated line transect data where the true abundance estimate is known to validate the new methods are working correctly. These funds are proposed to further develop the IWC simulated datasets to (i) provide a testing framework for hazard probability models for internally-estimated cue rates from Antarctic minke whales schools, and (ii) provide a realistic scenario to test variance estimation methods.

(11) IWC-POWER CRUISE

The Committee has strongly advocated the development of an international medium- to long-term research programme involving sighting surveys to provide information for assessment, conservation and management of cetaceans in the North Pacific, including areas that have not been surveyed for decades. The finalisation for the integrated mid-long-term program (IWC-POWER; the Pacific Ocean Whales and Ecosystem Research programme) that will provide information on stock structure, abundance and ultimately trends has been completed. The focus of the 2013 cruise is defined as the area bounded by longitudes 135W and 160W, and latitudes 30N and 40N. Line transect sightings abundance data collection, biopsy sampling, and photo-identification of cetaceans is planned. The cruise will last approximately 60 days between July and August 2013. By far the most important component of the cost of the provision of a research vessel, crew and fuel (up to US$1m) and that is generously being provided by Japan. The IWC funding will provide for international researchers, equipment and a meeting to finalise the details of the 2013 cruise.

(12) PREPARATION FOR THE APPLICATION OF THE STATISTICAL CATCH-AT-AGE ASSESSMENT METHOD FOR ANTARCTIC MINKE WHALES

This year the Committee received a full description of the statistical catch-at-age (SCAA) developed by Polachek and Punt, along with initial suggestions for a baseline analysis and sensitivity tests (SC/64/IA1). This approach allows for errors in catch-at-age data, more than a single stock, time-varying growth, multiple areas, environmental covariates, fleet-specific vulnerabilities, and changes over time in vulnerability. The SCAA can be used to evaluate various hypotheses regarding the reason (or reasons) for the change in abundance estimates from CPII to CPIII, as well as other questions regarding the dynamics of the Antarctic minke whale, such as whether growth and carrying capacity have changed. This proposal is to obtain the latest datasets and update the outputs and reference models to conduct baseline and key sensitivities. A final report will be presented to the 2013 Annual Meeting and the final code, data sets and documentation will be lodged with the Secretariat.

North Pacific minke whales

(13) "SECOND' INTERSESSIONAL WORKSHOP ON THE IMPLEMENTATION REVIEW FOR WESTERN NORTH PACIFIC COMMON MINKE WHALES

The Implementation Review for western North Pacific minke whales is more complex than an previous Implementation. The Committee is one year behind the normal Schedule for Implementations. The Committee is not ready to undertake the tasks allocated to the 'second' intersessional workshop according to it guidelines (IWC, 2012). The priority tasks are to run and evaluate all trials in accordance with guidelines and present the results at the 2013 Annual Meeting to enable the Committee to complete its review in 2013.

Revised Management Procedure

(14) ESSENTIAL COMPUTING FOR RMP/NPM AND AWMP

The approach used to evaluate RMP variants during *Implementation*s as well as candidate SLAs involves two main steps: (1) specification and conditioning of trials, and (2) projecting simulated populations forward under alternative RMP variants/SLAs. The complexity of the operating models on which simulation evaluations are conducted has increased in recent years. Unfortunately, the relatively simple optimization methods include in current control programs (which was more than adequate in the past), combined with a complicated objective function, has led to problems producing conditioned trials quickly. This proposal will provide the Secretariat with the essential support required to complete this issue during the intersessional period. It will also continue the arrangement of recent years by which essential support is provide to the Secretariat, particularly in the key area of estimating stock mixing proportions in input to the trials), both

intersessionally, and during meetings. Without this support it will be impossible for the Committee to undertake its present work on RMP *Implementations* and development of SLAs.

(15) MSYR REVIEW WORKSHOP

Since 2007 the Committee has been discussing maximum sustainable yield rate (MSYR) in the context of a general review of the plausible range to be used in population models used for testing the Catch Limit Algorithm (CLA) of the RMP. The Committee has agreed that it will finish work on this topic in 2013 whether or not the review can be completed. It has developed a work plan to try to ensure completion of the review. As part of this it is essential that a three-day intersessional meeting be held, with at least five participants, ideally back-to-back with another intersessional meeting, thus reducing overall costs of this workshop.

All sub-groups using abundance estimates

(16) REVIEW AND GUIDELINES FOR MODEL-BASED AND DESIGN-BASED LINE TRANSECT ABUNDANCE ESTIMATES

The RMP's 'Requirements and Guidelines for conducting surveys" (RIWC (Suppl.) 13: 509-517) were written when the only realistic paradigm for planning and analyzing good sighting surveys was the design-based approach. However, there is now potentially a legitimate alternative to design-based estimates: model-based estimates using spatial modeling (smoothers), which unlike design-based approaches, also give some basis for limited spatial extrapolation. In addition, many surveys resemble design-based surveys but do not strictly meet the design-based criterion, and in such cases there is a question regarding the adequacy of design-based estimates. The Committee has frequently considered model-based and quasi-design-based estimates, but without explicit criteria and not necessarily in the context of the RMP. This proposal will (1) review statistical aspects of design-based estimators for surveys which do not strictly adhere to design-based principles, and (2) review past and current issues related to model-based abundance estimators, drawing on examples from experience with these types of models. Empirical and simulation-based diagnostics will be suggested, and a quantitative description of pitfalls when extrapolating estimates beyond the surveyed area will be given. The intended outcome of the project is (1) propose a basis to assess the reliability of an abundance estimate either from a design-based analysis for which the statistical criteria are not met, or from a model-based analysis; and (2) provide draft text for inclusion in the "Requirements and Guidelines for conducting surveys" document. The work will be presented to the 2013 Annual Meeting and is for salary to complete this project.

Other Southern Hemisphere whale stocks

(17) MODELING OF SOUTHERN HEMISPHERE HUMPBACK WHALE POPULATIONS

The project will focus on a combined assessment of Southern Hemisphere humpback breeding stocks D, E and Oceania using the model proposed at this year's meeting, SC64. Methods used will be based upon the Bayesian methodology as developed and presented for breeding stock C and breeding stock B comprehensive assessments recently completed. Initial results will utilize the data agreed at SC64, and results will be presented at the 2013 SC Annual Meeting. Further model developments and refinements in association with the final set of agreed data (and their sensitivities) would be presented at 2014 SC meeting should the Scientific Committee decide to so request.

(18) ANTARCTIC HUMPBACK WHALE CATALOGUE

The Antarctic Humpback Whale Catalogue collates photo-identification information from Southern Hemisphere humpback whales. Increasing awareness of the project among research organizations, tour operators and other potential contributors has widened the scope of the collection; research efforts in areas that had not previously been sampled have extended the geographic coverage. This catalogue has grown by 25% in the last two years, adding 1127 new individuals, and increasing the time required to analyse photographs. In addition to these requested IWC funds, we will seek funding from other sources to provide the remaining funds required. Additional resources are provided by College of the Atlantic, including equipment, student assistants, and time donated by principal investigators of this proposal. As a result this catalogue is in an excellent position to make a substantial contribution to SORP and other research and management initiatives.

(19) PHOTO MATCHING OF ANTARCTIC BLUE WHALES

The goal of this project is to compare the existing IWC-SOWER Antarctic blue whale catalogue (about 160 individuals) and the existing photo-id material collected from JARPA which are already digitized. This project may add new individuals to the Antarctic blue whale catalogue and provide new data on the movements of Antarctic blue whales both within and between years. The Committee has requested for several years that this work be undertaken.

(20) SOUTHERN HEMISPHERE BLUE WHALE CATALOGUE 2012/13

The Southern Hemisphere Blue Whale Catalogue is an international collaborative effort to facilitate cross-regional comparison of blue whale photo-identifications catalogues. Results of comparisons among different regions in Southern Hemisphere will improve the understanding of basic questions relating to blue whale populations in the Southern Hemisphere such as defining population boundaries, migratory

routes and model abundance estimates. In 2008, the Committee endorsed a proposal to establish a central web-based catalogue of blue whale identification photographs, known as the Southern Hemisphere Blue Whale Catalogue (IWC, 2008).

Currently this catalogue holds photo-identification catalogues of researchers from major areas off Antarctica, Australia, Eastern South Pacific and the Eastern Tropical Pacific (IWC, 2011). Comparisons among catalogues off Chile found one match over ten years (Galletti Vernazzani and Cabrera, 2011). Preliminary results of the 2011-2012 catalogue comparisons between the eastern South Pacific Ocean, Eastern Tropical Pacific Ocean (ETP) and Southern Ocean found no matches (Galletti Vernazzani and Olson, 2012).

During 2012-2013 it is expected that comparisons between Australian catalogues and with the ETP, Southeast Pacific and Antarctica will be finalized. Results of these comparisons will be presented to the 2013 Committee Annual Meeting.

Special Permits

(21) EXPERT WORKSHOP FOR FINAL REVIEW OF ICELAND'S SPECIAL PERMIT PROGRAMME ON COMMON MINKE WHALES

Activities under Article VIII of the Convention should be reported to the Committee for review. The Committee has agreed a procedure for periodic and final reviews of results from Special Permit research (Annex P, IWC 2009). This procedure outlines an intersessional review meeting by an expert panel. The report from the intersessional expert meeting will be reviewed and discussed at the 2013 Committee Annual Meeting, SC65. The Icelandic Special Permit progamme on common minke whales is complete and thus is subject to a review by an expert panel during the 2012/2013 intersessional period. The experts to the review workshop will be identified by September 2012 and the expert workshop will be convened during four days in February/March 2013. The requested funds are for travel for the invited experts.

Whale watching

(22) WHALE WATCHING GUIDELINES AND OPERATOR TRAINING IN OMAN

Oman's whale watching industry has experienced gradual growth over the last 10 years reflecting a steady increase in tourism in the country and a growing awareness of the rich and accessible cetacean fauna, especially around the capital city of Muscat. Currently, dolphins are the main target of the industry, whilst sperm whales and other large whales are increasingly sighted as operators become more knowledgeable of their presence and distribution. The Arabian Sea humpback whale has recently become a target of opportunistic whale watching by a SCUBA dive operator in southern Oman. The precarious status of this species, represented by a resident and discreet sub-population numbering fewer than 100 individuals, and the identification of escalating anthropogenic impacts and threats has led to expression of serious concern by the IWC and recommendation for the development of a Conservation Management Plan (work in progress). Unregulated whale watching represents another potential threat to Arabian Sea humpback whales.

Most operators are currently unaware of (unofficial) guidelines for whale watching in Oman. Recognizing the need to complete the drafting of new guidelines for Oman with appropriate technical assistance, and to train operators to enable interpretation and implementation of guidelines, this proposal includes a request for funding to complete the revision of whale watching guidelines in Oman and to hold a training workshop for operators on the interpretation and implementation of the guidelines to promote best practice in the industry. Travel for relevant experts to Oman has already been secured and expert and other participant time will be donated and/or covered by other on-going projects.

All groups

(23) INVITED PARTICIPANTS (IPS) FUNDS

The Committee draws attention to the essential contribution made to its work by the funded IPs. The IWC-funded IPs play an essential role in the Committee's work, including the critically important role of Chairs and rapporteurs. They represent excellent value as they receive only travel and subsistence costs and thus donate their time, which is considerable. As was the case for previous meetings, where possible, effort will be made to accommodate scientists from developing countries.

24 WORKING METHODS OF THE COMMITTEE

24.1 Reducing the costs of Committee meetings

In 2011 the Commission asked the Secretariat to continue exploring opportunities for cost savings. One source of cost savings is to reduce freight charges and increase use of electronic documents at annual meetings of the Scientific Committee and Commission. A review of expenditures in 2011 indicated the costs of maintaining a paper based infrastructure for the meetings was around 5% of the IWC core budget. Particular cost arise because of packing and air freight of the pigeonholes and pre-prepared documents which are both heavy and bulky, and also the hire of high volume copiers which are usually dramatically more expensive than low volume copiers.

The Committee discussed the advantages and disadvantages of moving to an electronic distribution of primary papers, working papers, and reports. If there was to be electronic distribution of paper, then the

memory sticks with the primary documents will need to still be available in a timely manner. Members would be encouraged to submit meeting papers as soon as possible to allow other members to make their own copies at home before the meeting. There would also need to be a number of modern desktop laser printers available to members and especially a local high bandwidth secure wi-fi network and document server that would be available to only the Committee members and so would be independent to local internet access and thus be robust to local IT issues.

After much discussion, the Committee agrees that primary documents should be distributed wholly electronically both on the IWC webpage and on the memory sticks. In contrast, the Committee agrees that draft and final reports of sub-groups and plenary should be distributed by paper to ensure these reports are properly edited. The Committee also agrees that working papers should, at least for a trial period, be distributed mostly by paper, with the option of some working papers, particularly very long ones, be distributed mostly electronically. To reduce freight costs of the pigeonholes, the Committee suggests the Secretariat consider having pigeonholes for sub-groups as a means to distribute working papers rather than having personal pigeonholes.

24.2 Clarifying information on data availability for Procedure B requests

The present description of the process for obtaining data for issues that fit under Procedure B is described in the Data Availability Agreement (DAA; IWC 2004). SC/64/SCP1 described a recent incident where it became evident that the DAA process needed additional clarification. The Committee notes that the DAA process has generally worked well and especially so when the Committee has been able to properly specify the data request during the Committee meeting. Procedure B is designed for cases where the Committee itself believes that particular analyses (whether completely new analyses or revised analyses) are important in providing advice to the Commission. In such cases, it is important that the Committee takes the necessary time to complete and explicitly including the following within the report: objectives of the data request; details of the data required addressing the objectives; broad overview of the methods; and the principal investigators recommended by the Committee. With such report text, the Data Availability Group (DAG) can then complete and endorse a DAA request following the appropriate protocol in a timely manner. This would have, for example, removed the ambiguity that arose out of interpretation of the recommendation made last year on the blubber thickness analysis (IWC, 2012, Annex K1).

As the requests under Procedure B relate to Committee recommendations, it also seems appropriate that all correspondences between researchers and data holders are channelled through the DAG until a request has been granted. It should also be emphasised that DAG involvement in data requests applies only to requests based on recommendations by the Committee. Requests by individual scientists should occur at the bilateral level without DAG involvement.

In addition, there appears to have been some uncertainty over what is meant by collaboration and offers of co-authorship under the DAA. This has also been considered under Agenda Item 17, Special Permit reviews and 'Annex P'.

The Committee has always encouraged collaboration in all research projects. In the context of Annex P this was clarified in a footnote. For a more formal clarification, the Committee recommends an additional point be added to the DAA Procedure B text as follows, where the text under Item 2 is new:

Procedure B

This applies to data required for analyses deemed important in providing advice to the Committee other than catch limits (e.g. on the status of stocks not subject to whaling). For data not subject to Procedure A, the data owners shall produce, in collaboration with the Committee, a published protocol for data access that applies to requests generated by the Committee, to ensure clarity and a mutual understanding of the process.

(1) The Committee shall specify the nature of the work and the data required during the meeting at which the recommendation is made, to the fullest extent possible in the time available at the meeting and in accordance with the published protocol. It should also name the appropriate scientists to undertake the work and designate an appropriate timeline.

(2) The Committee encourages collaboration between the data requestors and data providers, although this is not mandatory. As a minimum, data requestors and providers should discuss the data sufficiently to avoid misinterpretations over the nature of the data themselves. When the data requestors send their draft paper to the data providers in accordance with the timetable, they must provide an offer of co-authorship to them. The data providers may or may not accept this offer. If data requestors and data providers do not agree with the contents of the paper then they may present separate analyses or comments to the Committee. This then allows the Committee to review all analyses. The Committee will then get a balanced single conclusion from the analyses for advice to the Commission. This is in line with the spirit of collaboration the Committee encourages.

(*3*) Applications to the data owners following the published protocol referred to above, should be submitted by the Data Availability Group assisted by a nominated member of the relevant delegation or

institute. The Data Availability Group will consult with relevant members of the Committee if further explanation or clarification is required.

(*4*) If the above process is followed, then the data owners will normally approve the applications within a specified time period in accordance with the published protocol.

(*5*) Applications shall only be granted under conditions given above.

24.3 Updating the Committee's guidelines and Handbook

After discussion last year, the Committee agreed that the Chair of the Scientific Committee should develop a review document for consideration at this year's meeting that discusses whether or not there is a need to expand on the guidelines related to Convenors, in particular with respect to further details about the roles of Convenors and co-convenors, time frames of service etc., as well as the roles of Heads of Delegation and, if so, to provide proposed text. This review document provided background information that clarified some of these issues and suggested additional text to be considered by the Committee that could be added to the Scientific Committee's Handbook (SC/63/SCP2).

This year the Committee discussed this review document and recommends the basic responsibilities of Convenor's and co-Convenor's as described in the Handbook did not need changing. However, it recommends that the full Committee should receive the list of proposed projects to be funded by the Commission in a timely manner to allow everyone to fully consider the prioritised list. Following this recommendation, the guidelines on the role of convenors should include a new item 'f' and move the present 'f' to 'g', where the new item 'f' should read:

> 'To develop with other members of the Convenors' Group a prioritised list for funding that should to be made available to the full Committee at least by 6 pm on the penultimate day of the Scientific Committee Annual Meeting.'

Co-Convenor's were created three years ago to assist some of the busier sub-groups and provide an opportunity to create a pool of experienced people that could become future Convenors. This concept has worked well, so the Committee recommends the following text on the eligibility of Convenors and co-Convenors be added to the Handbook:

> 'All Committee members are eligible to become Convenors or co-convenors. A co-convenor may be appointed to assist the Convenor of a sub-group, gain experience in chairing and learn Committee procedures. Requirements include appropriate scientific background and/or chairing experience, knowledge of Committee procedures and appropriate communication skills.'

The Committee discussed at length the time frame of Convenors' service. Some members suggested a general, though flexible, time frame could be added to the Committee's Guidelines, where this time frame would not a fixed length and would not be mandatory. However, other members considered the existing guidelines were sufficient and have worked effectively in the past and so did not need to be modified. Consequentially no changes to the Committee's guidelines were recommended this year. However, as noted in the existing guidelines, it was agreed that the Chair of the Committee would take carefully into account the length of service when choosing convenors. If necessary this issue can be revisited in future years.

The roles of Heads of Delegations were also discussed and the Committee agrees that the present guidelines are adequate as provided in the Handbook. The Committee also agrees that the Handbook, when updated, will also be available as a pdf file.

24.4 Assistance to new members on the working of the Committee

In order to assist new members, the Committee recommends that an introductory lecture should be given during the first or second day for new (and indeed nay) members that would cover primarily practical r issues including: methods of working, background history of the sub-groups and commonly used acronyms (the latter will also be added to the Handbook). In addition, the Committee recommends that all attendees are reminded of the website location of the Scientific Committee's Handbook when registering for the Annual Meeting.

24.5 Other

Galletti noticed that while management recommendations are widely given in some sub-committees, especially when addressing whaling issues, in other sub-committees and/or standing working groups, the attention seems to be more focused on scientific recommendations and only a few conservation recommendations arise. She believed that his was particularly true for small cetaceans, where there have been differences throughout the years. In this sense, the practice of the Scientific Committee should be reviewed and when there is concern over the status of any cetacean species or threats are identified, there should also be a focus on providing conservation recommendations.

Given the limited time available at this meeting, the Committee **agrees** that this matter should be placed on the agenda for discussion at next year's meeting.

25. ELECTION OF OFFICERS

This is the third and last year in the terms of the Committee's Chair (Palka - US) and Vice-Chair (Kitakado - Japan). Kitakado has agreed to assume at

the end of the 2012 Commission Annual Meeting the Chair of the Scientific Committee. To fill the vacant Vice-Chair position, the Heads of Delegations were happy to unanimously nominate Caterina Fortuna (Italy). Fortuna accepted the Vice-Chair position. The Committee stood in acclaim to thank Palka for her great contribution to the Committees work during the past three years and congratulated Kitakado and Fortuna on their new positions.

26. PUBLICATIONS

This had been a difficult year for the Journal with staff limited by maternity leave, reduced hours, illness and a change in staff. Despite that the department produced:

(1) the 520pp supplement;
(2) 3 issues of the journal (two are at the printers) with one more almost complete; and
(3) the special issue on Southern Hemisphere humpback whales.

Illness to Donovan resulted in less progress than anticipated on the special issue devoted to the RMP but the timetable for its publication has been finalised and it should be available in early 2013. Most of the chapters written by Hammond and Donovan are nearing completion and will be ready for formal review in autumn 2012. These include: (1) an introductory guide to the RMP; (2) a history of the scientific approach to whale management within the IWC prior to the RMP development; (3) a history of the RMP development process including the development of various Requirement and Guidelines; (4) a history of the *Implementation* (and *Implementation Review)* process summarising the cases for western North Pacific common minke whales, western North Pacific Bryde's whales, North Atlantic common minke whales, and North Atlantic fin whales; (5) a concluding overview. In addition, the volume will include the papers from all of the original developers summarising their work in the format determined by Kirkwood. Allison is preparing the appropriate graphs and tables in the new format, including the results of the cross validation trials developed after the *CLA* was adopted.

The special volume commemorating the IDCR/SOWER cruises will be undertaken under an Editorial Board under Bannister as reported elsewhere.

The testing and trial process for the online submission, review and finalisation process has been recently completed and has recently become operational – thanks are due to those members of the Committee who kindly acted as 'guinea pigs' and have helped shape the site and develop the online instructions.

All of the *Journal* volumes are now available as pdf files and the *Journal* will become available in that format either directly via the new IWC website or through an existing company; we are in the process of examining the practical and financial implications of this and will report back to the Committee next year, after consultation via a questionnaire by email. This issue has become particularly important given the difficulties with printers that have occurred over the past two years and the recent news that the Cambridge University Press printing division is likely to be taken over by another company.

The Committee thanked Donovan and his team for the excellent work on publications. It **reiterates the importance** of these to its work as well as providing outside scientists the opportunity to benefit from the Committee's work and to encourage co-operation.

27. OTHER BUSINESS

No other business was discussed.

28. ADOPTION OF REPORT

The report was adopted at 1700 on 23 June 2012. As is usual final editing was carried out by the convenors after the meeting. In closing the meeting the Chair thanked the Secretariat for carrying out its duties in its customary friendly and efficient manner, as well as once again thanked the Government of Panama and other Panamanian contributors for their hosting of the meeting and for providing snacks and lunches for us, which greatly enhanced productivity and mental health.

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Report of the
Scientific Committee

Panama City, Panama, 11-23 June 2012

Annex A: List of Participants

Annex B1: Agenda

Annex B2: Relationship Between Commission and Scientific Committee Agendas

Annex C: List of Documents

International Whaling Commission, Panama City, 2012

Annex A

List of Participants

ARGENTINA
Miguel Iñíguez (H)

AUSTRALIA
Mike Double (H)
Nick Gales (AH)
Elanor Bell
William de la Mare
Natalie Kelly
Stephanie Ierino
Victoria Wadley

AUSTRIA
Michael Stachowitsch (H)

BELGIUM
Fábian Ritter (H)

BRAZIL
Milton Marcondes
Arthur Andriolo

CHILE
Barbara Galletti Vernazzani (H)

COLOMBIA
Suana Caballero

COSTA RICA
Gabriela Hernandez (H)
Jose David Palacios
Javier Rodriguez
Frank Garita
Amaru Marquez Artavia

DENMARK
Lars Witting (H)

ECUADOR
Cristina Castro (H)

FRANCE
Vincent Ridoux (H)
Jean-Benoît Charassin

GERMANY
Karl-Hermann Kock (H)
Petra Deimer-Schütte (AH)
Helena Feindt-Herr
Justin Cooke

ICELAND
Gisli Víkingsson (H)
Thorvaldur Gunnlaugsson
Christophe Pampoulie
Bjarki Thor Elvarsson

ITALY
Caterina Fortuna (H)
Giovanni Di Guardo
Cristina Fossi
Giancarlo Lauriano
Adriano Mariani
Simone Panigada
Michela Podestá

JAPAN
Hidehiro Kato (H)
Kiyoshi Katsuyama (AH)
Tomio Miyashita (AH)
Luis Pastene (AH)
Yuji Uozumi (AH)
Shinji Hiruma
Takashi Hakamada
Naohisa Kanda
Toshihide Kitakado
Toshiya Kishiro
Hiroshi Okamura
Takaai Sakamoto
Saemi Baba (I)
Hiroko Yasokawa (I)

REPUBLIC OF KOREA
Hawsun Sohn (H)
Yong-Rock An
Gi Hun Kim
Hyun Woo Kim
Jung-Youn Park
Kyum Joon Park

LUXEMBOURG
Pierre Gallego (H)
Andrea Cosentino

MEXICO
Armando Legorreta Jaramillo (H)

NETHERLANDS
Meike Scheidat (H)

NEW ZEALAND
Louise Chilvers (H)

NORWAY
Lars Walløe (H)
Arne Bjørge
Nils Øien
Hans Julius Skaug

PANAMA
Anna Nuñez
Lissette Trejos

RUSSIAN FEDERATION
Valentin Ilyashenko (H)
Andrey Vinnikov
Olga Etylin (I)

SPAIN
Santiago Lens (H)

SWITZERLAND
Patricia Holm (H)

UK
Beatriz Roel (H)
Russell Leaper
Mark Simmonds
Chris Parsons
Sarah Baulch

USA
Robert Brownell, Jr. (H)
Debra Palka
Dee Allen
C. Scott Baker
John Bickham
John Craig George
Geof Givens
Aimee Lang
Jeff Moore
Sue Moore
Robert Pitman
Lori Quakenbush
Cheryl Rosa
Howard Rosenbaum
Jonathan Scordino
Raphaela Stimmelmayr
Robert Suydam
Peter Thomas
Paul Wade

Robin Waples
David Weller
Gina Ylitalo
Judy Zeh

INVITED PARTICIPANTS
Rob Baldwin
John Bannister
Simone Baumann-Pickering
Peter Best
Liliana Betancourt
Jaime Bolaños
Anabela Brandão
John Brandon
Mark Bravington
Koen Broker
Louise Burt
Doug Butterworth
Carole Carlson
Frank Cipriano
Carryn De Moor
Jennifer Dupont
Naoko Funahashi
Oscar Gaggiotti
Phil Hammond
Sharon Hedley
Rus Hoelzel
Jennifer Jackson
Toshio Kasuya
Kenji Konishi
Greg Kaufman
Aimee Leslie
Bruce Mate
Juan Mate
Koji Matsuoka
Laura May-Collado
Andrea Muller
Hiroto Murase
Leslie New
Daniel Palacios
Per Palsbøll
Andre Punt
Randall Reeves
Naomi Rose
Jorge Urbán-Ramirez
Mariano Sironi
Liz Slooten
Ralph Tiedemann
Olga Tyurneva
Rob Williams
Andrew Wright
Tadusu Yamada
Alexandre Zerbini
Igor Zhmaev (I)

OBSERVERS
Mark Simmonds (ASCOBANS)
Karl-Hermann Kock (CCAMLR)
Justin Cooke (IUCN)
Hidehiro Kato (PICES)
Carole Carlson (SPAW)

LOCAL SCIENTISTS
Inez Campbell

IWC
Cherry Allison
Simon Brockington
Greg Donovan
Marion Hughes

(I)=Interpreter
(H)=Head of Delegation
(AH)=Alternate Head of Delegation

Annex B1

Agenda

1. Introductory items
    - 1.1 Chair's welcome and opening remarks
    - 1.2 Appointment of rapporteurs
    - 1.3 Meeting procedures and time schedule
    - 1.4 Establishment of sub-committees and working groups
    - 1.5 Computing arrangements
2. Adoption of agenda
3. Review data, documents and reports
    - 3.1 Documents submitted
    - 3.2 National Progress Reports on research
    - 3.3 Data collection, storage and manipulation
        - 3.1.1 Catch data and other statistical material
        - 3.1.2 Progress of data coding projects and computing tasks
4. Cooperation with other organisations
    - 4.1 Convention on the Conservation of Migratory Species (CMS)
        - 4.1.1 Scientific Council
        - 4.1.2 Conference of Parties
        - 4.1.3 Agreement on Small Cetaceans of the Baltic and North Seas (ASCOBANS)
        - 4.1.4 Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS)
        - 4.1.5 Memorandum of Understanding (MoU) on the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia
        - 4.1.6 Memorandum of Understanding (MoU) for the Conservation of Cetaceans and Their Habitats in the Pacific Islands Region (MoU for Pacific Islands Cetaceans)
    - 4.2 International Council for the Exploration of the Sea (ICES)
    - 4.3 Inter-American Tropical Tuna Commission (IATTC)
    - 4.4 Agreement on the International Dolphin Conservation Program (AIDCP).
    - 4.5 International Commission for the Conservation of Atlantic Tunas (ICCAT)
    - 4.6 Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)
    - 4.7 Southern Ocean GLOBEC (SO-GLOBEC)
    - 4.8 North Atlantic Marine Mammal Commission (NAMMCO)
        - 4.8.1 Scientific Committee
        - 4.8.2 Council
    - 4.9 International Union for the Conservation of Nature (IUCN)
    - 4.10 Food and Agriculture Organisation (FAO) related meetings – Committee on Fisheries (COFI)
    - 4.11 Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES)
    - 4.12 North Pacific Marine Science Organisation (PICES)
    - 4.13 Eastern Caribbean Cetacean Commission (ECCO)
    - 4.14 Protocol on Specially Protected Areas and Wildlife (SPAW) of the Cartagena Convention for the Wider Caribbean
    - 4.15 Indian Ocean Commission (IOC)
    - 4.16 Permanent Commission for the South Pacific (CPPS)
    - 4.17 International Maritime Organisation (IMO)
    - 4.18 Conservation in the SE Pacific under the framework for the Lima Convention
    - 4.19 International Committee on Marine Protected Areas (ICMMPA)
5. Revised Management Procedure (RMP) – general issues (see also Annex D)
    - 5.1 Complete the MSY rates review
    - 5.2 Finalise the approach for evaluating proposed amendments to the *CLA*
    - 5.3 Evaluate the Norwegian proposal for amending the *CLA*
    - 5.4 Modify the 'CatchLimit' program to allow variance-covariance matrices
    - 5.5 Update requirements and guidelines for conducting surveys and *Implementations*
    - 5.6 Evaluate the optimisation method used when conditioning trials
    - 5.7 List of abundance estimates and their recommended uses
    - 5.8 Work plan

6. RMP – Preparations for *Implementation*
    - 6.1 Western North Pacific Bryde's whales
        - 6.1.1 Prepare for 2013 *Implementation Review*
        - 6.1.2 Recommendations
    - 6.2 North Atlantic fin whales
        - 6.2.1 Recommendations
    - 6.3 North Pacific common minke whales (continue *Implementation*)
        - 6.3.1 Report of the December 2012 Intersessional Workshop
        - 6.3.2 Conditioning
        - 6.3.3 Update to standard datasets - abundance estimates
        - 6.3.5 Final consideration of plausibility
            - 6.3.5.1 Stock structure
            - 6.3.5.2 MSYR and other factors
        - 6.3.6 Specifications of operational features and management variants
        - 6.3.7 Specifications and classification of final trials
        - 6.3.8 Consideration of data/analyses to reduce hypotheses in future
        - 6.3.9 Inputs for actual application of the *CLA*
    - 6.4 North Atlantic common minke whales
        - 6.4.1 Review new information
        - 6.4.2 Prepare for 2014 *Implementation Review*
    - 6.5 North Atlantic sei whales
    - 6.6 Work plan
7. Estimation of Bycatch and other Human-Induced Mortality (BC)
    - 7.1 Collaboration with FAO on collation of relevant fisheries data
    - 7.2 Estimation of bycatch mortality of large whales
    - 7.3 Estimation of risk and rates of entanglement
    - 7.4 Review progress on including information in National Progress Reports
    - 7.5 Ship strikes
    - 7.6 Continue to develop global database of ship strike incidents
    - 7.7 Other issues
    - 7.8 Work plan
8. Aboriginal Subsistence Whaling Management Procedure (AWMP)
    - 8.1 Complete *Implementation Review* of eastern North Pacific gray whales with an emphasis on the PCFG
        - 8.1.1 Stock structure
        - 8.1.2 Abundance
        - 8.1.3 Catch data (direct and incidental)
        - 8.1.4 Mixing
        - 8.1.5 Biological parameters and MSYR
        - 8.1.6 Variants
        - 8.1.7 Final trials and conditioning
        - 8.1.8 Review results of trials
        - 8.1.9 Conclusions and selection of *SLA*s
        - 8.1.10 Other business
    - 8.2 Complete *Implementation Review* of Bering-Chuckchi-Beaufort Seas bowhead whales
        - 8.2.1 Consideration of new information with a focus on whether this implies a need for new trials
            - 8.2.1.1 Stock structure
            - 8.2.1.2 Abundance and rate of increase
            - 8.2.1.3 Catch data
        - 8.2.2 Discussion of new trials
        - 8.2.3 Conclusions and recommendations
    - 8.3 Continue work on developing *SLA*s for the Greenlandic hunts (Annex E, Item 4)
        - 8.3.1 Common minke whales
        - 8.3.2 Fin whales
        - 8.3.3 Humpback whales and bowhead whales
    - 8.4 Guidelines for *Implementation Reviews*
    - 8.5 Scientific aspects of an aboriginal whaling scheme (AWS)
    - 8.6. Conversion factors for edible products for Greenland hunts

8.7 Workplan
9. Aboriginal Subsistence Whaling management advice
9.1 Eastern Canada and West Greenland bowhead whales
9.1.1 Review new information on Eastern Canada and West Greenland bowhead whales
9.1.2 Review recent catch information
9.1.3 Management advice
9.2 Eastern North Pacific gray whales
9.2.1 New information
9.2.2 Review of recent catch information
9.2.3 Management advice
9.3 Bering-Chukchi-Beaufort (B-C-B) Seas stock of bowhead whales
9.3.1 New information
9.3.2 Management advice
9.4 Common minke whales off West Greenland
9.4.1 New information
9.4.2 Management advice
9.5 Common minke whales off East Greenland
9.5.1 New information
9.5.2 Management advice
9.6 Fin whales off West Greenland
9.6.1 New information
9.6.2 Management advice
9.7 Humpback whales off West Greenland
9.7.1 New information
9.7.2 Management advice
9.8 Humpback whales off St Vincent and The Grenadines
9.8.1 New information
9.8.2 Management advice
10. Whale stocks
10.1 Antarctic minke whales (Annex G)
10.1.1 Stock structure
10.1.2 Abundance estimation of Antarctic minke whales
10.1.3 Reasons for differences between estimates from CPII and CPIII
10.1.4 Continue development of the catch-at-age models
10.2. Southern Hemisphere humpback whales
10.2.1 Begin assessment of breeding stocks D, E and F
10.2.1.1 Abundance, trends and population structure
10.2.1.2 Assessment models
10.2.2 Review new information on other breeding stocks
10.2.2.1 Breeding stock A
10.2.2.2 Breeding stock B
10.2.2.3 Breeding stock C
10.2.2.4 Breeding stock D
10.2.2.5 Breeding stock G
10.2.2.6 Feeding grounds
10.2.2.7 Antarctic Humpback Whale Catalogue
10.2.3 Work plan
10.3. Southern Hemisphere blue whales
10.3.1 Review new information
10.3.1.1 Photo-identification catalogues
10.3.1.2 Antarctic blue whales
10.3.1.3 Planning of future research
10.3.1.4 Pygmy blue whales
10.3.1.5 Chilean blue whales
10.4 Western North Pacific gray whales
10.4.1 New scientific information
10.4.1.1 Satellite Tagging
10.4.1.2 photo-identification

10.4.1.3 Other
10.4.2 Conservation advice
10.5 Southern Hemisphere right whales
10.5.1 Review report from intersessional workshop
10.5.1.1 Long-term population monitoring
10.5.1.2 Population structure and linkages
10.5.1.3 Modelling
10.5.1.4 Joint Argentina/Brazil assessment
10.5.1.5 Assessment of the Chile/Peru population
10.5.1.6 Identification of concerns and their monitoring
10.5.1.7 Development of Conservation Management Plans (CMPs)
10.5.1.8 Conclusion
10.5.2 Review new information
10.5.2.1 Southwest Atlantic
10.5.2.2 Southern Africa
10.5.2.3 Southwest Pacific and New Zealand
10.5.2.4 Australia
10.5.2.5 South East Pacific right whales
10.5.2.6 Genetic research
10.6 Other stocks of right whales and small stock of bowhead whales
10.6.2 Work
10.7 Arabian Sea humpback whales
10.7.1 Review intersession progress
10.7.2 The development of a CMP
10.7.3 Work plan
10.8 Cruises
10.8.1 The IWC-POWER programme
10.8.1.1 Planning the IWC-Power Programme
10.8.1.2 Report on the 2011 IWC-Power Cruise
10.8.1.3 The 2012 IWC-Power Cruise
10.8.1.4 Plans for the 2013 IWC-Power Cruise
10.8.2 Other North Pacific cruises (and see Item 6)
10.8.2.1 Report of Japanese cetacean sighting surveys in the north Pacific in 2011
10.8.2.2 Plans for Japanese cetacean sighting surveys in the north Pacific in 2012
10.8.3 Cruises in the Antarctic Ocean
10.8.3.1 Progress on IDCR-SOWER cruises publications
10.8.3.2 Report of the 2011/12 cetacean sighting survey in the Antarctic
10.8.3.3 Plans for cetacean sighting surveys in the Antarctic in the 2012/13 season
10.9 Progress towards an in-depth assessment of North Pacific sei whales
11. Stock Definition
11.1 Guidelines for DNA data quality and genetic analyses
11.2 Statistical and genetic issues related to stock definition
11.3 Progress on the Testing of Spatial Structure Models (TOSSM)
11.4 Terminology and unit-to-conserve
11.5 Workplan
12. Environmental Concerns (E)
12.1 State of the cetacean environment report (SOCER)
12.2 Pollution
12.2.1 Update on POLLUTION 2000+ Phase II progress
12.2.2 Oil spill impacts
12.2.2.1 Update on response to Deepwater Horizon oil spill in the Gulf of Mexico
12.2.2.2 Capacity building regarding oil spill impacts on cetaceans
12.2.3 Other pollution related issues
12.3 CERD (Cetacean Emerging and Resurging Disease)
12.3.1 Update from CERD Working Group
12.3.2 Progress on CERD Website
12.3.3 Other disease related issues
12.4 Anthropogenic sound

12.4.1 Mitigation of effects of anthropogenic sound on cetaceans
12.4.2 Other anthropogenic sound related issues
12.5 Climate change
12.5.1 Progress on recommendations from the 2nd Climate Change Workshop
12.5.2 Small cetacean restricted habitats Working Group
12.5.3 Planning for intersessional Arctic Anthropogenic Impacts Workshop
12.5.4 Other climate change related issues
12.6 Interactions between MREDs and cetaceans
12.7 Other habitat related issues
12.7.1 Cetaceans and marine debris
12.7.2 Issues related to the March 2011 tsunami in the NW Pacific
12.7.3 Cumulative impacts of anthropogenic activities
12.7.4 REMMOA aerial surveys in the French EEA
12.8 Work plan
13. Ecosystem Modelling
13.1 Review of ecosystem modelling efforts undertaken outside the IWC
13.1.1 Ecosystem modelling in the context of ecosystem-based fisheries management
13.1.2 Ecosystem models of the effect on predators of fishing forage fish
13.1.3 Status update on NAMMCO ecosystem modelling
13.2 Explore how ecosystem models contribute to developing scenarios for simulation testing of the RMP
13.3 Review of other issues relevant to ecosystem modelling within the committee
13.3.1 Update on Antarctic minke whale body condition analyses
13.3.2 Other issues
13.4 Review new information on ecosystem model skill assessment
14. Small Cetaceans (SM)
14.1. Review status of ziphiids whales in the North Pacific and northern Indian Ocean
14.1.1. Cuvier's beaked whale (*Ziphius cavirostris*)
14.1.1.1. Conclusions and other considerations of status
14.1.2. Baird's beaked whale (*Berardius bairdii*)
14.1.2.1 Life history parameters
14.1.2.2. Abundance and trends
14.1.2.3. Takes including bycatch
14.1.2.4. Other actual and potential threats
14.1.2.5. Conclusions and other considerations of status
14.1.3. Longman's beaked whale (*Indopacetus pacificus*)
14.1.3.1 Conclusions and other considerations of status
14.1.4. Hubbs' beaked whale (*Mesoplodon carlhubbsi*)
14.1.4.1 Conclusions and other considerations of status
14.1.5. Blainville's beaked whale (*Mesoplodon densirostris*)
14.1.5.1 Conclusions and other considerations of status
14.1.6. Ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*)
14.1.7. Perrin's beaked whale (*Mesoplodon perrini*)
14.1.8. Pygmy beaked whale (*Mesoplodon peruvianus*)
14.1.8.1 Conclusions and other considerations of status
14.1.9. Stejneger's beaked whale (*Mesoplodon stejnegeri*)
14.1.9.1 Conclusions and other considerations of status
14.1.10. Deraniyagala's beaked whale
14.1.10.1 Conclusions and other considerations of status
14.1.11. Common issues and threats
14.1.11.1 Military sonar and other noise sources
14.1.11.2. Marine debris
14.1.11.3 General recommendations
14.2. Report on the voluntary fund for small cetacean conservation research
14.2.1. Status of the voluntary fund for small cetacean conservation research
14.2.2. Review on Progress on Funded Projects
14.3. Progress on previous recommendations
14.3.1. Vaquita
14.3.2. Harbour porpoise

14.3.3. Franciscana
14.3.4. Narwhal and white whale
14.3.5. Atlantic humpback dolphin
14.3.6. River dolphins
14.3.6.1 Boto and tucuxi
14.3.6.2 Indus river dolphin
14.3.6.3 Mekong river population of irrawaddy dolphins
14.3.7 Killer whales
14.3.8 Clymene dolphin
14.4 Takes of small cetaceans
14.5. Local studies
14.6 Hector's dolphins
14.7. Workplan
15. Whalewatching
15.1 Assess the impacts of whalewatching on cetaceans
15.2 Review whalewatching off Central America
15.3 Reports from intersessional working groups
15.3.1 Large-scale whalewatching experiment (LaWE) steering group
15.3.2 LaWE budget development group
15.3.3 Online database for worldwide tracking of commercial whalewatching and associated data collection
15.3.4 Swim-with-whale operations
15.3.5 In-water interactions
15.4. Other issues
15.4.1 Review scientific aspects of the Commission's Five Year Strategic Plan for Whalewatching
15.4.2 Consider information from platforms of opportunity of potential value to the Scientific Committee
15.4.3 Review whalewatching guidelines and regulations
15.4.4 Review of collision risks to cetaceans from whalewatching vessels
15.4.5 Swim-with-whales operations
15.4.6 Emerging whale watching industry in Oman
15.5 Work plan
15.6 Other matters
16. DNA testing
16.1 Review genetic methods for species, stock and individual identification
16.2 Review results of the amendments of sequences deposited in GenBank
16.3 Collection and archiving of tissue samples from catches and by-catches
16.4 Reference databases and standards for diagnostic registries
16.5 Work plan
17. Scientific Permits
17.1 Review of results from existing permits
17.1.1 JARPN II
17.1.1.1 Authors' summaries
17.1.1.2 Discussion
17.1.2 JARPA II
17.1.2.1 Authors' summary
17.1.2.2 Discussion
17.1.3 Planning for a final review of results from Iceland - North Atlantic common minke whale
17.1.4 Planning for a periodic review of results from JARPA II
17.2 Review of new or continuing proposals
17.2.1 JARPA II
17.2.2 JARPN II
18. Whale sanctuaries
19. SORP
19.1 Review of progress since IWC 63
19.1.1 SORP Antarctic Blue Whale Project
19.1.2 Ways to expand Antarctic Blue Whale Project (ABWP) work
19.1.3 Killer whales in the Southern Ocean
19.1.4 Foraging ecology and predator prey interactions of baleen whales and krill

19.1.5 Oceania humpback whale mixing
19.1.6 Fin and blue whale acoustics
19.1.7 Living Whales Symposium and non-lethal research techniques workshops
19.2 Budget
19.2.1 Budget overview
19.2.2 Request for funds from projects
19.2.3 Reallocation of funds
19.2.4 Allocation of funds
19.2.5 Seeking additional funding
19.3 Requirements for formalising participation in SORP and development of new projects
19.4 Workplan
20. Research and Workshop proposals and results
20.1 Review results from previously funded research proposals
20.2 Review proposals for 2012/13
21. Committee priorities and initial Agenda for the 2013 meeting
22. Data processing and computing needs for 2011/12
23. Funding requirements for 2012/13
24. Working methods of the Committee
24.1 Reducing the costs of Committee meetings
24.2 Clarifying information on data availability for Procedure B requests
24.3 Updating the Committee's guidelines and Handbook
24.4 Assistance to new members on the working of the Committee
25. Election of Officers
26. Publications
27. Other business
28. Adoption of Report

Annex B2

Relationship Between Commission and Scientific Committee Agendas

This table is intended to assist readers in finding information relative to the Commission agenda (IWC/64) in the Scientific Committee Report (SC/64) and the Chair's Report (2012) of IWC/63 (held in 2011). Commission agenda items not in this summary were not addressed at the Scientific Committee meeting.

No.	Commission Agenda (IWC/64)	Scientific Committee Agenda Item and Annex (SC/64)	Chair's Report (IWC/63: Agenda Item)
4.	SANCTUARIES		9
4.1	South Atlantic Whale Sanctuary		9.2
4.2	Other sanctuary issues raised in the Scientific and Conservation Committees		
4.2.1	Report of the Scientific Committee	18	9.1.1
4.2.2	Report of the Conservation Committee		9.1.2
5	THE IWC IN THE FUTURE		4
6.	WHALE STOCKS		5
6.1	Antarctic minke whales		5.1
6.1.1	Report of the Scientific Committee	10.1; Annex G	
6.2	Southern Hemisphere humpback whales		5.2
6.2.1	Report of the Scientific Committee	10.2; Annex H	
6.3	Southern Hemisphere blue whales		5.3
6.3.1	Report of the Scientific Committee	10.3; Annex H	
6.4	Western North Pacific gray whales		5.4
6.4.1	Report of the Scientific Committee	10.4; Annex F	
6.5	Southern Hemisphere right whales		5.5
6.5.1	Report of the Scientific Committee	10.5; Annex F	
6.6	North Pacific and North Atlantic right whales and small stocks of bowhead whales		5.6
6.6.1	Report of the Scientific Committee		
	• Right whales	10.6; Annex F	5.6.1
	• Bowhead whales	8.2, 9.1, 9.3, 10.6; Annexes E, F	
	• Gray whales	8.1, 9.2, 10.4; Annexes E, F	
6.7	North Pacific Research cruises (SOWER and North Pacific)		5.7
6.7.1	Report of the Scientific Committee	10.7; Annex G	
6.8	Other stocks		
7.	ABORIGINAL SUBSISTENCE WHALING		7; Annex F
7.1	Aboriginal Subsistence Whaling Management Procedure		7.1
7.1.1	Report of the Aboriginal Subsistence Whaling Sub-committee	8; Annex E	7.1.1
7.2	Aboriginal Whaling Scheme		7.2
7.2.1	Report of the Aboriginal Subsistence Whaling Sub-committee	8.3; Annex E	7.2.1
7.3	Aboriginal subsistence whaling catch limits		7.3
7.3.1	Report of the Aboriginal Subsistence Whaling Sub-committee	9; Annexes E, F	7.3.1.1, 7.3.2.1, 7.3.3.1, 7.3.4.1, 7.3.5.1, 7.3.6.1, 7.3.7.1, 7.4.1
8	CONSERVATION COMMITTEE		18; Annex G
8.1	Investigation of inedible 'stinky gray whales		
8.1.1	Report of the Conservation Committee	12.2.3; Annex K	
8.2	Ship Strikes		
8.2.1	Report of the Conservation Committee	7.7, 8.8; Annex K	
8.3	Southern Right Whales of Chile-Peru		
8.3.1	Report of the Conservation Committee	10.6.1; Annex F	
8.4	National Reports on Cetacean Conservation		
8.4.1	Report of the Conservation Committee		
8.5	Marine Debris		
8.5.1	Report of the Conservation Committee	12.7.1; Annex K	
8.6	Voluntary fund for small cetacean conservation research		
8.6.1	Report of the Conservation Committee	14.2; Annex L	
9.	CONSERVATION MANAGEMENT PLANS		14; Annex G
9.1	Report of the Conservation Committee	10.4, 10.5.2, 10.7; Annexes F, H	
10.	WHALEWATCHING		15; Annex G
10.1	Report of the Conservation Committee	15; Annex M	
11.	WHALE KILLING METHODS AND ASSOCIATED WELFARE ISSUES		6

No.	Commission Agenda (IWC/64)	Scientific Committee Agenda Item and Annex (SC/64)	Chair's Report (IWC/63: Agenda Item)
11.1	Report of the Working Group on Whale Killing Methods and Associated Welfare Issues		6.1
12.	SOCIOECONOMIC IMPLICATIONS AND SMALL-TYPE WHALING		10
13.	REVISED MANAGEMENT PROCEDURE (RMP)		8.1
13.1	Report of the Scientific Committee		8.1.1
13.1.1	General issues	5; Annex D	8.1.1.1
13.1.2	*Implementation* process		8.1.1.2
	• Western North Pacific Bryde's whale	6.1; Annex D	8.1.1.2
	• Central North Atlantic fin whales	6.2; Annex D	8.1.1.2
	• Western North Pacific common minke whales	6.3; Annex D1	8.1.1.2
13.1.3	Bycatch	7; Annex J	8.1.1.3
14.	SCIENTIFIC PERMITS		11
14.1	Report of the Scientific Committee	17	
14.1.1	Review of results from existing permits	17.1	
14.1.2	Review of new or continuing proposals	17.2	
14.1.3	Procedures for reviewing scientific permit proposals	17.1.3	
14.1.4	Other		
15.	SAFETY ISSUES AT SEA		12
16	CATCHES BY NON-MEMBER NATIONS		19
16.1	Report of the Scientific Committee	9.1	
17.	INFRACTIONS, 2011 SEASON		20
18.	ENVIRONMENTAL AND HEALTH ISSUES		13
18.1	State of the Cetacean Environment (SOCER)		
18.1.1	Report of the Scientific Committee	12.1; Annex K	
18.2	POLLUTION 2000+: Phase II Planning Workshop		
18.2.1	Report of the Scientific Committee	12.2; Annex K	
18.3	Cetacean diseases		
18.3.1	Report of the Scientific Committee	12.3; Annex K	
18.4	The impacts of oil and dispersants on cetaceans		
18.4.1	Report of the Scientific Committee	12.2; Annex K	
18.5	Marine renewable energy developments and cetaceans		
18.5.1	Report of the Scientific Committee	12.6; Annex K	
18.6	Anthropogenic sound		
18.6.1	Report of the Scientific Committee	12.4; Annex K	
18.7	Climate Change		
18.7.1	Report of the Scientific Committee	12.5; Annex K	
18.8	Ecosystem modelling		
18.8.1	Report of the Scientific Committee	13; Annex K1	
18.9	Proposal for a workshop on anthropogenic impacts to cetaceans in the Arctic		
18.9.1	Report of the Scientific Committee	12.5.3; Annex K	
18.10	Reports from Contracting Governments on national and regional efforts to monitor and address the impacts of environmental change on cetaceans and other marine mammals		
18.11	Health issues – Commission discussions and action arising		
18.12	Other		
19.	OTHER SCIENTIFIC COMMITTEE ACTIVITIES, ITS FUTURE WORK PLAN AND ADOPTION OF SCIENTIFIC COMMITTEE REPORT		17
19.1	Small cetaceans		17.1
19.1.1	Report of the Scientific Committee	14; Annex L	17.1
19.2	Regional non-lethal research partnerships		17.2
19.2.1	Report of the Scientific Committee	10.3;19; Annex H	17.2
19.3	Other activities		17.3
19.3.1	Report of the Scientific Committee	11, 16, 20, 22, 24-28	17.3
19.4	Scientific Committee Future Work Plan		17.4
19.4.1	Report of the Scientific Committee	21, 23	17.4
20	CO-OPERATION WITH OTHER ORGANISATIONS		16
20.1	Report of the Scientific Committee	4	
21	ADMINISTRATIVE MATTERS		21
21.1	Meeting arrangements and Procedures		21.1
21.2	The Commission's website		21.2
21.3	Operational effectiveness		
21.4	Cost saving measures		
22	FORMULAT FOR CALCULATING CONTRIBUTIONS AND RELATED MATTERS		21.5

No.	Commission Agenda (IWC/64)	Scientific Committee Agenda Item and Annex (SC/64)	Chair's Report (IWC/63: Agenda Item)
23	REPORT OF THE INTERSESSIONAL CORRESPONDENCE GROUP ON STRENGTHENING IWC FINANCING		
24	FINANCIAL STATEMENTS, BUDGETS AND OTHER MATTERS CONSIDERED BY THE BUDGETARY SUB-COMMITTEE		21.7
25	ADOPTION OF THE REPORT OF THE FINANCE AND ADMINISTRATION COMMITTEE		21.8
26	DATE AND PLACE OF FORTHCOMING MEETINGS		22
27	ADVISORY COMMITTEE		23
28	SUMMARY OF DECISIONS AND REQUIRED ACTIONS		24
29	OTHER MATTERS		25

Annex C

List of Documents

SC/64/AWMP

1. Philips, C.D., Hoffman, J.I., George, J.C., Suydam, R.S., Huebinger, R.M., Patton, J.C. and Bickham, J.W. Molecular insights to historical demography in bowhead whales. 20pp.
2. D'Intino, A.M., Darling, J.D., Urbán-Ramirez, J. and Frasier, T.R. Substructuring of mitochondrial, but not nuclear, markers in the 'southern feeding group' of eastern North Pacific gray whales. 14pp.
3. Morin, P.A., Archer, F.I., Pease, V.L., Hancock-Hanser, B., Robertson, K.M., Huebinger, R.M., Martien, K.K., Bickham, J.W., George, J.C., Postma, L.D. and Taylor, B.L. An empirical comparison of SNPs and microsatellites for population structure, assignment, and demographic analyses of bowhead whale populations. 27pp.
1. Lang, A.R. and Martien, K.K. Update on the use a simulation-based approach to evaluate plausible levels of recruitment into the Pacific Coast Feeding Group of gray whales. 34pp.
2. George, C. and Zeh, J. Population trend, 1978-2004, of Bering-Chukchi-Beaufort bowhead whales (*Balaena mysticetus*). 3pp.
3. George, C., Suydam, R., Givens, G.H., Bickham, J., Stimmelmayr, R., Moore, S. and Zeh, J. Selected research relevant to the 2012 bowhead *Implementation Review*. 17pp.
4. George, C., Herreman, J., Givens, G.H., Suydam, R., Mocklin, J., Clark, C., Tudor, B. and DeLong, R. Brief overview of the 2010 and 2011 bowhead whale abundance surveys near Point Barrow, Alaska. 9pp.
5. Suydam, R. and George, C. Preliminary analysis of subsistence harvest data concerning bowhead (*Balaena mysticetus*) taken by Alaskan Natives, 1974 to 2011. 13pp.
6. Bickham, J.W., Huebinger, R.M., Philips, C.D., Patton, J.C., Postma, L.D., George, J.C. and Suydam, R.S. Assessing molecular substitution patterns in the mitochondrial control region compared to protein coding genes in bowhead whales: update of SC/63/BRG13. 12pp.
7. Laake, J. Evaluation of potential bias in abundance estimates for seasonal gray whales in the Pacific Northwest. 10pp.
8. Brandon, J.R., Scordino, J., Butterworth, D.S., Donovan, G.P. and Punt, A.E. Towards the selection of a final set of trials for the 2012 ENP gray whale *Implementation Review*. 6pp.
9. Witting, L. Information of relevance on Evaluation Trials for West Greenland fin whales. 23pp.
10. Witting, L. Information of relevance on Evaluation Trials for West Greenland humpback whales (including general non-species specific issues). 14pp.
11. Witting, L. Information of relevance on Evaluation Trials for the hunt of bowhead whales in West Greenland. 9pp.
12. Witting, L. Information of relevance on Evaluation Trials for West Greenland minke whales. 11pp.

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1. Bellazzi, A., Orri, R. and Montanelli, S. Entanglement of southern right whales (*Eubalaena australis*) in Gulf Nuevo, Chubut, Argentina. 12pp.
2. Rodriguez-Fonesca, J., Cubero-Pardo, P., Montenegro-Hidalgo, V. and Jimenez-Tabush, Z. Three remarkable strandings in the last ten years in the Pacific of Costa Rica (eastern tropical Pacific). 4pp.

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1. Quakenbush, L., Citta, J., George, J.C., Heide-Jørgensen, M.P., Small, R., Brower, H., Harwood, L., Adams, B., Brower, L., Tagarook, G., Pokiak, C. and Pokiak, J. Seasonal movements of the Bering-Chukchi-Beaufort stock of bowhead whales: 2006-2011 satellite telemetry results. 22pp.
2. Suydam, R., George, J.C., Person, B., Hanns, C., Stimmelmayr, R., Pierce, L. and Sheffield, G. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2011. 8pp.
3. Mocklin, J., George, J.C., Ferguson, M., Brattström, L.V., Beaver, V., Rone, B., Christman, C., Brower, A., Shea, B. and Accardo, C. Aerial photography of bowhead whales near Barrow, Alaska, during the 2011 spring migration. 9pp.
4. Givens, G.H., Edmondson, S.L., George, J.C., Tudor, B., DeLong, R.A. and Suydam, R. Detection probability estimates from the 2011 ice-based independent observer surveys of bowhead whales near Barrow, Alaska. 25pp.
5. Burdin, A.M., Sychenko, O.A. and Sidorenko, M.M. Status of western gray whales off northeastern Sakhalin Island, Russia, 2011. 10pp.
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7. Martino, J., Wise, S.S., Perkins, C., Kerr, I., Rowntree, V.J., Sironi, M. and Wise, J.P., Sr. Metal levels in southern right whale (*Eubalaena australis*) skin biopsies from Península Valdés, Argentina. 8pp.
8. Bickham, J.W., Stuart, G.W., Patton, J.C., George, J.C. and Suydam, R.S. Bowhead Whale Genome Project: progress on the transcriptome. 6pp.
9. Moore, J.E. and Weller, D.W. Probability of taking a western North Pacific gray whale during the proposed Makah hunt. 5pp.
10. Weller, D.W. and Brownell, J.R. A re-evaluation of gray whale records in the western North Pacific. 4pp.
11. No paper.
12. Sironi, M., Rowntree, V.J., Di Martino, M., Chirife, A., Bandieri, L., Beltramino, L., Franco, M. and Uhart, M. Southern right whale mortalities at Península Valdés, Argentina: updated information for 2010-2011. 5pp.
13. Urbán R., J., Weller, D., Tyurneva, O.Y., Swartz, S.L., Bradford, A., Yakovlev, Y.M., Sychenko, O., Rosales, N., Martinez, S., Burdin, A.M. and Gómez-Gallardo, U. Report on the photographic comparison of the western and Mexican gray whale catalogues. 6pp.
14. Swartz, S.L., Urbán R., J., Gómez-Gallardo, U., Martinez, S., Olavarrieta, T., Lopez, D.C., Rodirguez, L. and Rojas-Bracho, L. Numbers of gray whales (*Eschrichtius robustus*) utilizing Laguna San Ignacio, Baja California Sur, Mexico during the winter breeding seasons: 2007-2012. 8pp.
15. Slikas, B., Baker, C.S., Clapham, P., Frasier, T.R., Seger, J., Valenzuela, L.O. and Wade, P. Proposal to the Scientific Committee: Worldwide genetic diversity and phylogenetic relationships among right whales based on next-generation sequencing of complete mitochondrial geneomes and multiple nuclear loci. 8pp.

16. No paper.
17. No paper.
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19. Vladimirov, V.A., Starodymov, S.P. and Kornienko, M.S. Distribution and abundance of western gray whales and their prey off northeast Sakhalin Island, Russia, 2011 (with retrospective comparisons). 20pp.
20. Vermeulen, E. and Cammareri, A. Abundance estimates of southern right whales (*Eubalaena australis*) in Bahia San Antonio, Patagonia, Argentina. 7pp.
21. Blokhin, S.A., Litovka, D., Vimmikov, A.V. and Kosiak, A.V. Gray whale *Eschrichtius robustus* coastal counts and harvest monitoring results off Chukotka Peninsula, Russian Far East, 2011. 6pp.
22. Tyurneva, O.Y., Yakovlev, Y.M. and Vertyankin, V. Photographic identification study of gray whale (*Eschrichtius robustus*) offshore northeast Sakhalin Island and southeast Kamchatka peninsula, Russia: 2002-2011. 13pp.
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24. Brandão, A., Butterworth, D.S., Müller, A. and Best, P.B. Application of a photo-identification based assessment model to southern right whales in South African waters. 15pp.
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2. Stachowitsch, M., Parsons, E.C.M. and Rose, N.A. State of the Cetacean Environment Report (SOCER) 2012. 6pp.
3. Dolman, S.J. and Simmonds, M.P. Ensuring adequate consideration of cetaceans in Scotland's ambitious marine renewable energy plans. 20pp.
4. Fossi, M.C., Marsili, L., Panti, C., Maltese, S., Coppola, D., Guzman C., D., Aguilar S., M. and Urban, J. Preliminary results on ecotoxicological investigation on gray whales (*Eschrichtius robustus*) in the San Ignacio Lagoon, Mexico. 7pp.
5. Hall, A.J., Schwacke, L.H., Kershaw, J.K., McConnell, B.J. and Rowles, T.K. An individual based modelling approach to investigate the impact of pollutants on cetacean population dynamics - effects on calf survival and immunity. 31pp.
6. Simmonds, M.P., Green, M., James, V.C., Eisfeld, S.M. and Lott, R. Towards evaluating the effectiveness of MPAs for cetacean conservation in Wales. 22pp.
7. Dyke, K.N. and Simmonds, M.P. Does the literature on marine debris and its impacts on cetaceans indicate any trends? 7pp.
8. Hernandez-Mora, G., Palacio-Alfaro, J.D. and González-Barrientos, R. Stranded cetaceans in Costa Rica: micro-organism and diseases with public health and conservation impact. 7pp.
9. No paper.
10. Baulch, S. and Perry, C. A sea of plastic: evaluating the impacts of marine debris on cetaceans. 24pp.
11. Wright, A.J. and Kyhn, L.A. Practical cumulative impact management. 6pp.
12. Galletti Vernazzani, B. and Veirs, V. Wind farm projects near cetacean critical habitat in Chile: a case study. 7pp.
13. Asmutis-Silvia, R., Kennedy, J., Schulte, D., Toepfer, M. and Bradt, S. High risk of marine debris ingestion by large whales in the southern Gulf of Maine, USA. 6pp.
14. Laran, S., Doremus, G., Mannocci, L., Van Canneyt, O., Watremez, P., Cadinouche, A., Dulau-Drouot, V., Mayer, F.X., Monthy, D., Andrianarivelao, N., Razafindrakoto, Y., Toilibou, A. and Ridoux, V. Progress of the REMMOA aerial surveys conducted in the French EEZ and adjacent waters: contrasted cetacean habitats in the southwest Indian Ocean. 14pp.
15. Scheidat, M. and Feindt-Herr, H. Collecting data on marine debris during cetacean aerial surveys. 3pp.

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1. Link, J.S. An overview of ecosystem models germane to whale population issues. 10pp.
2. Col, L.A., Link, J.S., Cadrin, S. and Palka, D. Marine mammal consumption on the northeast US continental shelf. 52pp.
3. De La Mare, W.K. Lurking variables and the interpretation of statistical analyses of data collected under JARPA. 65pp.

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1. Punt, A.E., Hakamada, T. and Pastene, L.A. A full description of the statistical catch-at-age analysis method for Southern Hemisphere minke whales. 39pp.
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2. International Whaling Commission. Report of the second 'First Intersessional Workshop' for the *Implementation Review* of western North Pacific common minke whales. 17pp. [Data files available separately].
3. International Whaling Commission. Report of the AWMP Workshop focussing on the PCFG gray whale *Implementation Review*. 31pp.
4. International Whaling Commission. Report of the 2012 intersessional IA Workshop on estimating abundance of Antarctic minke whales. 8pp.
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6. International Whaling Commission. Report of the workshop on interactions between marine renewable projects and cetaceans worldwide. 32pp.
7. International Whaling Commission. Report of the planning meeting for the 2012 IWC-POWER cruise. 14pp.

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No Exhibit

Report of the
Scientific Committee

Bled, Slovenia, 12-24 May 2014

Although this report has been carefully read by many people, it contains almost 88,000 words. If any errors are found, please inform the Secretariat (jessica.peers@iwc.int).

**International Whaling Commission,
Bled, Slovenia, 2014**

Report of the Scientific Committee

Bled, 12-24 May 2014

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The meeting (SC/65b) was held at the Golf Hotel, Bled, Slovenia from 12-24 May 2014 and was chaired by Toshihide Kitakado. The next meeting of the Commission (IWC/65) will take place during September 2014 and the next meeting of the Scientific Committee in 2015 will be SC/66a. The list of participants is given as Annex A.

1. INTRODUCTORY ITEMS

1.1 Chair's welcome and opening remarks

Kitakado welcomed the participants to the 2014 Annual Scientific Committee meeting. He thanked the Government of Slovenia for hosting the meeting and for providing the excellent facilities in the beautiful town of Bled.

Secretary of State at the Ministry of Agriculture and the Environment, Andreja Jerina, underlined the importance of nature preservation which, in many cases, is not an easy task. She highlighted that size, 'charisma' or unfamiliarity of a species alone should not play a role in nature conservation – what counts for conservation of any species is knowledge, perseverance and enthusiasm. She also stressed the importance of knowledge and good scientific propositions for political decisions in this field. She wished the participants a lot of success in their preparation of a decision basis for the September meeting in Portorož.

On behalf of the Commission, Brockington thanked the State Secretary for the invitation for the Scientific Committee to meet in Slovenia. He expressed his thanks for the excellent work of Andrej Bibic, the Commissioner for Slovenia, and his colleagues at the Ministry of Agriculture and Environment and the Ministry of Foreign Affairs. Their hard work, along with that of the staff at Sava Resorts and Hotels meant that making the preparations for this meeting had been extremely smooth and pleasant. He also referred to the great value of the work of the Scientific Committee and the wide range of topics it covers when providing its advice to the Commission.

1.2 Appointment of rapporteurs

Donovan was appointed rapporteur with assistance from various members of the Committee as appropriate. Chairs of sub-committees and Working Groups appointed rapporteurs for their individual meetings.

1.3 Meeting procedures and time schedule

The Committee agreed to the meeting procedures and time schedule outlined by the Chair.

1.4 Establishment of sub-committees and working groups

As agreed last year (IWC, 2013a) and included in the draft agenda, two pre-meetings took place in Bled prior to the Annual Meeting. A pre-meeting of the sub-committee on the Revised Management Procedure (RMP) met on 9-11 May 2014 to continue the *Implementation Review* for North Atlantic minke whales. Its report is given as Annex D, Appendix 5. The sub-committee on Other Southern Hemisphere Whale Stocks met 10-11 May 2014 to work towards the completion of the assessment of humpback whale Breeding Stocks D, E and F. It continued its work during the meeting and its report is subsumed into Annex H.

A number of sub-committees and working groups were established. Their reports were either made Annexes to this report (see below) or, in the case of that on Sanctuaries, was incorporated directly into the plenary report.

Annex D – Sub-Committee on the Revised Management Procedure;

Annex E – Standing Working Group on Aboriginal Subsistence Whaling Management Procedures;

Annex F – Sub-Committee on Bowhead, Right and Gray Whales;

Annex G – Sub-Committee on In-Depth Assessments;

Annex H – Sub-Committee on Other Southern Hemisphere Whale Stocks;

Annex I – Working Group on Stock Definition;

Annex J – Working Group on Non-deliberate Human-Induced Mortality of Large Whales;

Annex K – Standing Working Group on Environmental Concerns;

Annex K1– Working Group to Address Multi-species and Ecosystem Modelling Approaches;

Annex L – Sub-Committee on Small Cetaceans;

Annex M – Sub-Committee on Whalewatching;

Annex N – Working Group on DNA;

Annex O – Working Group on Special Permits;

Annex P – Revisions to the Annex P process;

Annex Q – Ad hoc working group on progress reports;

Annex R – Terms of reference for Sanctuary reviews;

Annex S – Budget related matters;

Annex T – Intersessional working groups;

Annex U – Statements on the Agenda.

1.5 Computing arrangements

Allison outlined the computing and printing facilities available for delegate use**.**

2. ADOPTION OF AGENDA

The adopted agenda is given as Annex B. A number of statements on the Agenda were received on items related to small cetaceans, whalewatching and the JARPA II programme. These are given in Annex U.

3. REVIEW OF AVAILABLE DATA, DOCUMENTS AND REPORTS

3.1 Documents submitted

The documents available are listed in Annex C. As agreed at the 2012 Annual Meeting, primary papers were only available at the meeting in electronic format (IWC, 2013a, pp.78-9).

3.2 National Progress Reports on research

As agreed last year, all National Progress Reports were submitted electronically thought the IWC National Progress Reports data portal. This data portal now allows multiple levels of data entry users within each country and has been improved to address the recommended changes provided at last year's meeting (Annex O, IWC 2014). The Committee again **thanks** Miller of the Secretariat for developing and enhancing the data portal.

Table 1

List of data and programs received by the IWC Secretariat since the 2012 meeting.

Date	From	IWC ref.	Details
Catch data from the previous season:			
17-03-14	Iceland: A. Þormar	E115 Cat2013	Individual catch records from the Icelandic commercial catch 2013
1-05-14	St. Vincent: J. Compton	E115 Cat2013	Individual records from the 2013 aboriginal hunt by St. Vincent and the Grenadines
6-05-14	Norway: N. Øien	E115 Cat2013	Individual minke records from the Norwegian 2013 commercial catch. Access restricted (specified 14-11-00)
12-05-14	Japan: N. Okazoe	E115 Cat2013	Individual data from Japan's catch in 2013 in the North Pacific (JARPN II) & 2012/3 in the Antarctic
15-05-14	USA: R. Suydam	E115 Cat2013	Individual data from the 2013 bowhead hunt in Alaska
13-02 & 23-05-14	Canada: L. Vuckovic	E115 Cat2013	Details of the Canadian bowhead harvest from the 2013 season and notification of the 2014 quota
Catch data from earlier seasons:			
16-06-13	Japan: L. Pastene	E111	Corrected data from the Japan Antarctic catches 1987-2012 following a thorough comparison by Japan of IWC data (from annual data submissions) and the scientists' data
27-08-13	Canada: B. Green	E108 Cat2012	Details of the Canadian bowhead harvest for the 2012 season
9-10-13	P. Best	E112	Sierra records 1976-78 in the North Atlantic (as described in Best, 1992)
17-10-13	Greenland: N. Levermann	E113	Individual catch data from Greenland 2007-2012.
18-04-14	Iceland: T. Gunnlaugsson	E116	Individual records of minke whales caught by Iceland 1973-85 and summaries of catches in earlier years
Sightings data:			
2-12-13	Japan: K. Matsuoka	E114	POWER cruise sightings data – 2013 including photographs and data forms (electronic and paper)
2-12-13	Japan: K. Matsuoka	CD98	Blue whale ID photographs from 2005/06-2012/13 JARPA II data; submitted under IWC data access Procedure B.
23-04-14	Japan: K. Matsuoka	E117	Data from the JARPN II 2013 dedicated sightings survey

This year, 16 countries provided National Progress Reports including data on bycatch, entanglement, ship strikes, direct and indirect takes, sampling, sightings and tracking studies. These countries were: Australia, Belgium, Brazil, Croatia, Denmark, Germany, Iceland, Ireland, Italy, Japan, Mexico, New Zealand, Republic of Korea, Spain, UK and the USA. Between 2010 and 2012, 22, 18 and 20 countries submitted national reports.

The National Progress Reports have their origin in Article VIII, Paragraph 3 of the Convention. All member nations are urged by the Commission to provide Progress Reports to the Scientific Committee following the most recent guidelines developed by the Scientific Committee and adopted by the Commission. The report is intended as a concise summary of the cetacean research undertaken in member countries as well as a summary of information on direct and incidental anthropogenic mortality.

The Committee again **recommends** that all member states submit National Progress Reports to the IWC through the IWC data portal (*http://portal.iwc.int*).

Further improvements were discussed in an *ad hoc* Working Group and the Committee **endorses** the report of that Group (see Annex Q) and its recommendations.

3.3 Data collection, storage and manipulation

3.3.1 Catch data and other statistical material

Data received by the Secretariat since the 2013 meeting are listed in Table 1, including catch data from the 2013 season.

3.3.2 Progress of data coding projects and computing tasks

Allison reported that work has continued on the entry of catch data into both the IWC individual and summary catch databases, including data received from the 2012 season. Additional information from earlier seasons has been entered, including catch records from British Columbia received from J. Ford in 2012, common minke whale catch data from Iceland for the period 1973-85 and some data from the catcher/factory *Sierra* in 1976-8 received from P. Best. An exercise to reconcile the IWC Japanese Antarctic catch data 1987-2012 with that held by Japanese scientists has been completed. A new version of the catch databases will be released shortly.

Validation of the data from the 2011 POWER sightings cruise has been completed and validation data from the 2012 cruise has commenced.

In response to a question about how a blue/fin whale hybrid identified in the Icelandic catch data should be recorded, Allison noted that at present this whale is included as a fin whale in the database, with a footnote to show that it is a hybrid.

Programming work during the past year has included the compilation of the final set of tables and plots from the Western North Pacific minke whale *Implementation Review* completed last year. Other work is described under the relevant sub-committee items.

4. CO-OPERATION WITH OTHER ORGANISATIONS

The Committee noted the great value of co-operation with other international organisations to its work. The observers' reports below briefly summarise relevant meetings of other organisations. The contributions of several collaborative efforts are dealt with in the relevant sub-committees.

4.1 Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)

The report of the IWC observer at the 32nd Meeting of the CCAMLR Scientific Committee (SC-CCAMLR), held in Hobart, Australia from 21-25 October 2013 is given as IWC/65/4(2014)A. The main items considered at the CCAMLR meeting of relevance to the IWC included: (1) fishery status and trends of Antarctic fish stocks, krill, squid and stone crabs; (2) incidental mortality of seabirds and marine mammals in fisheries in the CCAMLR Convention Area; (3) harvested species; (4) ecosystem monitoring and management; (5) management under conditions of uncertainty about stock size and sustainable yield; (6) scientific research exemption; (7) CCAMLR Scheme of International Scientific Observation; and (8) new and exploratory fisheries.

Reports of SC-CCAMLR and its Working Groups on Ecosystem Monitoring and Management (WG-EMM) and Fish Stock Assessment (WG-FSA) and their various subgroups are available through the CCAMLR secretariat and on the CCAMLR website[1].

The CCAMLR Working Group on Incidental Mortality in Fisheries (WG-IMAF) did not meet in 2013 and no new information on cetacean-fisheries interactions in the Southern Ocean became available to CCAMLR. The next meeting of the Working Group is likely to take place prior to the annual meeting of CCAMLR in 2014.

The Committee **thanks** Koch for attending on its behalf and for his service in this position for the past 24 years. The Committee **appoints** Currey to represent the Committee as an observer at the next SC-CCAMLR meeting.

4.2 Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES)[2]

The Conference of the Parties did not occur during the intersessional period.

4.3 Convention on the Conservation of Migratory Species (CMS)[3]

4.3.1 Scientific Council

There was no meeting of the Scientific Council during the intersessional period.

4.3.2 Conference of Parties (COP)

There was no Meeting of the Parties during the intersessional period.

4.3.3 Agreement on Small Cetaceans of the Baltic and North Seas (ASCOBANS)[4]

The report of the IWC observer at the 20th meeting of the Advisory Committee to ASCOBANS, held in Warsaw, Poland from 27-29 August 2013 is given as IWC/65/4E. The main discussions at the meeting are summarised below.

(1) progress with three harbour porpoise action plans, including new abundance for the 'gap' area and ongoing analyses of the SAMBAH project for the Baltic Sea;
(2) involvement in current developments concerning bycatch of small cetaceans;
(3) mitigation advice regarding underwater noise;
(4) chemical pollutions should accorded greater attention (ECS Workshop on Chemical Pollution and Marine Mammals) - it is possible that bottlenose dolphins and killer whales in parts of Europe are suffering from high levels of contamination;
(5) a series of recommendations from the Marine Debris Working Group including collecting data on the distribution of debris and necropsies (in the future, information on entanglement and debris could be added to the ASCOBANS national reports);
(6) ASCOBANS will ask Parties to provide details of those responsible for cetacean rescue and what laws require, allow and prohibit in each country.
(7) SCANS III is a high priority that aims to establish the current abundance of cetaceans in the European Atlantic, assess mortality arising from human activities and to compare methods to create a best practice guide for monitoring to inform European directives;
(8) the ASCOBANS/ACCOBAMS Population Structure Workshop included a definition for the term 'Management Unit (MU)'- MUs need to be established for all regularly occurring small cetacean species in the area of overlap of ACCOBAMS and ASCOBANS with priority to be given to those species for which there is not only evidence of sub-structuring but also which appear to be especially vulnerable to anthropogenic activities (include *inter alia* killer whale, bottlenose dolphin, Risso's dolphin, pilot whale and harbour porpoise);
(9) the results of the joint ASCOBANS/ACCOBAMS workshop on 'The challenge of spatially managing cetaceans – a highly mobile animal group' were presented.

No Meeting of Parties to ASCOBANS occurred in the intersessional period.

The Committee **thanks** Scheidat for her report and **agrees** that she should represent the Committee as an observer at the next ASCOBANS Meeting of Parties and Advisory Committee meeting.

4.3.4 Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS)[5]

Due to the attendance of Donovan at an IWC Workshop, Fortuna kindly attended the ninth meeting of the ACCOBAMS Scientific Committee held in Monaco from 14-18 April 2013. Her report is given as IWC/65/4(2014). The full report of the meeting can be found on the ACCOBAMS website.

The issues most relevant to the work of the IWC Scientific Committee included: (a) the ACCOBAMS-IWC joint effort on ship strikes; (b) the most recent involvement of IWC experts in research programmes (i.e. aerial surveys in the Tyrrhenian and Adriatic seas and a telemetry programme to

[1] *http://www.ccamlr.org/.*
[2] *http://www.cites.org.*
[3] *http://www.cms.int.*
[4] *http://www.ascobans.org.*
[5] *http://www.accobams.org.*

investigate the movements and distribution of fin whales outside the summer season); (c) the IWC experience in drafting and helping the implementation of Conservation Plans (e.g. the case of recently adopted Conservation Management Plans).

ACCOBAMS and the IWC have recognised the problem of ship strikes and have been working together to develop a better understanding of the issue and to develop effective mitigation measures inter alia within the ACCOBAMS area for several years. A Working Group and according Steering Committee were established under the auspices of the ACCOBAMS Scientific Committee to ensure that the recommendations of the joint ACCOBAMS/IWC workshop and the resolutions from the Meeting of the Parties are acted upon. The Steering Committee and Working Group will work in close contact with the ACCOBAMS Secretariat, the IWC, the Pelagos Sanctuary and other relevant experts.

The IWC Secretariat and Italy have been co-operating on aerial surveys in the region to determine the extent and abundance of cetaceans as well as on a telemetry programme investigating the movements and distribution of fin whales outside the summer season. Results of these studies will be useful in addressing and potentially mitigating the issue of ship strikes within the Mediterranean Sea as well as informing the drafting of Conservation Plans at regional and sub-regional level (e.g. the future Adriatic Cetacean Conservation Plan).

With respect to conservation plans, information on the IWC experience in developing Conservation and Management Plans was presented, including relevant references and the information on the IWC's adopted process on how to handle the preparation of conservation plans including approved IWC guidelines were provided to the Scientific Committee.

The importance of continued co-operation between ACCOBAMS and the IWC was recognised.

The Committee **thanks** Fortuna for attending the meeting on its behalf and **agrees** that Donovan should represent the IWC at the next ACCOBAMS meeting.

4.4 Food and Agriculture Organisation of the United Nations (FAO)

No observer for the IWC attended the 2013 meeting of FAO.

4.5 Inter-American Tropical Tuna Commission (IATTC)

The reports of the IWC observer at the 85th and 86th meetings of the IATTC held in Veracruz, Mexico 10-14 June 2013 and 14-15 October 2013 respectively are given as IWC/65/4(2014)D. The Antigua Convention came into force on 27 August 2010 and under this the IATTC is expected to give greater consideration to non-target and associated species, including cetaceans, in taking management decisions. A summary was given of ongoing work describing what is known about the direct impact of the fisheries on other species in the ecosystem and the environment. This ongoing work will shape future directions of AIDCP (see Item 4.6) and IATTC measures aimed at managing fisheries and conserving dolphins.

The IATTC continues to focus much of its attention on conservation and management of target tunas and sharks and other non-target species. Discussions of tuna conservation measures have implications for dolphin conservation. Fishing effort on dolphins may increase if, for example, future measures focus on further restricting the sector of the fishery that takes the greatest number of juveniles (vessels that set on floating objects). This could provide an incentive to fish on dolphins in order to remain active during closure periods for the floating object fishery and/or to not exceed bigeye tuna catch limits.

The Committee **thanks** Rusin for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next AITTC meeting.

4.6 Agreement on the International Dolphin Conservation Program (AIDCP)

The report of the IWC observer at the 27th and 28th Meetings of the Parties to the AIDCP held in Veracruz, Mexico on 4 June 2013 and in Del Mar, CA, USA 18 October 2013 respectively is given as IWC/65/4(2014)E. The AIDCP mandates 100% coverage by observers of fishing trips by purse seiners of carrying capacity greater than 363t in the agreement area and in 2013 all trips (750) by such vessels were sampled by independent observers.

The overall dolphin mortality limit (DML) for the international fleet in 2013 was 5,000 animals and the unreserved portion of 4,900 was allocated to 90 qualified vessels that requested DMLs. In 2013, no vessel exceeded its DML. The number of sets on dolphin associated schools of tuna made by vessels over 363t has been increasing in recent years, to 11,645 in 2010. However, since then, the number has been decreasing and was 8,025 in 2013. Reported dolphin deaths and mortality limits, presented by species and stock, can be found in IWC/65/4(2014)E.

While fewer dolphin sets were made since 2010, this remains a frequent practice and the predominant method for catching yellowfin tuna by purse-seine. There have been insufficient resources to conduct dolphin and ecosystem assessment surveys since 2006 so it is unclear when updated abundance estimates for cetaceans in the ETP will be available.

In 2013, the AIDCP focused significant discussion on consideration of reducing observer coverage and developing an 'Ecosystem Friendly' certification scheme for tuna caught in association with dolphins. Due to the increasing sentiment among some Parties that the dolphin problem has been solved and that dolphin-fishing methods are better economically and environmentally than dolphin-safe methods, in 2014 the AIDCP Parties are expected to continue consideration of these proposals and others that have the potential to increase fishing effort on dolphins and the magnitude of associated direct and indirect effects of this practice.

The Committee **thanks** Rusin for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next AIDCP meeting.

4.7 International Committee on Marine Protected Areas (ICMMPA)

The report of the observer documenting the activities ICMMPA is given as IWC/65/4(2014)K. The International Committee for Marine Mammal Protected Areas was formed as an international committee of experts in 2006 to address common issues and challenges faced by scientists and managers using spatial management tools to manage and conserve important cetacean habitats or populations. In 2008, the IWC endorsed and supported a proposal by ICMMPA to

host the first international conference on marine mammal protected areas in 2009. Since that time, the ICMMPA has undertaken several initiatives and has co-hosted, with France, a second conference in Martinique, in 2011[6]. Since that conference, the Committee has been working with the Australian Government and WDC Australia in order to hold the third International Conference on Marine Mammal Protected Areas (ICMMPA3) 9-11 November 2014 in Adelaide, Australia.

The IUCN Marine Mammal Protected Areas Task Force (IUCN-MMPA-TF) was officially announced at the third International Marine Protected Areas Congress in Marseille, France, 24 October 2013, at which time it began its first major initiative by holding a workshop to develop criteria for defining 'important marine mammal areas' (IMMAs). It was agreed that:

(1) the Task Force should start to apply existing suites of criteria specifically to IMMAs as a means to test their utility and to refine or add any additional sub-criteria as may be useful for marine mammals;
(2) IMMAs will be able to provide important data to support the identification of between Ecologically or Biologically Significant Areas EBSAs;
(3) the similarity in objectives between Important Bird Areas (IBAs) and IMMAs, which both focus on wide-ranging species, and the fact that IBAs are considered to be a subset of Key Biodiversity Areas (KBAs), would suggest that IMMAs could fit adjacent to IBAs and other taxa-based sets of criteria, with KBAs as the global umbrella;
(4) EBSA descriptions draw on all available information including KBAs, IBAs, plus other data sets, and would take IMMAs into account, if such designations were available; and
(5) the Task Force will endeavour to work with partners including the CBD Secretariat and the IUCN to ensure IMMAs are included in the EBSA and KBA

The Committee **thanks** Ridoux for his report and **agrees** that he should represent the Committee as an observer at the next ICMMPA meeting.

4.8 International Council for the Exploration of the Sea (ICES)[7]

The report of the IWC observer documenting the 2013 activities of ICES is given as IWC/65/4(2013)B. The ICES Working Group on Marine Mammal Ecology (WGMME) met 4-7 February 2013.

Requests for determining Good Environmental Status (GES) were reviewed and delineated for cetaceans. Boundaries were specified so that the management units can be populated with abundance and bycatch estimates. As previously agreed, these boundaries coincide with ICES Area/Division boundaries where possible. Further consideration was given to ICG-COBAM's common indicators for marine mammals.

There was discussion of monitoring efforts to determine the distribution and habitat use of marine mammals, in relation to environmental impact assessments e.g. for marine renewable energy developments. Too often, monitoring programmes in adjacent marine renewable energy developments occur independently without broader coordination. Regulators and seabed owners need to acknowledge the need for data pooling, require it as an integral part for marine renewable consenting and develop internationally standardised comparable data formats for easy access and analysis. The Joint Cetacean Protocol (JCP) may serve as such an example.

The ICES Working Group on Bycatch of Protected Species (WGBYC) met 4-9 February 2013. WGBYC reviewed EU Member States' reports to assess the status of information on recent bycatch estimates and evaluate the extent of the implementation of bycatch mitigation measures. It was noted that estimates are still very patchy and several member states have not fulfilled their monitoring obligations. Bycatch monitoring remains less than optimally directed in many cases.

WGBYC reviewed recent bycatch mitigation trials, including trials of gillnet modifications and experiments that attempt to quantify the effect of pingers on porpoise displacement. Implementation of bycatch mitigation measures was also found to be patchy, with few EU member states able to provide unequivocal confirmation that the obligations are being met. WGBYC continued to develop a streamlined and effective database for the collation, storage and analysis of European bycatch monitoring and fishing effort data for those fishing sectors where bycatch monitoring is mandated.

The 2013 ICES Annual Science Conference was held in Reykjavik, Iceland from 23-27 August 2013. Some sessions were designed with marine mammals included as an integral part. A number of sessions were of relevance to the Committee, including those describing:

(1) responses of living marine resources to climate change and variability;
(2) marine spatial planning: The multidisciplinary approach; and
(3) advances in studying spatial distribution.

The Committee **thanks** Haug for the report and **agrees** that he should represent the Committee as an observer at the next ICES meeting.

4.9 International Maritime Organisation (IMO)[8]

The report of the IWC observer to the IMO is given as IWC/65/4(2014)H. The IWC has contributed to IMO discussions on addressing ship strikes and the impacts of underwater noise from shipping. In April 2014 at the 66th meeting of its Marine Environment Protection Committee, the IMO adopted 'Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life' (MEPC.1/Circ.833). These non-mandatory, technical guidelines recognise that underwater-radiated noise from commercial ships may have both short and long-term negative consequences on marine life, especially marine mammals. The guidelines intend to provide general advice about reduction of underwater noise to designers, shipbuilders and ship operators.

The IMO also continued to develop a mandatory Polar Code. This is intended to augment existing measures to reduce the environmental impacts of shipping in polar waters, taking into account their greater environmental sensitivity. This

[6] *http://second.icmmpa.org*
[7] *http://www.ices.dk.*
[8] *http://www.imo.org.*

work will continue through 2014. Chapter 12 of the draft Polar Code addresses voyage planning which will be considered in detail by the Maritime Safety Committee (MSC 93) in May 2014. This draft contains a broader mandatory requirement for ships to take into account important areas for cetaceans during voyage planning. Some concerns have been expressed about the availability of such information and this is an area where the IWC may be able to help.

In addition, the noise guidelines note that 'Speed reductions or routing decisions to avoid sensitive marine areas including well-known habitats or migratory pathways when in transit will help to reduce adverse impacts on marine life'. The IMO and shipping industry are therefore likely to welcome further information on cetacean distribution patterns.

The Committee thanked Leaper for his report and **agrees** that he or the Secretariat should represent the Committee at the next IMO meeting.

4.10 International Union for the Conservation of Nature (IUCN)[9]

Cooke, the IWC observer, reported on the considerable cooperation with IUCN that had occurred during the past year and this is given as IWC/65/4(2014)L.

Red List updates

The Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*), the world's only freshwater porpoise, has been uplisted to Critically Endangered following an estimated decline of over 50% during 2006-12 (see also Annex L item 8.7).

The last comprehensive assessment of cetacean species for the Red List was completed in 2008, and most cetacean species are due for reassessment in 2014. Barbara Taylor, who has replaced Bill Perrin as the Red List Authority Coordinator for the Cetacean Specialist Group, will be coordinating the revision of the cetacean listings. All cetacean species and selected subpopulations will be updated and newly recognised species in the genera *Inia* and *Sousa* will be added.

Western gray whales

Two further meetings of the Noise Task Force of the IUCN Western Gray Whale Advisory Panel (WGWAP) have been held in the past year, to determine mitigation measures for seismic surveys near the Sakhalin gray whale feeding ground in summer 2015. A paper was recently published on best practices for mitigation of the effects of seismic surveys on cetaceans, based on the work of the Panel's Noise Task Force (Nowacek *et al.*, 2013).

Cetacean Specialist Group

A Marine Mammal Protected Area Task Force was established in October 2013 jointly by the IUCN Species Survival Commission (SSC) and the IUCN World Commission on Protected Areas (WCPA), to develop improved practices for the designation and implementation of different types of protected areas for marine mammals. More details of this and other activities of the IUCN Cetacean Specialist Group are provided on the its website *http://www.iucn-csg.org/* and also see Item 4.7.

The Committee **thanks** Cooke for his report and **agrees** that he should continue to act as observer to IUCN for the IWC.

4.11 North Atlantic Marine Mammal Commission (NAMMCO)[10]

4.11.1 Scientific Committee

The report of the IWC observer at the 20th meeting of the NAMMCO Scientific Committee (NAMMCO SC) held in Reykjavik, Iceland from 13-16 November 2013 is given as IWC/65/4(2014)I.

HUMPBACK WHALES

Following the completion of the major survey effort, T-NASS 2007, NAMMCO is to conduct a formal assessment of humpback whales. The assessment for West Greenlandic waters has been completed, but assessment in other areas not yet initiated.

NARWHALS AND WHITE WHALES

A symposium focusing on narwhals and white whales is planned for 2015.

BOTTLENOSE AND KILLER WHALES

Faroese bottlenose dolphin sightings data were analysed together with CODA and SCANS II data. The preliminary designed based estimate for the Faroese block of T-NASS 2007 was 16,284. A recent increase in catches of killer whales off Tasiilaq in East Greenland (8 on average per year from 2010 to 2012) was reported and there is a possibility of a high struck and lost rate in this hunt. Higher levels of annual catches of killer whales (19 on average per year from 2010 and 2012) and low levels of bottlenose catches (20 animals) were noted for West Greenland.

PILOT WHALES

The T-NASS surveys have indicated decreasing abundance of pilot whales subsequent to the 1989 survey. An index has been developed in order to determine trends in abundance. It uses only the three largest surveys and including the data from the CODA survey for enlarging the reference area. The reference area still comprises only a small portion of the summer range of the species and changes in distribution may have influenced the results.

Estimation of pilot whale group size has a strong influence on estimated abundance and varied significantly among the surveys. Although it seems unlikely that an annual harvest of around 1,000 whales could have caused the population to decline, the apparent reduction of pilot whale abundance in the reference areas, which include the hunting area around the Faroes, should be of concern. Tagging of pilot whales in the Faroes has recently been conducted. More tracking data should be obtained from offshore areas, with a focus on the period during sightings surveys (July-August).

HARBOUR PORPOISES

An aerial survey conducted in West Greenland in August-September 2007 gave an abundance estimate of 274,883. Another estimate from Danish waters resulted in a corrected estimate of 50,461. There were large increases in catches in the past 19 years in the settlements with the largest catches, which may be due to multiple factors, including technological improvements, increased harbour porpoise population, and the new reporting system. The catches were corrected based on a survey among hunters for missing data on harbour

[9] *http://www.iucn.org/*.
[10] *http://www.nammco.no/*.

porpoise catches. A struck and lost rate of 8% was also revealed. The WG used age-structure data from the hunt and combining the two different availability corrections of the abundance estimate, with three different estimates of the historical catches, the model estimated the dynamics of harbour porpoises in West Greenland quite differently, from increase to rapid decline. Hence, to obtain a consistent assessment model that is useful for providing management advice, it is essential that the uncertainties associated with the abundance and catch history estimates are resolved. Nevertheless, the working group noted that the average annual catches since 1993 in West Greenland were 2,126 harbour porpoises and that a large abundance is needed to sustain such catches.

Bycatch by coastal monkfish and cod in Norwegian gillnet fisheries is estimated to be about 6,900 harbour porpoises per year. Although no abundance estimate is available for the coastal harbour porpoise population, the annual bycatch is likely not sustainable. Incidental sightings show that the species is commonly observed in near coastal waters, archipelagos and fjord systems along the entire Norwegian coast. Harbour porpoises have been observed in the southern Barents Sea, including the Pechora Sea, and a vessel-based survey gave uncorrected estimates of about 3,000 animals.

BOWHEAD WHALES

Aerial surveys were completed in West Greenland in 2012 and a comparison with a simultaneous genetic mark recapture study showed the genetics give higher abundance estimates. The reasons for the higher estimates are that the aerial surveys are snapshots of the situation, whereas the genetics represent a whole influx of bowhead whales.

SURVEY PLANNING

Acoustics are not included in the NAMMCO T-NASS 2015 proposal, but could be conducted during national survey activities. The specific objectives for the planned T-NASS 2015 are to obtain unbiased abundance estimates of:

(1) pilot whales around Faroe Islands - useful for assessing the sustainability of the hunt;
(2) common minke whales in West Greenland, around Iceland, Jan Mayen and Svalbard and the central Norwegian Sea; and
(3) fin whales southwest of Iceland.

The Committee **thanks** Walløe for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next NAMMCO Scientific Committee meeting.

4.11.2 Council

The report of the IWC observer at the 22nd Annual Council Meeting of NAMMCO held in Oslo, Norway from 25-27 February 2014 is given as IWC/65/4(2014)C.

A number of topics were discussed including T-NASS 2015, tagging efforts end the international observer scheme. A planning group is preparing for a meeting in 2015 focusing on marine mammals in the context of food security.

NAMMCO has completed two authoritative manuals; one dealing with large baleen whaling and the use of whaling cannon and the penthrite grenade and a second dealing specifically with the use of the spinal lance and hook in the pilot whale hunt. An English language version of each is accessible on the NAMMCO website, they will be available in native languages as required for the hunting communities in due course.

The Committee **thanks** Sakamoto for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next NAMMCO Council meeting.

4.12 North Pacific Marine Science Organisation (PICES)[11]

The report of the IWC observer at the 22nd annual meeting of PICES held from 11-20 October 2013 in Nanaimo, Canada is given as IWC/65/(2014)F. The Marine Birds and Mammals Advisory Group (AP-MBM) requested that a seabird observer be included in the IWC-POWER cruise, however the IWC observer noted that this was difficult due to the capacity of the sighting vessel. The AP-MBM proposed the following topics for projects starting in 2015:

(1) marine climate impacts on MBMs through food web;
(2) marine mammals and seabirds as indicators of temporal and spatial variations of pollutants;
(3) MBMs as a predictive indicator of forage fish; and
(4) MBMs as consumers.

The Committee **thanks** Tamura for attending on its behalf and **agrees** that he or Kato should represent the Committee as an observer at the next PICES meeting.

4.13 Protocol on Specially Protected Areas and Wildlife of the Cartagena Convention for the Wider Caribbean (SPAW)[12]

The report of the IWC observer to SPAW is given as IWC/65/4(2014)/M. At the 5th Meeting of the Scientific and Technical Advisory (STAC), 22 October 2012, Punta Cana, Dominican Republic, the SPAW recommended that:

(1) 'The Secretariat emphasises the activities in support of the Marine Mammal Action Plan, including follow-up to the work and recommendations emanated from implementation of the LifeWeb Project; and
(2) The Secretariat continues to collaborate and to identify synergies, to the extent possible with relevant partners and MEAs and strengthens collaboration with IWC through the possible conclusion of a Memorandum of Cooperation.'

Two training workshops have recently been held, focusing on the forensic detection of human impacts and the response to entangled large whales. These workshops assisted participants in developing improved and safer human impact capabilities and entanglement responses. A further Joint IWC and SPAW/UNEP Workshop to address collisions between marine mammals and ships, with a focus on the wider Caribbean will take place in June 2014 in Panama.

Implementation of the Spain-UNEP LifeWeb project 'Broad-scale Marine Spatial Planning of Mammal Corridors and Protected Areas in Wider Caribbean and Southeast & Northeast Pacific' has led to regional maps and factsheets have been produced for the following issues:

(1) distribution of the 25 marine mammals species that occur regularly in the WCR (24 cetaceans);
(2) species richness;

[11] *http://www.pices.int/.*

[12] *http://www.cep.unep.org/cartagena-convention.*

(3) threats and human impacts faced by marine mammals: pollutions, interactions with fisheries, maritime traffic, etc.; and
(4) existing policies, marine protected areas and governance for the conservation of marine mammals.

All the outputs are available from the SPAW website. Data from the project has led to identification of three priority areas of study for conflicts between marine mammal and human activities. A workshop on transboundary marine mammal management in the wider Caribbean was recently held in Puerto Rico. Proposed scenarios for the three priority areas identified were discussed along with possible mitigation measures and application of marine spatial planning for transboundary management of marine mammals. A similar workshop focusing on Northern South America was held last year.

The Committee **thanks** Carlson for attending on its behalf and **agrees** that she should represent the Committee as an observer at the next SPAW meeting.

4.14 Other organisations

4.14.1 Pacific Regional Environment Programme (SPREP)

Following the 2013 Annual Meeting, the IWC Secretariat was invited to give a presentation about areas of possible cooperation at the annual meeting of the Secretariat of the Pacific Regional Environment Programme (SPREP), in Noumea, New Caledonia, 17-19 September 2013. Since that meeting the two Secretariats have continued to communicate and are working together on two upcoming cooperative projects; (1) SPREP is actively involved in the preparation for the IWC's second workshop on marine debris, which will be held August 5-7 2014, in Honolulu, Hawaii; and (2) IWC technical adviser Mattila, is working with SPREP to co-host an IWC entanglement response training in Tonga.

The Committee **thanks** Mattila for his report and **agrees** that he continue reporting on the activities of SPREP on its behalf.

4.14.1 Regional Convention on Fisheries Cooperation among African States Bordering the Atlantic Ocean (ATLAFCO)

The main objective of ATLAFCO is to foster effective and active cooperation between Member States for conservation and sustainable development of fisheries in the region. ATLAFCO encourages Member States to exchange their experiences in scientific research and promotes coordination between their institutions and the sharing of scientific data on fish stocks. ATLAFCO began cetacean sighting surveys in maritime waters of Member States in order to obtain scientific information on cetaceans, which are top predators in the ecosystem. The first was conducted in Gabonese waters in 2011 and the second in the gulf of Guinea covering the EEZ of Côte d'Ivoire, Ghana, Togo and Benin in 2013. The results are presented as Diallo and Bamy (2013). ATLAFCO will continue cetacean sighting surveys in waters of Member States, where scientific information on cetaceans are relatively insufficient.

The Committee **thanks** Diallo for his report and **agrees** that he should continue reporting on the activities of ATLAFCO on its behalf.

5. REVISED MANAGEMENT PROCEDURE (RMP) – GENERAL ISSUES

The Committee **draws attention** to the fact that the RMP (and AWMP) approach, which was pioneered at the IWC and is now increasingly being used in fisheries management, is of broad relevance to the work of the Committee when examining status and the effects of human-related mortality. Irrespective of whether the *Catch Limit Algorithm* (or a *Strike Limit Algorithm*) itself is used, the modelling framework and approach to dealing with uncertainty are of wide application (Bunnefeld *et al.*, 2011; Dichmont *et al.*, 2013; Punt, 2006). Lessons learned during the RMP *Implementati*ons and *Implementation Reviews* are of value in assessments generally. The Committee **notes** that this approach is now being used for North Pacific gray whales (e.g. see SC/65b/Rep08).

5.1 Use of individual based energetics model

Last year, the Committee recommended that $MSYR_{1+}$=1% be adopted as a pragmatic and precautionary lower bound for use in trials, and that $MSYR_{mat}$=7% be changed to the roughly equivalent $MSYR_{1+}$=4%. However, it recognised that much remains to be learnt regarding MSYR for baleen whales and that the issue of the appropriate range for MSYR should continue to be reviewed as new information becomes available. A workplan was developed to consider the incorporation of the individual based energetics model (IBEM) into the RMP software framework.

SC/65b/RMP03 reported on progress with this work noting that there were no technical difficulties in linking to the existing FORTRAN master program. Results from one set of 100 trials for the MSYR ~ 4% development case showed that the software produced results broadly consistent with those using the standard population models.

The Committee **welcomes** this work which allows it to conduct trials of the RMP where the operating model is spatially- and individual-based. Prior to use of this model by the Committee, the code would need to be validated by the Secretariat.

5.2 Relationship between $MSYR_{mat}$ and $MSYR_{1+}$

SC/65b/RMP04 included results requested last year (IWC, 2014d) which had used the IBEM to examine the relationship between the $MSYR_{1+}$ and $MSYR_{mat}$. The results revealed that the relationships between the 1+ and mature MSY rates are quite different from those derived from the standard Baleen II model, and attributed the difference to the action of density dependence in the IBEM acting on a wide range of demographic parameters. The author of SC/65b/RMP04 concluded that the standard Baleen II model should not be used for inferring the relationship between $MSYR_{1+}$ and $MSYR_{mat}$.

The Committee noted that the energetics-based model is rather complex, with several functional relationships leading to different density-dependent processes. Several qualitative outcomes from the model runs were consistent with results from the stochastic model of Cooke (Cooke *et al.*, 2007) and were *a priori* plausible; at this stage it is not possible to reach conclusions on the quantitative nature of the results. The Committee considered it important to obtain a better understanding of the reasons underlying these emergent properties, including whether the conclusions regarding the

relationship between $MSYR_{mat}$ and $MSYR_{1+}$ were robust to, *inter alia*, species life history.

As discussed fully under item 2.2 of Annex D, the Committee **agrees** that it is desirable to further explore the relationship between $MSYR_{mat}$ and $MSYR_{1+}$ arising out of the IBEM results, and developed a workplan to achieve that. The work is necessary before any conclusions or the need for additional RMP/*CLA*-related trials are considered. This work does not imply a need to change or delay the current *Implementations* of the RMP for North Atlantic minke and fin whales. The Committee established a Steering Group under de la Mare (see Annex D, Items 2.2 and 5) to coordinate intersessional work.

Recognising that the IBEM is just one approach to this issue, the Committee also **encourages** the development/presentation at the 2015 Annual Meeting of alternative models which represent alternative plausible density-dependent processes.

5.3 Finalise the approach for evaluating proposed amendments to the *CLA*

The Committee agreed in 2006 that two steps needed to be completed before the evaluation of the Norwegian proposal to amend the *CLA* could be completed. The first was the review of MSY rates, completed in 2013, and the second was specification of additional trials for testing the *CLA* and amendments thereto and to the RMP. Last year, the Committee re-established a working group under Allison (see Annex D, Items 2.3 and 5) to formulate and run trials related to environmental degradation.

The trials agreed by the intersessional group in which the density-dependence function is modified so that the change in fecundity with density for stocks sizes above *K* are not as extreme as implied by the conventional Pella-Tomlinson model. The results (see Annex D, Appendix 3) suggest that the proposed solution does not lead to results which differ much from those when density-dependence is modelled using the standard Pella-Tomlinson approach.

The Committee thanked Punt and Allison for conducting this work but **agrees** that allowing natural mortality to be density-dependent would provide a more stringent test for the impacts of environmental change. It **recommends** that Allison and Punt include the model of density-dependence in natural mortality in Annex D, Appendix 3 into the common control rule program and provide results of such tests of the *CLA* to the 2015 Annual Meeting.

5.4 Evaluate the Norwegian proposal for amending the *CLA*

Walløe reminded the Committee that Norway had stated that it intended to develop and propose a change to the *CLA* of the RMP at the 2004 meeting (IWC, 2005). Norway proposed a new tuning mechanism for the *CLA* and that the MSYR should refer to the 1+ component of the population (with $MSYR_{1+}$= 1% as the minimum) instead of the mature component. The revised tuning mechanism and some simulation results were presented to the 2006 meeting, and were discussed extensively. The Committee established two working groups then, one of which led to the MSYR review completed in 2013, and the other to specify trials and diagnostic plots for testing amendments to the *CLA*. Revised results (Aldrin and Huseby, 2007) were presented to the Committee in 2007. However, the MSYR review had not been completed so no decision had been made at that time.

The MSYR review was completed last year and it concluded that the lower bound for MSYR in trials would be $MSYR_{1+}$=1%. However, as noted in Item 5.3, some work remains to be completed in regard to trials in which MSYR and *K* change over time.

The Committee **recommends** that Punt and Allison include the variants of the RMP considered by Aldrin and Huseby (2004) in their further analyses. This item has been outstanding for many years and the Committee **confirms** its intention that the evaluation of the Norwegian proposal would be completed at the 2015 Annual Meeting.

5.5 Other computing matters related to the *CLA*

Allison noted that a few minor issues related to how the code for the CLA was integrated into the control program remained outstanding. However, there had been insufficient time during the intersessional period to address these issues. They would be addressed during the current intersessional period, for report to the 2015 Annual Meeting.

5.6 Update 'Requirements and Guidelines for conducting surveys and *Implementations*'

SC/65b/RMP11 had been written in response to a request (and contract) from the Committee to update the Requirements and Guidelines for Conducting Surveys and Analysing Data within the Revised Management Scheme (IWC 2012, hereafter 'the Guidelines'). The specific tasks were to summarise developments in design- and (spatial) model-based abundance estimation since 2004 when the Guidelines were last revised, and to provide suggested text for updates to the Guidelines. SC/65b/RMP11 reviewed the fundamentals of design-based abundance estimation; described new approaches to variance estimation for design-based analysis; considered how the Committee might decide whether the criteria for design-based assessment might be met; suggested some ways to evaluate the adequacy of design-based estimates when the strict criteria are not met; presented a paradigm for (spatial-)model-based abundance estimation, and a checklist of decisions that need to be made when making a spatial abundance estimate; and proposed some updated text for the Guidelines. An important overall conclusion concerned the necessity, when the Committee reviews an abundance estimate for 'acceptability', for thorough descriptions of the design and analysis process, including the rationale for making particular choices.

The Committee **welcomes** this review, recognising the value of updated criteria for evaluating abundance estimates (both design- and model-based) to the full Committee rather than simply the sub-committee on the RMP, since abundance estimates are central to much of its work (see Annex D, Appendix 4). To progress the update of Guidelines (both in an RMP sense and in a wider context) to (1) assist evaluation of design-based estimates of abundance, and (2) accommodate recent (and future) developments in abundance estimation, the Committee **recommends**:

(1) development of a simple-to-use diagnostic software that uses model-based analysis to assist in evaluating design-based estimates that can be applied when design-based criteria are not strictly met;

(2) refinement of the material in SC/65b/RMP11, both in the explanatory background text and in the proposed Guidelines, on specific issues (see Annex D);
(3) hold a workshop with two objectives:
   (a) to test the proposed new Guidelines against several test cases of model-based abundance estimates made specifically for and during the workshop;
   (b) to demonstrate and discuss the proposed diagnostic software with a wider Committee audience involved in basic line-transect abundance estimation.

Part (a), which would involve only a small number of analysts familiar with spatial modelling, could be held as a pre-meeting next year, and part (b) could follow on at the start of the Committee meeting. Updates to the Guidelines could then be considered during the full Committee meeting.

An appreciable amount of intersessional work would be required, particularly for item (1) and preparation for item (3). The Committee appointed at Steering Group under Bravington (see Annex D, items 2.6 and 5) to develop an agenda for the workshop and facilitate preparations.

5.7 Imbalanced sex ratio in incidental catches

Last year, the Committee requested further consideration of the generic issue of how to deal with imbalanced sex ratios in incidental catches under the RMP. The Committee **agrees** that the current specifications for the RMP are sufficient but it **recommends** that annotation 26(a) to the RMP be adjusted to improved clarity as follows:

'Any subtraction of incidental catches from the catch limits output from the RMP as above would take place at the end of this process at the Small Area level, and separately at the Medium/Large Area level if Catch-capping was applied. However, as this is an RMS rather than an RMP feature, no wording to cover this is proposed here. Since imbalanced sex ratios in incidental catches have been taken into account in (iv) above, as this computation is with respect to the total catch, there is no need for further adjustment for this factor in this subtraction.'

5.8 Workplan

The Committee **notes** that the iterative nature of its work means that it is challenging to determine the exact nature of its work plan beyond a single year. Detailed work plans for before and during the 2015 meeting, and before and during the 2016 meeting, are given in Annex D, item 2.8 although there is some uncertainty about the latter. Prioritised budget requests are detailed in Annex D, item 6. The Committee budget is discussed under item 26. An overview of the workplan is given as Table 2.

6. RMP –IMPLEMENTATION-RELATED MATTERS

6.1 North Pacific common minke whales (additional work from completed *Implementation Review*)

6.1.1 Review of intersessional work

Last year, the *Implementation* for the North Pacific common minke whales identified six RMP variants which were 'acceptable without research' and four RMP variants which were candidates for being 'acceptable with research'. The latter are variants that lead to higher catches in some specific sub-areas in this instance. RMP variants which are 'acceptable with research' need to have a research programme that the Committee agrees has a good chance of determining within ten years whether trials on which performance was not 'acceptable' should have been assigned low plausibility. The Committee established an Advisory Group under Butterworth (see Annex D, items 3.1.1 and 5) to provide feedback to those developing research programmes during the intersessional period if requested. Pastene reported that Japan had not developed a research programme to date.

The Committee re-**establishes** the Advisory Group to provide advice to those developing research programmes if required.

6.1.2 Survey plans

SC/65a/RMP02 presented a research plan for a sighting survey for common minke whales in the Sea of Okhotsk, including the Russian EEZ, in summer 2014. It was revised from that presented last year owing to logistical and permit issues. The primary aim is now to obtain biopsy samples in one sub-area rather than obtaining abundance estimates for the whole of the Okhotsk Sea. A joint Russian-Japanese sighting survey in the Okhotsk Sea will occur in summer 2015 (see SC/65b/RMP02).

The Committee noted the revised research plan and **welcomes** the plan for a joint Russian-Japanese survey for common minke whales in Okhotsk Sea. It looks forward to seeing a detailed research plan for the latter survey at the 2015 Annual Meeting. The Committee appointed Miyashita to provide oversight on its behalf.

Table 2

Overview of work on RMP general matters 2015-2016

Topic	Intersessional 2014-15	SC66a 2015	Intersessional 2014-15	SC66b 2015
Evaluate energetics based model	For details see Annex D, item 2.2	Review progress	Continue work	Review results
Evaluate *CLA* performance when density-dependence acts upon natural mortality	For details see Annex D, item 2.3 and 2.4	Review results	If necessary	Complete if not done at SC66a
Other *CLA* related tasks	For details see Annex D, item 2.5		If necessary	As above
Diagnostic software to assist in evaluating design-based estimates	For details see Annex D, item 2.6	Hold pre-meeting	If necessary	As above
Evaluate Norwegian *CLA* proposal	For details see Annex D, item 2.4	Review results	If necessary	As above
Refine workplan		In light of progress		

6.1.3 Recommendations
The Committee:

(a) again **strongly requests** that the Commission **urges** the Government of the Russian Federation to give permission for the survey to take place in its EEZ throughout sub-area 12, noting that there are often major difficulties making use of abundance estimates for only part of a sub-area; and
(b) **recommends** that future surveys be more synoptic, as this will better facilitate their use in the RMP.

6.2 North Atlantic fin whales (*Implementation Review*)
6.2.1 Report of intersessional workshop
Donovan introduced SC/65b/Rep07, the report of the technical intersessional Workshop on the *Implementation Review* for North Atlantic fin whales, held in Copenhagen in January 2014. The Workshop was primarily technical, to finalise trial specifications and make progress towards conditioning the trials.

The Workshop reviewed the progress made since SC/65a (see Annex D, item 3.2.1) and made several additional changes to the code for the operating model. Given the complexity of the trials, it had not been possible to complete conditioning successfully by the end of the workshop.

The Workshop developed a workplan with the objective of finishing the *Implementation Review* at the 2015 Annual Meeting, and established a Steering Group under Elvarsson (see Annex D, items 3.2.1 and 5) to assist with implementing the workplan.

The Committee **thanks** Donovan for chairing the workshop and the participants for their work during the workshop and subsequently, in particularly Elvarsson. In reviewing progress made since, it noted that further changes to the optimisation method had been implemented and the density-dependent dispersal model had been developed and included in the control program. Progress had been made assembling data and in updating the catch series to include incidental catches off Eastern Canada. In addition, Elvarsson had conditioned base-case trials for eight stock-structure hypotheses (Annex D, item 3.2.1).

6.2.2 Consideration of available results
Elvarsson provided an overview of progress on conditioning the set of trials identified during the workshop. Many of the trials can now be conditioned successfully, but some problems remain (see Annex D, item 3.2.2).

The Committee received two papers that may be useful when assigning plausibility ranks to the *Implementation Simulation Trials* during the 2015 Annual Meeting. SC/65b/RMP06 presented cetacean sightings and effort during winter fishery (mainly capelin) surveys conducted during 1991-1995, 2003 and 2009 around Iceland, while SC/65b/RMP08 investigated differences between the first and second or later fin whales taken per catching trip.

6.2.3 Recommendations
The Committee **recommends** that a workshop takes place in early 2015 to ensure that it is in a position to complete the *Implementation Review* at the 2016 Annual Meeting, if not earlier. A Steering Group was appointed under Donovan (see Annex D, Items 3.2.2 and 5). Holding this meeting back to back with the workshop proposed under Item 6.3 will reduce costs.

6.3 North Atlantic common minke whales *(Implementation Review*)
The *Implementation Review* for North Atlantic minke whales started with an AWMP/RMP joint workshop on stock structure in April 2014 (SC/65b/Rep04), and continued with a pre-meeting of a working group whose report is given as Annex D, Appendix 5.

The Working Group built upon the excellent progress made at the joint Workshop where a major review of data including comprehensive new genetic information led to an agreed set of stock structure hypotheses. The Working group built upon this to evaluate abundance estimates, biological and operational parameters, removals data, and trials structure. The preliminary results from the sighting surveys suggest that the abundance in the E *Medium Area* has not changed from the last six-year period, but that there has been a decrease in abundance in the C *Medium Area*. It developed a workplan with the objective of completing the *Implementation Review* at the 2015 Annual Meeting (Annex D, Appendix 5, item 7).

6.3.3 Recommendations
The Committee **endorses** the report of the Working Group and **adopts** its work plan. It **thanks** Donovan for chairing the pre-meeting and the participants for their work. It established a Steering Group under Walløe (see Annex D, item 3.3) to guide the intersessional work that will include a technical intersessional workshop.

6.4 North Atlantic sei whales
6.4.1 Pre-Implementation Assessment
The North Atlantic sei whale Steering Group (see IWC 2014, Item 6.4) proposed that the feasibility of a pre-Implementation assessment be investigated further during the intersessional period by a Correspondence Group chaired by Víkingsson (see Annex D Item 3.4.1) and with Terms of Reference to finalise the compilation of the available data and develop a draft set of possible stock structure hypotheses for consideration during the 2015 Annual Meeting. It **notes** that initiation of an *Implementation* follows only from a decision by the Commission.

As for other North Atlantic balaenopterids, genetic analyses conducted so far for sei whales indicate low levels of population genetic structure. There is value in conducting further genetic analyses to aid in the formulation of plausible stock hypotheses for North Atlantic sei whales.

6.4.2 Recommendations
To maximise the amount of genetic data from the existing set of samples, the Committee **recommends** the generation and analysis of ddRAD-based SNP genotypes from the available tissue samples. In addition, it **agrees** that information on the distribution of sei whales from catch records be summarised by the intersessional group.

6.5 Western North Pacific Bryde's whales
6.5.1 Prepare for 2016 Implementation Review
The *Implementation Review* for Western North Pacific Bryde's whales was originally scheduled for 2013. However, in 2012, the Committee postponed the *Review* until 2016 to allow additional sightings and genetics data to be available and analysed (IWC, 2013a). Miyashita, on behalf of Japan, requested that the *Implementation Review* be deferred to 2017 for reasons detailed in Annex D, item 3.5.1.

Table 3

Overview of the work plan as it relates to *Implementations.*

Species / area	Intersessional 2014-15	SC66a 2015	Intersessional 2015-16	SC66b 2016
Common minke whales (WNP)	Possible work by Advisory Group (if requested)	Review hybrid RMP variants & research proposals if submitted; agree abundance estimates for use in actual applications of the RMP		Review hybrid RMP variants & research proposals; agree abundance estimates for use in actual applications of the RMP
Common minke whales (NA)	Assemble data; finalise trial specifications; validate code and condition; hold intersessional workshop	Assign plausibility to trials; review trial results; complete *Implementation Review?*	Run trials and hold intersessional workshop (if needed)	Complete *Implementation Review* (if needed)
Fin whales (NA)	Assemble data; validate code; Hold intersessional workshop	Review trial results; Assign plausibility; finish *Implementation Review?*	Run trials and hold intersessional workshop (if needed)	Complete *Implementation Review* (if needed)
Sei whales (NA)	Summarise data on stock structure and develop hypotheses	Decide to initiate or not pre-implementation assessment		Pre-implementation assessment (if agreed at SC66a)
Bryde's whale (WNP)		Review new information		Review new information

In discussion, it was noted that considerable new data were likely to be available by 2017. It was also noted that since no new abundance estimates had been adopted by the Committee, application of the RMP would lead to use of the 'phase out rule'.

6.5.2 Recommendations

The Committee **agrees** that the next *Implementation Review* be deferred to 2017, and that it be a 'full review' such as those currently being undertaken for North Atlantic minke and fin whales. Since the *Implementation Reviews* for North Atlantic minke and fin whales will not both be completed before the 2016 Annual Meeting – it is infeasible for the Committee to initiate another 'full' *Implementation Review* until these two reviews are completed.

6.6 Updated table of abundance

Allison advised that the 2001 estimate of abundance for sub-areas CG+CIP for the North Atlantic minke whales of 23,592 was an error and the correct estimate is 10,740. The estimate had been used in the applications of the RMP, which took place in 2010 (IWC, 2011a).

Annex D, Appendix 6 lists updated abundance estimates for North Atlantic minke and fin whales and North Pacific minke and Bryde's' whales. Allison advised that review of these estimates is continuing and Annex D, Appendix 6 will be updated with any new information.

6.7 Workplan

Detailed Work Plans, both for 2015 and 2016, are given in Annex D, Item 3.7, and prioritised Budget Requests are detailed in Annex D, item 6 and Appendix 7. An overview of the workplan is given in Table 3.

7. NON-DELIBERATE HUMAN-INDUCED MORTALITY OF LARGE WHALES

The report of the Working Group on Non-deliberate Human-induced Mortality of Large Whales is given as Annex J. This work originally arose out of the need for information on such mortality for use in the RMP but has now broadened in scope, amongst other things providing advice to the Commission working groups on such matters.

7.1 Entanglement of large whales

7.1.1 Estimation of rates of entanglement, risks of entanglement and mortality

Online tools are now available to allow data entered into National Progress Reports to be queried. In reviewing the output from such queries it was noted that only a small proportion of countries submit bycatch data and it is important to distinguish no report from no data. The Committee **recommends** that member nations fill out the relevant fields appropriately and provide information on efforts to estimate total bycatch of large whales. Some discrepancies in field codes were also noted with reports of ship strikes.

The Secretariat's technical adviser, Mattila, has provided entanglement response training for 156 individuals from 14 different countries in the past year. A result of this work is that detailed data on large whale entanglements are being brought to the Committee. The IWC's expert group on entanglement will discuss the development of a global database at its next meeting, currently planned for December 2014. The Commission has recommended that the expert group develop this database and that it is hosted by the IWC.

Entanglement injuries have been noted for decades during post-mortem examinations of harvested bowhead whales, raising concerns about potential interactions with pot fisheries for cod and blue king crab (Citta *et al.*, 2013). Young whales showed less scarring than older animals and this was attributed to a gradual accumulation in scars from entanglement as whales grow older. Although the spatial distribution of 21 satellite tagged bowhead whales partially overlapped fishery areas, there was no temporal overlap suggesting that lost gear was the most likely source of entanglement. The finding of a spatial but not temporal overlap suggested that this type of analysis might be helpful in the Committee's work on determining entanglement risk from debris versus actively fished gear.

A sperm whale calf and female pair were reported entangled in a mass of ropes, nets and plastic cans off Guadeloupe in November 2013 (SC/65b/HIM02). The material was suggestive of local artisanal Fish Aggregating Devices which

would represent the first data on large whale entanglement in this type of fishing gear.

Of the 63 baleen whale entanglement records off Western Australia from 1982-2010, humpback whales accounted for 56. Almost half of entanglements occurred in rock lobster fishing gear. There is an upward trend in entanglements reported between 1990 and 2010 in this fishery despite a reduction in fishing effort (Groom and Coughran, 2012). The numbers of entanglements have increased significantly since the fishery went from a seasonal to year-round. Fisheries and conservation agencies have responded by developing cooperative relationships and protocols to reduce entanglement risk. The Committee noted that other countries have been investigating and attempting to mitigate whale entanglements in similar pot fishery gear but currently the most certain way to avoid entanglement is to minimise the amount of entangling materials in the water column used by the whales. One solution for the Western Australian rock lobster fishery would be for the fishery to return to a seasonal one, avoiding gear in the water during whale migration. The Committee **recommends** that a careful monitoring scheme is enacted prior to any modifications of the fishery, so that the effectiveness of any changes can be determined. This might include a scar or wound monitoring programme. The Committee **recommends** that the relevant authorities in Australia contact Kristy Long (co-ordinator of the USA Take Reduction Teams) and Robbins, who is using monitoring of the annual accumulation of raw wounds on both humpback and right whales in the region affected by the USA lobster fishery.

The Committee **recommends** that Australia reports on any potential solutions that it tests as these could have beneficial global applications. In addition, recognising the global nature of the problem and the Commission's recommendation to prevent entanglement, the Committee **strongly encourages** members to bring forward papers on the effectiveness of various mitigation measures to future meetings, and that a dynamic matrix or table of various potential measures and their effectiveness be maintained.

7.1.2 Collaboration with Commission's Whale Killing Methods and Associated Animal Welfare Issues Working Group including consideration of mitigation measures and future work

The aim of the IWC Workshop on Euthanasia Protocols to Optimise Welfare Concerns for Stranded Cetaceans held in 2013 was to bring together international experts to inform guidelines on achieving the best welfare outcome when cetaceans strand (IWC/65b/Forinfo42). The Workshop recommended that where chemical euthanasia methods were used additional studies or evaluations on the persistence and relay toxicity of chemicals used should be undertaken. In particular, at a minimum the injection site should be removed and disposed of, and when barbiturates are used, the whole carcass must be removed from predation possibilities. The Workshop recognised the effectiveness of penthrite grenades and encourages the development of a darting gun delivery device that may be suitable for use by trained personnel in specific large whale stranding situations. The addition of further fields into the national progress report would allow evaluation of techniques for euthanasia and disposal of live stranded whales. The workshop recommended euthanasia of injured cetaceans at sea and the issues related to mass strandings should be considered for future workshops. Finally, the Workshop recommended that IWC member nations refine existing or develop new incident response protocols based on the principles and guidelines in the workshop report. The Committee **endorses** these recommendations, including those to refine the data requested in National Progress Reports.

7.2 Ship strikes

7.2.1 Progress on the global database

The ongoing development of the IWC ship strike database requires data gathering, communication with potential data providers and data management. The second year of work carried out by the data coordinators resulted in a variety of outreach actions, with a large number of contacts being established, and the drafting of a series of documents, including guidance documents for sailing and cruise ships. In May 2014, the database held a total of 1,221 incidents. A downloadable summary is available on the IWC website[13].The Committee **recommends** that the important work of the data coordinators continue, both for its value to the Commission's mitigation efforts, contribution to a better understanding of the factors that relate to risk (such as ship type and speed), as well as estimates of ship strike mortalities.

7.2.2 Estimating rates of ship strikes, risk of ship strikes and mortality

Vessel strike risk for bowhead and gray whales in the Bering Strait region has been assessed using Automatic Identification System (AIS) data combined with data on habitat use and satellite telemetry data. The recent IWC workshop on the Arctic discussed the possibility of seeking Particularly Sensitive Sea Area status for some high risk areas of bowhead distribution through the International Maritime Organisation (IMO). It was noted that the IMO was now considering known high density whale areas in relationship to voyage planning within the development of a Polar Code. Voyage planning in relation to high density areas will be further discussed at the ship strike workshop in Panama, June 2014. Other examples of mapping the co-occurrence of whales and shipping to assess risk included data from satellite tagged humpback whales in the eastern South Atlantic, and from Arabian Sea humpback whales off the coast of Oman. Preliminary findings showed all three whales off Oman passed through the main approach channels to major international shipping ports.

A simulation study was conducted to estimate the impact of ship strikes on the small Magellan Strait population of humpback whales (SC/65b/SH18). A single collision every three years randomly distributed among sexes and age classes would result in the median population growth shifting from stable to slightly decreasing. The concentrated shipping traffic through the area and the relatively small size of the population suggests potentially high vulnerability to ship strikes. Given the estimated size of the population (<100), the low estimated survival rate and the restricted nature of the Straits of Magellan, the Committee **expresses concern** over this situation and **agrees** that mitigation measures may be needed. While the Committee **agrees** that further studies of shipping and whale density are needed, the confined waters

[13] http://iwc.int/ship-strikes

allow little scope for routing options and there may be a need to consider speed limits, if feasible.

AIS data has been used in cases of known ship strikes where a vessel has entered port with a carcass on the bow in an attempt to re-trace a ship's path to determine if any abrupt change in speed could indicate where the collision may have occurred. The Committee **recommends** that NOAA collaborate with the IWC to further test this application of AIS by attempting to retrace the routes and speeds of relevant ship strikes in the IWC ship strike database.

The probability of whale-vessel collisions in the Hawaiian breeding grounds for humpback whales was investigated by systematic transects recording surprise encounters and near misses as proxies for collisions with vessels. The rate of surprise encounters was found to increase with vessel speed. It was noted that there is not currently a standard definition of a 'near miss' which will depend on the size and manoeuvrability of the vessel involved. The Committee **encourages** work to develop definitions of a 'near miss' which could be considered at next year's meeting. Noting that the suggested speed of 15knots to reduce risk was greater than the 10-12knots in some other areas, the Committee **agrees** that the size and type of vessel associated with any speed recommendations needs to be explicit; otherwise speed recommendations might be used inappropriately.

Literature on ship strike records around Japan was reviewed to identify possible cases that could be included in the IWC database (SC/65b/HIM03). Twelve incidents between 1978 and 2012 were identified all of which involved jetfoil vessels. In two thirds of the incidents reviewed, pieces of meat or blubber were found suggesting potential for DNA analysis to identify species in future cases if samples are collected and appropriately preserved.

The Committee has previously noted an urgent need for long-term monitoring of the blue whale population in Sri Lankan waters and elsewhere in the northern Indian Ocean because of the potential for population impacts from ship strikes (IWC, 2014c). In 2012, two blue whales were struck and killed off Sri Lanka within a 12-day period (De Vos *et al.*, 2013) but it was noted that the observed mortality was an unknown fraction of actual mortality. Consequently, ship strikes could limit the recovery of this endangered subspecies, particularly given the projected doubling of large vessel traffic in the next 10-20 years (Southall, 2005). Surveys off the southern coast of Sri Lanka were conducted during February to April 2014 to investigate the distribution patterns of blue whales in relation to current shipping lanes and further offshore. The highest densities of blue whales were observed in the current shipping lanes, peaking at an average of 0.12 individuals km^{-2} in the westbound shipping lane. These high densities of whales combined with one of the busiest shipping routes in the world suggest a severe risk of ship strikes. The results suggest that the blue whale distribution is related to bathymetry and that observed distribution patterns may be consistent over time. Hence moving the current Traffic Separation Scheme further offshore would likely substantially reduce risk of collisions with blue whales. The Committee **agrees** that further surveys of blue whale distribution in the area at different times of year would provide important data. Given that Sri Lanka is not a member of the IWC, but there has been a dialogue between IWC and the Government of Sri Lanka on the issue, the Committee **recommends** that the IWC should begin to discuss possible mitigation measures with the relevant authorities and stakeholders in the area. The Committee **requests** that the Secretariat send a letter to the Sri Lankan Government, with an update on the information from its discussion of this topic and ways in which the Committee or the IWC Ship Strikes Working Group may assist. In addition, it **recommends** that a representative from Sri Lanka be invited to relevant IWC meetings and workshops.

Information was provided on an ongoing project between the University of California, Santa Cruz (De Vos *et al.*, 2013) and Southwest Fisheries Science Center (Redfern *et al.*, 2013) on reducing the risk of ship strikes to blue whales in Sri Lankan waters. The project will attempt to assess ship-strike risk to this population including (i) developing habitat models that can be used to predict blue whale distributions off Sri Lanka and validating predictions using available data from the region; (ii) re-examination of strandings records for baleen whales to confirm data and any evidence of ship strikes; (iii) use available shipping data to characterise traffic patterns; (iv) evaluate strategies to mitigate risk by overlaying predicted blue whale distributions with alternative shipping lanes (Redfern *et al.*, 2013); (v) expand the sightings data available for this region, especially in the context of the two monsoon periods; and (vi) work with industry and economists to determine short-term economic costs of moving shipping lanes.

A dead male blue whale stranded in Puerto Montt, southern Chile in February 2014, with its right flipper and left mandible broken and the bone exposed (SC/65b/HIM08). This evidence strongly suggests that this whale was hit by a large vessel. The Committee **agrees** that the evidence was most consistent with the authors' conclusions that one of the two recently arrived cruise ships had likely brought the carcass into the harbour on its bow. The Chilean Navy does provide information about whales and collision risk to vessels in the area but an IWC guidance document for cruise ships would be very useful support to these outreach efforts. The Committee **endorses** the suggestion that the reporting system needs to be expanded to collect additional details on vessel strikes in Chile, especially in the inland passage region, and that mitigation measures may be needed. Similar to the Straits of Magellan, the confined waters allow little scope for routing options and there may be a need to consider speed limits.

The Hellenic Trench southwest of Greece is a known area of high sperm whale density which coincides with major shipping routes. This area had been identified as potentially high risk during the IWC/ACCOBAMS workshop in 2010 (IWC, 2011a). An analysis of twelve seasons of visual and acoustic observations of sperm whales identified high risk areas where whales were exposed to very high shipping densities. The potential for small changes in shipping routes to dramatically reduce risk in these high risk areas suggest considerable scope for effective mitigation. Given the evidence for a high incidence of ship strikes from stranded sperm whales the Committee **recommends** that a dialogue should be initiated with shipping regulators and interests in the area, perhaps in conjunction with ACCOBAMS. Leaper will work with the Secretariat to establish contacts. However, given the possibility of fin whales occurring further offshore of the current shipping routes, it was suggested that there

Table 4

Overview of the work plan as it relates to non-deliberate human-induced mortality.

Species / area	SC66a 2015	SC66b 2016
Reviews of mitigation measures for ship strikes and entanglement	Review information collated intersessionally (see Annex J, item 9) and produce simple summary information and advice table	Finalise if not completed at SC66a
Entanglement (annual reviews)	Continue to examine new information on rates, risks and mortality and provide advice	Continue to examine new information
Entanglement (support Commission initiatives)	Communication of key issues; advice in relation to specific CMPs; review recommendations from December 2014 workshop, incl. database; assist in work with other organisations	Continue to support
Ship strikes (annual reviews)	Continue to examine new information on rates, risks and mortality and provide advice	Continue to examine new information
Ship strikes (database)	Work with co-ordinators and Secretariat to update and improve database, including review process and criteria	Continue
Ship strikes (support Commission initiatives)	Communication of key issues; advice in relation to specific CMPs; review recommendations from June 2014 workshop; assist in work with other organisations	Continue to support

should be further study of those deeper waters prior to recommending that shipping move offshore.

The efficacy of mandatory 10 knot speed restrictions in high risk areas for North Atlantic right whales has been evaluated by Laist *et al.* (2014). The results indicated a statistically significant reduction in right whale ship strikes in Seasonal Management Areas (SMAs) where speed limits were imposed, suggesting that these have been effective. Noting previous recommendations regarding reducing anthropogenic mortality to North Atlantic right whales (e.g. IWC, 2011a), the Committee **endorses** the recommendations in the paper for extension to the SMAs to cover a greater portion of vessel tracks across core migratory areas.

7.2.3 Collaboration with the Commission's Ship Strikes Working Group including consideration of mitigation measures and future work

Collisions between sailing vessels and cetaceans have been reported for a number of species, and this appears to be an increasing problem (Ritter, 2012). Many of these collisions have caused serious damage to the vessel or even vessel loss, as well as and serious or fatal injury to the whale. A draft guidance document was developed so as to provide information to sailors and offshore race organisers. A similar draft guidance document for reducing collisions with cruise ships was also reviewed. Both guidance documents contain information on relevant mitigation measures currently in place, as well as educational resources and existing reporting tools. It is foreseen that these documents will be discussed at the upcoming joint UNEP-CEP-SPAW-IWC workshop on ship strikes in Panama in June and then be brought to the attention of the IMO. The Committee **recommends** that similar guidance be developed for other classes of vessels where there may be specific issues to that type of vessel not covered by the general IMO guidance on reducing ship strikes.

7.3 Marine debris

Aspects of this issue are discussed under Item 12.6.1.

7.4 Other issues including mortality from acoustic sources

Aspects of this issue are discussed under Item 12.4.

7.5 Workplan

The workplan includes a planned review of mitigation measures for both ship strikes and entanglements. This should lead to a simple summary table that would provide a useful communication tool. Such a table might be of particular value to the Secretariat in reaching out to other organisations.

The Committee **welcomes** a proposal for a workshop on preventing the entanglement of large whales in fishing gear to be held in 2016 noting that advice for preventing entanglements would be relevant to many countries and that this would best be achieved by collaboration with fishers, managers, gear manufacturers and scientists.

The Committee's budget proposal is discussed under Item 26. The detailed workplan is given in Annex J, item 9. A simple overview is given as Table 4.

8. ABORIGINAL SUBSISTENCE WHALING MANAGEMENT PROCEDURE (AWMP)

This item continues to be discussed as a result of Resolution 1994-4 of the Commission (IWC, 1995). The report of the Standing Working Group (SWG) on the development of an aboriginal whaling management procedure (AWMP) is given as Annex E. The Committee's deliberations, as reported below, are largely a summary of that Annex, and the interested reader is referred to it for a more detailed discussion. The primary issues at this year's meeting comprised: (1) developing *SLA*s (*Strike Limit Algorithms*) and providing management advice for Greenlandic hunts, with an initial focus on bowhead and humpback whales; and (2) providing management advice for the Greenland hunts and the humpback whale fishery of St. Vincent and The Grenadines (see Item 9). Considerable progress on item (1) was made as a result of an AWMP intersessional workshop (SC/65b/Rep06), a joint AWMP/RMP intersessional workshop (SC/65b/Rep04) and the AWMP Developers' Fund.

The Committee **notes** that the approach used by the SWG (and the sub-committee on the RMP) is of broad relevance to the work of the Committee when examining status and the effects of human-related mortality. The modelling framework and approach to dealing with uncertainty is of wide application, for example when assessing the effects of bycatch in fishing gear or ship strikes. This approach is now being used for North Pacific gray whales (SC/65b/Rep08).

8.1 Progress on *SLA* development for the Greenland hunts

In Greenland, a multispecies hunt occurs and the expressed need for Greenland is for 670 tonnes of edible products from large whales for West Greenland; this involves catches of common minke, fin, humpback and bowhead whales. The flexibility among species is important to the hunters and satisfying subsistence need to the extent possible is an important component of management. For a number of reasons, primarily related to stock structure issues, development of *SLA*s for some Greenland aboriginal hunts (especially for common minke and fin whales) is more complex than previous *Implementations* for stocks subject to aboriginal subsistence whaling. The Committee endorsed an interim safe approach to setting catch limits for the Greenland hunts in 2008 (IWC, 2009a), noting that this should be considered valid for two blocks i.e. the target will be for agreed and validated *SLA*s, at least by species, for the 2018 Annual Meeting at the latest.

The Committee has recognised that in a multi-species fishery, hunters would like to have some flexibility across species in terms of meeting the overall need expressed in terms of edible products. It has agreed that the inclusion of such flexibility across a series of interlinked *SLAs* is complex (e.g. IWC, 2011b). The Committee has therefore agreed that this aspect only be considered after single species *SLA*s have been developed and adopted.

In accordance with the Workplan developed last year, the SWG on the AWMP made considerable intersessional progress, in particular through three intersessional workshops, one of which was a dedicated AWMP workshop with a focus on finalising the trial structure for the bowhead and humpback whale hunts of Greenland (SC/65b/Rep06); the second was a joint AWMP/RMP workshop on the stock structure of common minke whales in the North Atlantic (SC/65b/Rep04) and the third was an RMP workshop focussing on fin whales for which the operating model discussions were relevant (SC/65b/Rep07).

8.1.1 Development of an SLA for the bowhead whale hunt off West Greenland

8.1.1.1 DATASETS, TRIAL STRUCTURE AND CONDITIONING

An important component of the intersessional Workshop was the finalisation of the datasets to be used in the trials. The question of stock structure had been extensively discussed last year (IWC, 2014c). Although the Committee's current working hypothesis is a single Baffin Bay-Davis Strait stock, pending the availability of some genetic analyses, the Committee had agreed that the possibility that there are two stocks present in the overall area, (with the second being the Foxe Basin-Hudson Strait stock) could not be ruled out (e.g. see IWC, 2009b). The Committee had therefore agreed to

'proceed first on a conservative basis that assumed that the absolute abundance of bowhead whales on the West Greenland wintering area would be informed by abundance estimates from data for that region only (see below). Only if such an SLA proved unable to meet need would abundance estimate information and stock structure considerations from the wider area be taken into account.'

With respect to abundance estimates, two new abundance estimates for West Greenland were discussed (see item 3.1 of SC/65b/Rep06). The Committee **endorses** the agreement of the Workshop that:

(1) the mark-recapture abundance estimate of 1,274 (CV=0.12) constituted the best available estimate of abundance for the number of whales visiting West Greenland;
(2) given the present operating model, it was appropriate for this *Implementation* to continue to use (and project into the future), sighting survey estimates – determining an approach to use mark-recapture estimates should however be undertaken in the future (this is a major task);
(3) conditioning would be based therefore on (a) the fully-corrected 2012 sighting survey abundance estimate of 744 (CV=0.34, 95% CI: 357-1,461); and (b) a comparable estimate for the 2006 survey of 1,103 (CV0.47). See Annex E of SC/65b/Rep06 to see how this comparable estimate was obtained.

With respect to removals, considerable work was undertaken to compile a complete list of direct and incidental catches and to discuss how Canadian catches should be incorporated into the trial structure (item 3.2 of SC/65b/Rep06). Greenland indicated that the need envelope that increased strikes to 15 over the 100-year period should be removed.

The Committee **endorses** the final trial structure given in Annex D of SC/65b/Rep06. This provides *inter alia* details on the population model, conditioning, trials, removals, need envelopes and abundance.

Factors considered within the trials are summarised in Table 5 and the *Evaluation Trials* are given in Table 6; the *Robustness Trials* can be found in SC/65b/Rep06 (Annex D, table 6). The conditioning of the operating models was conducted intersessionally. The SWG reviewed the conditioning by examining the diagnostic plots in the usual manner and agreed that conditioning had been achieved successfully except for one trial. The Committee **endorses** this view.

8.1.1.2 CANDIDATE *SLA*S

In SC/65b/AWMP/03, Brandão and Butterworth presented initial results for four potential *SLA*s.

(1) the 'Interim *SLA*' agreed by the Committee in 2008 (IWC, 2009b) which is based on the most recent estimate of abundance;
(2) a weighted-average 'Interim *SLA*' which uses all abundance estimates, but earlier abundance estimates are downweighted compared to more recent ones.
(3) and (4) were variants of the weighted-average interim *SLA* that apply an adjustment to the multiplier of the abundance estimate in the interim *SLA* that depends on the trend of the abundance indices. This allows for additional reduction of the *Strike Limit* if abundance shows a reasonably precise downward trend. The two *SLA*s differ in the values for the control parameters. The *SLAs* can thus provide either a 'large' or 'lesser' change in depletion compared to the weighted-average *SLA* so that the resource is not reduced as much by strikes if MSYR is low.

The authors noted that although the weighted-average *SLA* performs well in terms of need satisfaction, it performs poorly for some 1% $MSYR_{1+}$ trials in terms of conservation; improvement in terms of relative increase in population size with the variants comes at the expense of need satisfaction. This trade-off also occurs for trials with a higher $MSYR_{1+}$.

Table 5

Summary of factors tested in the trials

Factors	Levels (Reference levels shown bold)	
	Humpback whales	Bowhead whales
MSYR $_{1+}$	1%, 3%, **5%**, 7%	1%, **2.5%,** 4%
$MSYL_{1+}$	0.6	**0.6**, 0.8
Time dependence in *K* *	Constant, Halve linearly over 100yr	
Time dependence in natural mortality, *M* *	Constant, Double linearly over 100yr	
Episodic events *	None; 3 events occur between yrs 1-75 (with at least 2 in yrs 1-50) in which 20% of the animals die; Events occur every 5 years in which 5% of the animals die	
Need envelope	A: 10, 15, 20; 20 thereafter B: 10, 15, 20; 20->40 over years 17-100 C: 10, 15, 20; 20->60 over years 17-100 D: 20, 25, 30; 30->50 over years 17-100	A: 2, 3, 5; 5 thereafter B: 2, 3, 5; 5 -> 10 over years 17-100
Future Canadian catches	N/A	A: 5_constant over 100 years B: 2-> 8 over 100 years D: 2 constant over 100 years
Survey frequency	5 yr, **10 yr**, 15 yr	
Historic survey bias	0.8, **1.0**, 1.2	0.5, **1.0**
First year of projection, τ	1960	1940
Alternative Priors	S_{1+} ~ U[0.9, 0.99]; f_{max} ~ U[0.4, 0.6]; a_m ~ U[5, 12]	N/A
Strategic surveys	Extra survey if a survey estimate is less than half of the previous survey estimate	
Asymmetric environmental stochasticity	$\tilde{\rho}_f$ = **0.320**	
Depletion	Depletion = 0.3 Depletion = 0.15/ 0.6	

*Effects of these factors begin in year 2013 (i.e. at start of management). The adult survival rate is adjusted so that if catches were zero, then the average population size during years 250-500 equals the carrying capacity. Note: for some biological parameters and levels of episodic events, it may not be possible to find an adult survival rate which satisfies this requirement.

Table 6

Bowhead whale *Evaluation Trials* (each conducted conditioning to the estimate of abundance for West Greenland, treating this as absolute abundance). Values given in bold type show differences from the base trial

Trial	Description	$MSYR_{1+}$	Need Scenario	Survey freq.	Canadian Catches	Historic Survey Bias
1A	$MSYR_{1+}$ = 2.5%	2.5%	A, B	10	A	1
1B	$MSYR_{1+}$ = 1%	1%	A, B	10	A	1
1C	$MSYR_{1+}$ = 4% (and $MSYL_{1+}$=0.8)	4%	A, B	10	A	1
2A	5 year surveys	2.5%	A, B	5	A	1
2B	5 year surveys; $MSYR_{1+}$ =1%	1%	A, B	5	A	1
3A	15 year surveys	2.5%	A, B	15	A	1
3B	15 year surveys; $MSYR_{1+}$ =1%	1%	A, B	15	A	1
4A	Survey bias = 0.5	2.5%	A, B	10	A	0.5
4B	Survey bias = 0.5; $MSYR_{1+}$ =1%	1%	A, B	10	A	0.5
5A	3 episodic events	2.5%	A, B	10	A	1
5B	3 episodic events; $MSYR_{1+}$ =1%	1%	A, B	10	A	1
6A	Stochastic events every 5 years	2.5%	A, B	10	A	1
6B	Stochastic events every 5 years; $MSYR_{1+}$ = 1%	1%	A, B	10	A	1
7A	Alternative future Canadian catches	2.5%	A, B	10	B	1
7B	Alternative future Canadian catches; $MSYR_{1+}$=1%	1%	A, B	10	B	1
9A	Alternative future Canadian catches	2.5%	A, B	10	D	1
9B	Alternative future Canadian catches; $MSYR_{1+}$=1%	1%	A, B	10	D	1
10A	Asymmetric environmental stochasticity (depletion = 0.3)	2.5%*	A, B	10	A	1
10B	Asymmetric environ. stochasticity; $MSYR_{1+}$=1% (depletion = 0.3)	1%*	A, B	10	A	1

In SC/65b/AWMP02, Witting outlined candidate *SLA*s based on adjustments to the 'Interim *SLA*'. The core calculation is an initial *Strike Limit* that is given as a percentage of a lower percentile of an abundance estimate. The percentage is determined by an *r* parameter, that is specified as a proportional take (e.g., *r*=0.03). The lower percentile is determined by a point estimate of abundance for the most recent survey estimate, a percentile parameter *p*, and the CV of the estimate (assuming a log normal distribution). The point estimate is given by a linear regression over the most recent four survey estimates, so that noise from random fluctuations between estimates is reduced, while a possible trend over time is maintained in the calculation. The CV is a time-weighted average of the CV's of the four estimates.

The initial *Strike Limit* is modified for increased need satisfaction and increased protection. Need satisfaction is increased by a 'snap to need' function, which sets the *Strike Limit* equal to need if the initial *Strike Limit* is greater or equal

Table 7

Proportion of times that each *SLA* achieves the conservation performance benchmark for various subsets of the 36 *Evaluation Trials* for bowhead whales off West Greenland, and the mean of the 5th percentile need satisfaction (N9 over 20 and 100 years) values within each such subset of trials. For all table entries, higher numbers indicate better performance.

(a) Results by MSY rate

	Interim	*SLA*1	*SLA*2	*SLA*3	*SLA*4
$MSYR_{1+}$=2.5% trials (18 trials)					
Conservation performance	1.00	1.00	1.00	1.00	1.00
Need satisfaction 20 yrs	0.92	0.97	0.98	0.73	0.74
Need satisfaction 100 yrs	0.96	0.88	0.97	0.81	0.82
$MSYR_{1+}$ = 1% (18 trials)					
Conservation performance	0.50	0.56	0.50	1.00	0.89
Need satisfaction 20 yrs	0.81	0.97	0.98	0.71	0.72
Need satisfaction 100 yrs	0.76	0.53	0.76	0.38	0.39

(b) Results by need envelope

	Interim	*SLA*1	*SLA*2	*SLA*3	*SLA*4
Need Scenario A (18 trials)					
Conservation performance	0.78	0.78	0.78	1.00	0.94
Need satisfaction 20 yrs	0.86	0.97	0.98	0.72	0.73
Need satisfaction 100 yrs	0.88	0.73	0.89	0.62	0.62
Need Scenario B (18 trials)					
Conservation performance	0.72	0.78	0.72	1.00	0.94
Need satisfaction 20 yrs	0.86	0.97	0.98	0.72	0.73
Need satisfaction 100 yrs	0.84	0.67	0.85	0.57	0.59

(c) Results by future Canadian catches

	Interim	*SLA*1	*SLA*2	*SLA*3	*SLA*4
Canadian Scenario A (28 trials)					
Conservation performance	0.75	0.79	0.75	1.00	0.93
Need satisfaction 20 yrs	0.87	0.97	0.97	0.72	0.73
Need satisfaction 100 yrs	0.86	0.71	0.86	0.60	0.61
Canadian Scenario B (4 trials)					
Conservation performance	0.50	0.50	0.50	1.00	1.00
Need satisfaction 20 yrs	0.84	1.00	1.00	0.72	0.72
Need satisfaction 100 yrs	0.81	0.66	0.84	0.53	0.53
Canadian Scenario D (4 trials)					
Conservation performance	1.00	1.00	1.00	1.00	1.00
Need satisfaction 20 yrs	0.85	1.00	1.00	0.72	0.72
Need satisfaction 100 yrs	0.88	0.72	0.91	0.62	0.61

to 80% of need. If the point estimate of abundance is lower than a specified abundance, a protection function forces the *Strike Limit* to be very low. For the case of West Greenland bowhead whales, the yearly *Strike Limit* is set to 2 if the point estimate of abundance is 800, and it is then scaled linearly downwards to zero at a point estimate of 400.

After examining the influence of the variation in the CV on the performance of the *SLA*, p=2 was chosen for the candidate *SLA*s (equal to an approximate lower 5th percentile). The *SLA* was then tuned to p=2 to obtain the highest average need satisfaction. This was achieved under the conservation constraint that the lower 5th percentile of the ratio of the final 1+ population size at the end of the simulation period to that at the start was larger than 1 (for the *Evaluation Trials* with $MSYR_{1+}$=0.01). The result was a proposed 'best' candidate (denoted p2r0.9) with r=0.009.

8.1.1.3 TRIAL RESULTS

The Committee has previously agreed the appropriate the statistics and plots to compare candidate *SLA*s (e.g. see IWC, 2014). Initial evaluation of the candidate *SLA*s focussed primarily on the following tables and plots (the full set is available from the Secretariat):

(1) a table with rows by trial for the interim SLA and each candidate SLA, along with scenarios in which all future catches are set to zero, in which there are only incidental catches into the future (no aboriginal catches), and in which the strike limit equals need. The tables include the lower 5th percentile and median for the following performance statistics (see Annex D of SC/65b/Rep6 for definitions): D1 (final depletion) for the 1+ component of the population; D1for the mature female component of the population; D8 (rescaled final depletion) based on incidental catches; D8 based on no future catches, D10 (relative increase), and N9 (need satisfaction) for 20 and 100 years.
(2) Time-trajectories of the lower 5th percentiles and medians for 1+ population size in which the area which encompasses the results for zero future catches and future strikes equal to need is shaded, and lines are shown for the scenario in which there are only incidental catches into the future as well as for the 'Interim SLA' and the candidate SLAs (see example in Annex E, fig 2a).
(3) 'Zeh' plots which show the same results as the table, except that the N12 (mean downstep) statistic is also reported (see example in Annex E, fig 2b).

The performance of four new *SLA*s was examined in detail, along with the 'Interim *SLA*' for comparison. These were:

(1) SLA1: (SLA3 of SC/65b/AWMP03).
(2) SLA2: (SLA4 of SC/65b/AWMP03).

(3) SLA3: SLA p2r0.9 of SC/65b/AWMP02
(4) SLA4: SLA p2r1 of SC/65b/AWMP02

The Committee noted that the time taken to determine and condition the trials meant that developers had had relatively little time to work on their *SLA*s.

Evaluation of the *SLA*s concentrated on: (a) the conservation performance, particularly for trials with $MSYR_{1+}$=1%, high need, and high future Canadian catches; and (b) their performance in relation to the current 'Interim *SLA'*. The four *SLA*s are tuned to somewhat different need-conservation trade-offs, which is reflected in the results of the trials.

In order to summarise inferences from the trials, attention was focussed on cases where either the lower 5th percentile of the D1 (1+) statistic exceeded 0.6 or the 5th percentile of D10 statistic was below 1 and in addition, examined the average of the lower 5th percentile of the N9 statistic.

Table 7 summarises various aspects of the trials in terms of conservation and need performance using these criteria. Overall, all of the *SLA*s performed adequately in terms of conservation performance if $MSYR_{1+}$=2.5% but as would be expected, performance was more variable for $MSYR_{1+}$=1% (Table 7a). From an examination of the tabular and graphical results, the Committee identified some general features:

(a) SLAs 3 and 4 generally had better conservation performance but poorer need satisfaction;
(b) SLAs 1 and 2 had better conservation and need satisfaction performance for the MSYR1+=2.5% trials;
(c) SLAs 3 and 4 exhibited higher levels of variability than SLAs 1 and 2;
(d) as expected, performance in terms of need satisfaction was better for the trials in which the Canadian catches were lower than for the basecase trials.

The Committee **agrees** that the performance of the 'Interim SLA' in these trials confirms the earlier recommendation of the Scientific Committee that at least for up to two quota block it was indeed a suitable *SLA.* However, the Committee also **agrees** that for the longer 100-year period, the results showed that better performance than the 'Interim SLA' could be obtained for bowhead whales off West Greenland.

Performance for the *Robustness Trials* is generally as expected given the results of the *Evaluation Trials*, as discussed under Annex, item 2.5.

8.1.1.4 CONCLUSIONS AND RECOMMENDATIONS

The Committee **agrees** that developing *SLA*s for bowhead whales off West Greenland that fully meet both conservation and need objectives is particularly difficult since:

(1) the *SLA* is only able to 'control' one source of mortality, i.e. strikes for the Greenland hunt, whereas mortality also occurs from catches by a non-member nation and from bycatches;
(2) it is also not possible to assume that future Canadian abundance surveys will occur; and
(3) the remaining uncertainty over stock structure (and therefore abundance) means that the scenarios that must be considered may be overly conservative.

With respect to (3) the Committee **strongly encourages** scientists from Canada and Greenland to co-operate on issues related to stock structure and abundance that may allow revision of the trial structure at a future *Implementation Review*.

Given the difficulties presented by these circumstances, the Committee **agrees** that although improved performance over the *SLA*s considered this year was possible, it was unlikely that an *SLA* could be developed that fully met the conservation objectives (the highest priority) whilst also meeting need fully for the most difficult scenarios. Given this, the SWG **requested** Witting to consult within Greenland as to whether it wished to proceed with the 'high' need envelope.

The Committee **concludes** that further work should be undertaken by the developers during the coming year. It noted that now conditioning had been completed, progress on *SLA* development could take place at a faster rate, with progress being reported at the proposed intersessional workshop discussed below. The objective would be for the Committee to be in a position to recommend an *SLA* to the Committee next year (see the Workplan).

8.1.2. Development of an SLA for the humpback whale hunt off West Greenland

8.1.2.1 DATASETS, TRIAL STRUCTURE AND CONDITIONING

An important component of the intersessional Workshop was the finalisation of the datasets to be used in the trials. With respect to stock structure, the Committee has agreed that the appropriate 'unit-to-conserve' is the West Greenland feeding aggregation (e.g. see IWC, 2008a; 2012b).

The abundance estimates (including indices of abundance) for use in the trials have been discussed previously by the Committee and were agreed last year (IWC, 2014c); they are summarised in Annex E, table 7 and in SC/65b/Rep06 (Annex D).

Intersessional work (SC/65b/Rep06) focussed on developing removals series that took into account the incidental captures of 'Greenland' animals elsewhere in their range based *inter alia* on photographic matches from the College of the Atlantic (SC/J14/AWMP1) and movement information from telemetry data. The full review of information confirmed that approach previously adopted to incorporate bycatches outside Greenland. The final series can be seen in Annex F of SC/65b/Rep06.

The Committee **endorses** the final trial structure given in Annex D of SC/65b/Rep06. This provides *inter alia* details on the population model, conditioning, trials, removals, need envelopes and abundance.

The factors considered in the trials are given in Table 5. The *Evaluation Trials* are shown in Table 8. The conditioning of the operating models was conducted intersessionally. The SWG reviewed the conditioning by examining the diagnostic plots in the usual manner and agreed that conditioning had been achieved successfully. The Committee **endorses** this view.

8.1.2.2 CANDIDATE *SLA*S

In SC/65b/AWMP01, Witting outlined candidate *SLA*s for humpback whales off West Greenland, that have the same

structure, parameters and 'snap to need' function as those applied to bowhead whales (SC/65b/AWMP02; see Item 8.1.1.2 above). The selected 'protection level' within the *SLA* is slightly higher than that for bowhead whales. While this may seem counterintuitive given the higher growth rates of humpback whales, the developer's choices reflect that the bowhead whale is managed on what is known to be a sub-component of a stock, which allows for a somewhat lower protection level. 'Snap to need' occurs when the *Strike Limit* is 80% of need, and *p* is set to 2.The value of *r* was tuned which results in an *SLA* with *r*=0.04 that provides full need satisfaction for all of the *Evaluation Trials*, and also ensures that the 1+ population size at the end of the 100-year simulation period is higher than that at the start of this period for all of the *Evaluation Trials*.

The *SLA*s developed for humpback whales off West Greenland by Brandão (SC/65/AWMP04) have the same structure as those developed for the bowhead whales (see Item 2.3). The control parameters of these *SLA*s were not 'tuned' for the humpback case; rather the same values were used as for the bowhead case, due to a lack of time.

Table 8

The *Evaluation Trials* for humpback whales. Values given in bold type show differences from the base trial

Trial	Description	$MSYR_{1+}$	Need Scenarios	Survey freq.	Historic Survey Bias
1A	$MSYR_{1+}$ = 5%	5%	A, B, C, D	10	1
1B	$MSYR_{1+}$ = 3%	3%	A, B, C, D	10	1
1C	$MSYR_{1+}$ = 7%	7%	A, B, C, D	10	1
2A	5 year surveys	5%	B, C, D	5	1
2B	5 year surveys; $MSYR_{1+}$ =3%	3%	B, C, D	5	1
3A	15 year surveys	5%	B, C	15	1
3B	15 year surveys; $MSYR_{1+}$ =3%	3%	B, C	15	1
4A	Survey bias = 0.8	5%	B, C, D	10	0.8
4B	Survey bias = 0.8; $MSYR_{1+}$ =3%	3%	B, C, D	10	0.8
5A	Survey bias = 1.2	5%	B, C, D	10	1.2
5B	Survey bias = 1.2; $MSYR_{1+}$ =3%	3%	B, C, D	10	1.2
6A	3 episodic events	5%	B, C, D	10	1
6B	3 episodic events; $MSYR_{1+}$ =3%	3%	B, C, D	10	1
7A	Stochastic events every 5 years	5%	B, C, D	10	1
7B	Stochastic events every 5 years; $MSYR_{1+}$ = 3%	3%	B, C, D	10	1
8A	Asymmetric environmental stochasticity (depletion = 0.3)	5%	B, C, D	10	1
8B	Asymmetric environmental stochasticity (depletion = 0.3)	3%	B, C, D	10	1

8.1.1.3 TRIAL RESULTS

The Committee explored the performance of four new *SLA*s in detail as well as the interim *SLA* for comparison. These were the same as for the bowhead whale:

(1) SLA1: SLA3 of SC/65b/AWMP03.
(2) SLA2: SLA4 of SC/65b/AWMP03.
(3) SLA3: SLA p2r4 of SC/65b/AWMP01
(4) SLA4: SLA p2r3 of SC/65b/AWMP01

The Committee noted that the time taken to determine and condition the trials meant that developers had had relatively little time to work on their *SLA*s. However, it also noted that the humpback case was relatively data rich compared to the bowhead case and that future catches from non-member nations was not an issue.

Consideration of the full set of graphical and tabular results (available from the Secretariat) followed the process agreed for the bowhead whale described under Item 8.1.1.3. There was relatively little impact of the need envelope in terms of need satisfaction performance of the SLAs (Table 9b). Performance in terms of conservation and need satisfaction was primarily evaluated using the same performance evaluation statistics (D1, D10 and N9) as for West Greenland bowhead whales (Table 9) as well as consideration of the graphical output. All of the *SLA*s except SLA 1 achieved satisfactory levels of performance when $MSYR_{1+}$=5%. However, only SLAs 3 and 4 achieved fully satisfactory performance when $MSYR_{1+}$=3%. Generally, *SLA*s 3 and 4 achieve notably better performance than the other *SLA*s, especially with respect to need satisfaction.

Table 9

Number of times that the each *SLA* does *not* achieve the benchmark levels for *SLA* performance for the 18 *Evaluation Trials* for humpback whales off West Greenland. In this table, low numbers represent better performance.

(a) Results by MSY rate

	Interim	SLA1	SLA2	SLA3	SLA4
$MSYR_{1+}$=5% trials (24 trials)					
Conservation performance	0	0	0	0	0
Need satisfaction 20 yrs	0	0	0	0	0
Need satisfaction 100 yrs	0	3	0	0	0
$MSYR_{1+}$ = 3% (24 trials)					
Conservation performance	0	0	0	0	0
Need satisfaction 20 yrs	9	3	3	0	0
Need satisfaction 100 yrs	0	7	0	0	0

(b) Results by Need Level *

Need Level A (2 trials)					
Conservation performance	0	0	0	0	0
Need satisfaction 20 yrs	1	0	0	0	0
Need satisfaction 100 yrs	0	0	0	0	0
Need Level B (16 trials)					
Conservation performance	0	0	0	0	0
Need satisfaction 20 yrs	1	0	0	0	0
Need satisfaction 100 yrs	0	2	0	0	0
Need Level C (16 trials)					
Conservation performance	0	0	0	0	0
Need satisfaction 20 yrs	1	0	0	0	0
Need satisfaction 100 yrs	0	3	0	0	0
Need Level D (16 trials)					
Conservation performance	0	0	0	0	0
Need satisfaction 20 yrs	6	3	3	0	0
Need satisfaction 100 yrs	0	5	0	0	0

The Committee **agrees** that the performance of the 'Interim *SLA*' in these trials confirmed the earlier recommendation of the Scientific Committee that it was indeed a suitable *SLA*, at least for up to two block quotas. However, the Committee also **agrees** that for the longer 100-year period, the results showed that better performance than the 'Interim SLA' could be obtained for humpback whales off West Greenland.

In terms of *Robustness Trials*, performance was as expected for all *SLA*s.

8.1.1.4 CONCLUSIONS AND RECOMMENDATIONS

Unlike the situation for the bowhead whales, the Committee **agrees** that the performance of two of the candidate *SLA*s (*SLA*s 3 and 4) meets the Commission's objectives in terms of conservation and need. However, in terms of need satisfaction, *SLA*3 performed slightly better than *SLA*4. For example, the lower 5th percentile of need satisfaction exceeded 0.99 for all except one trial for *SLA*3 while *SLA*4 achieved lower than 99% need satisfaction with 95% probability for 3 trials (20 year need satisfaction) and 8 trials (100-year need satisfaction). In accordance with its previous agreement (e.g. see IWC, 2014) that once an *SLA* had been developed that fully met the Commission's objectives, that time would not be spent trying to improve it even further, the Committee **recommends** that *SLA3* (hereafter the *Humpback SLA*) be used to provide long-term management advice to the Commission on the subsistence hunt of humpback whales off West Greenland, subject to final validation of the code by the Secretariat and archive running of the full set of statistics and graphical output.

The Committee was pleased to note that this component of its workplan had been completed and **thanks** the SWG on the AWMP for its hard work in this regard since focussing on this case in 2012. In particular, it wished to thank the developer of *The Humpback SLA*, Witting, and the other developers, Brandão and Butterworth, for their hard work in reaching this stage. Special thanks are also due to Brandão, Witting and Punt for their conscientious work in developing and finalising the operating model and conditioning. The Committee **stresses** that this work could not have been accomplished without assistance from the AWMP Developer's Fund established by the Commission, the funded intersessional workshops and the hard work of the intersessional Steering Group. It **agrees** that this process (i.e. maintenance of the Developer's Fund, holding of intersessional workshops and an active Steering Group) should be followed with respect to completing the development of the remaining *SLA*s for the Greenland hunts.

8.1.3 Development of an SLA for the common minke whale hunt off Greenland

The Committee has previously noted connection between the development of an *SLA* for the Greenland hunts and the RMP *Implementation Review* for common minke whales in North Atlantic and the need for consistency in a number of aspects of operating model development and stock structure hypotheses (see IWC, 2013b). Given this, the joint AWMP/RMP intersessional workshop was held in Copenhagen in April 2014; an important component of this successful workshop was simulation work and co-operative genetic analyses supported by the IWC. A short Chair's summary of the results of the workshop is given in Annex D, Appendix 5, Item 2.1.

The Workshop had developed stock structure hypotheses based on a thorough review of the data from a suite of sources and began the work to develop the appropriate modelling framework. This work continued intersessionally and was reviewed at the pre-meeting of the RMP (Annex D, Appendix 5). The Committee **agrees** that framework developed for the RMP *Implementation Review* (Annex D, Appendix 5, Adjunct 5) is applicable to progress work on *SLA* development.

Much of the discussion within the SWG on the AWMP focussed on developing a workplan for *SLA* development with the objective of having a recommended *SLA* ready by the 2017 Annual Meeting. The Committee thanked Punt for working hard at this meeting to ensure that the initial conditioning of the basic operating model had begun. This will allow a preliminary version of the program to be available to developers shortly after the end of the SC meeting. However, the full version of the control program will not be finalised until after the end of the proposed intersessional workshop. In view of the new approach being used to model the sex-ratio, minor amendments to the operating model may be necessary following consideration of the conditioning results, particularly given the interaction between aboriginal and commercial catch patterns.

The need envelopes for West Greenland common minke whales will be confirmed later but will include a constant level of 200 whales for West Greenland and of 12 whales for East Greenland.

The Committee **welcomes** the information that Witting, Butterworth and Brandão expect to begin work intersessionally on the development of candidate *SLA*s for Greenlandic minke whales.

8.1.4 Development of an SLA for the hunt of fin whales off West Greenland

The Committee has previously noted connection between the development of an *SLA* for the Greenland hunts and the RMP *Implementation Review* for fin whales in North Atlantic and the need for consistency in a number of aspects of operating model development and stock structure hypotheses (see IWC, 2013a). A technical RMP workshop was held in Copenhagen in January 2014 and this was followed up by work at the present meeting (see Annex D, item 3.2).

The Committee **confirms** that the general trial specifications developed for the *Implementation Review* for North Atlantic fin whales are suitable for testing *SLA*s in the West Greenland area. However, the operating model is complex and is not yet operational. The Committee is concerned that the complexity of the model may not allow development of an *SLA* for fin whales in time for the 2017 Scientific Committee meeting. It **agreed** that priority should be given to development of an *SLA* for minke whales, in view of the greater contribution of minke whales to the overall interspecies need satisfaction for Greenland. With respect to fin whales, the Committee **agrees** that an alternative approach to develop a single-stock operating model will be conservative (i.e. from a conservation perspective) in that it assumes that the animals found of West Greenland comprise a single stock, and should be investigated. The trials steering group (Witting, Givens, Brandão, Butterworth, Punt, Allison, and Donovan) will consider this suggestion further and report back to the Intersessional workshop.

Table 10

Two-year workplan (the second year is more tentative than the first and depends on progress)

Topic	Intersessional 2014-15	SC66a May-June 2015	Intersessional 2015-16	SC66b May-June 2016
Validate *Humpback SLA*	Complete by July 2014	Receive report formally	No	No
Development of *SLA* for bowhead whales	Workshop (January) Developers' work	Expect to finalise *SLA* recommendation	Probable workshop (January) Developers' work	Finalise *SLA* recommendation if not completed in 2015
Development of *SLA* for common minke whales	Workshop Developers' work	Review progress Developers' work	Workshop Developers' work	Hope to finalise *SLA*
Development of *SLA* for fin whales	Workshop Developers' work	Review progress	Workshop Developers work	Review progress Developers' work
Annual review of catch limits	No	Complete	No	Complete
Implementation Reviews	No	None scheduled	No	Prepare for gray whale *Implementation Review*

8.2 Follow-up work on conversion factors for the Greenland hunt

This item relates to follow up work on conversion factors (i.e. related to converting edible whale products in to numbers of whales by species) that was undertaken by Donovan *et al.* (2010) at the request of the Commission. That report, endorsed by the Scientific Committee, provided a conversion factor for the common minke whale (for which data were abundant) and provisional factors for the other species (often by analogy with other areas as data are sparse for Greenland). They had recommended *inter alia* that data for those species be collected in Greenland such that the factors could be modified if necessary.

SC/65b/AWMP05 provided a full report on the work undertaken on conversion factors within Greenland, including explaining improved procedures for data collection and updating the new information obtained. All reliable weights obtained since 2009 are listed in table 2 of SC/65b/AWMP05 (bowhead whale n=6; humpback whales, n=8; fin whale, n=4). A detailed summary is given in Annex E, item 8. Greenlandic biologists will continue their close contact with hunters to improve the number of reported weights.

The Committee **thanks** the authors for this work which responded appropriately to its recommendations last year for a full report and **encourages** continuation of the study. It noted that the provisional conversion factors developed in 2009 (Donovan *et al.* 2010) appear to overestimate the amount of edible products actually obtained (although sample sizes are small), but were generally within the confidence intervals. It also noted the low numbers of lost whales in the Greenlandic hunts.

The Committee **recognises** the difficulties inherent in obtaining the weight data, including (í) persuading the hunters to modify their behaviour and obtain accurate weight measures; and (ii) enabling researchers to be present to assist in the data collection. The latter is extremely difficult given the opportunist nature of the hunt and the variety of locations (both in distance and difficulties in access) where flensing is carried out.

Recognising (1) the difficult field conditions; (2) the relatively low number of catches (and thus slow increase in sample size) of the species for which the conversion factors were deemed provisional; (3) the fact that the new data, albeit few, did not suggest that the provisional factors from the 2010 study required major modification: and (4) that the information was not required for *SLA* development, the Committee **agrees** that annual update reports are unnecessary for the work of the Scientific Committee. It **suggests** that data are submitted directly to the Commission when it meets and incorporated as necessary into need statements.

8.3 Aboriginal Whaling Management Scheme

In 2002, the Committee **strongly recommended** that the Commission adopt the Aboriginal Subsistence Whaling Scheme (IWC, 2003). This covers a number of practical issues such as survey intervals, carryover, and guidelines for surveys. The Committee has stated in the past that the AWS provisions constitute an important and necessary component of safe management under AWMP *SLA*s and it **reaffirms** this view as it has for the previous 12 years.

8.4 Workplan

The Committee noted that this year it was expected to put forward a draft workplan and budget for a two-year period. The two-year workplan for AWMP work summarised in Table 10 has to include a degree of expectation of progress that may not be realised.

9. ABORIGINAL SUBSISTENCE WHALING MANAGEMENT ADVICE

The Committee noted that the Commission had not reached agreement on strike limits for Greenland at the 2012 Annual Meeting (IWC, 2013a). The Committee has based its management advice this year on the same need requests considered last year. In providing this advice, the Committee noted that the Commission had endorsed the interim safe approach (based on the lower 5th percentile for the most recent estimate of abundance) for providing advice for the Greenland hunts developed by the Committee in 2008 (IWC, 2009b, p.16); it was agreed that that this should be considered valid for two blocks i.e. up to the 2018 Annual Meeting. The Committee **emphasises** that the results of the simulation exercise being undertaken as part of the development process for *SLA*s for the Greenland humpback and bowhead whales **reconfirms** the Committee's original advice with respect to the interim safe approach (see Items 8.1.2 and 8.1.3).

The Committee notes that when providing management advice on subsistence whale hunts it provides advice in a specific way i.e. it comments only on whether the need request or present limits can be safely met from the perspective of the Commission's conservation objectives. If

it or they cannot be safely met then the Committee provides advice on what strike limit is acceptable from a conservation perspective.

9.1 Bowhead whales off West Greenland

9.1.1 New information (incl. catch data and agreed abundance estimates)

No bowhead whales were taken in West Greenland in 2013 while three bowhead whales were taken in North East Canada in 2012 and 2013; no struck and lost whales were reported. The catch corresponds with the quota set by the Canadian authorities. Samples were reported to have been collected from the Canadian hunt and the Committee **encourages** collaboration with Canada on genetic work (and see Item 2.6). The Committee **thanks** Canada for providing this information and **encourages** future reporting to the IWC Secretariat.

It was reported that 65 biopsy samples had been collected from West Greenland bowhead whales in 2013. The Committee **welcomes** this information and **encourages** continuation of the work and collaboration with Canadian scientists to resolve the outstanding stock structure issues.

The Committee **endorses** the following two new abundance estimates for 2012 (SC/65b/Rep06): (i) a fully-corrected sighting survey abundance estimate of 744 (CV=0.34, 95% CI: 357-1,461); and (ii) a mark-recapture estimate of 1,274 (CV=0.12). It **agrees** that the mark-recapture estimate provides the best estimate of abundance for the number of whales visiting West Greenland.

9.1.2 Management advice

Based on the agreed best 2012 estimates of abundance for bowhead whales (1,274 CV=0.12), and using the agreed interim approach, the Committee **repeats** its advice that an annual strike limit of two whales will not harm the stock.

9.2 North Pacific gray whales

9.2.1 The report of the rangewide workshop and related future work

A rangewide review of the population structure and status of North Pacific gray whales was carried out at an IWC workshop in La Jolla, California, 8-11 April 2014 (SC/65b/Rep08).

The Workshop objectives, as agreed last year (IWC, 2014c), were to: (1) review available information (especially new telemetry, genetics and photo-ID data) and reappraise the population structure and movements of North Pacific gray whales with a focus on examining status; (2) develop a modelling framework to better assess the status of gray whales and the potential impact of human activities and possible changes in regime or climate; and (3) provide information for updating the IUCN/IWC Conservation Management Plan for western gray whales.

The Workshop put considerable effort into reviewing all of the sources of data that could provide insights in to the movements and stock structure of gray whale across the North Pacific, including identifying available data that remained to be analysed. Using the stock structure hypotheses for the western North Pacific put forward last year as a starting point the data review, the Workshop developed a series of plausible stock structure hypotheses to take forward into the modelling exercise. In order to make progress in developing operating models to further explore the potential implications of these hypotheses, the Workshop agreed that the initial focus should be on three of these hypotheses (and one sensitivity test). The full range of hypotheses are illustrated in Annex F of SC/65/Rep08.

The Workshop then went on to review and compile the extensive data sources and information on parameters that would be needed for the modelling exercise, including removals data, abundance and trends, population parameters and other human activities that might affect status.

The Workshop recognised that the process would necessarily be an iterative process. The first step of developing an age- and sex-aggregated model which includes multiple stocks would be taken primarily to understand whether sufficient data are available to justify the various stock structure hypotheses and whether parameterisation of the model based on the associated hypotheses can provide reasonable fits to the data. The Workshop developed a workplan and made a number of recommendations for future research. These can be found in SC/65b/Rep08, items 9 and 10.

The Committee **welcomes** the workshop report, **thanks** the participants and **endorses** its recommendations.

In response to part of the workplan of the Workshop, SC/65b/BRG1 provided the mathematical specifications for a sex- and age-aggregated population dynamics model which can represent the stock hypotheses developed during the workshop. The model allows for multiple stocks, each of which can have sub-stocks, multiple feeding and wintering grounds, as well as migratory corridors.

Based on this paper and the recommendations from the gray whale workshop, Committee **recommends** the detailed workplan provided in Annex G to take this work forward.

9.2.2 Other new information.

PACIFIC COAST FEEDING GROUP (PCFG) WHALES

SC/65b/BRG19 presented research on gray whales in northwest Washington with the goals to (1) increase our understanding of gray whale use of the study area, (2) document the annual and seasonal fluctuations in the numbers of whales utilising the area, and (3) to assess the fidelity of whales to the study area within and between years. The study confirms that even though Northwest Washington is an important feeding area, most PCFG gray whales do not have strong fidelity to this one region within the PCFG.

Mate described the satellite-tagging of 35 PCFG gray whales off the coasts of Oregon from September to mid-October (n=12) and northern California near Pt. St. George, CA (n = 23) from late October to December during 2009, 2012 and 2013. The 33 telemetry tracks ranged from 3-383d ($\bar{x}$ = 118, SD = 98.1d) with one of the 2013 tags still transmitting at 193d at the time of manuscript preparation. The area off Pt. St. George (Crescent City, CA) is a consistent late fall 'hot spot' that attracts large numbers of PCFG whales just prior to the southerly migration. One healthy mature adult male was tracked for 383 d and did not migrate, the first such documentation for a gray whale. Six of 12 whales that migrated to Baja for the reproductive season and back into the PCFG area, spent from 1-5 days in the Makah U&A[14] area as

[14] Usual and Accustomed Fishing Grounds

they migrated north. Three of the same 12 whales (one in each year) migrated as far as Icy Bay, Alaska (60°N), considerably farther north than the conventional definition of the PCFG area, spending up to 55 there.

The Committee **welcomes** this new paper and **encourages** more telemetry effort in the PCFG area, noting its value with respect to better understanding of stock structure and movements in the context of the work of the workshop and the modelling exercise discussed above.

9.2.2 Review of recent catch information

A total of 127 gray whales were struck off Chukotka, Russia in 2013 resulting in 125 landed. Of those, 39 were males and 86 were females. Two of the whales were inedible because of a strong medicinal smell (i.e. 'stinky whales'). The body length of whales ranged between 7.9 and 15.5m (average = 10.1m). Body weights ranged between 5.9 and 39.1 tons (average = 11.9 tons).

9.2.3 Management advice

The Committee **agrees** that the *Gray Whale SLA* remains the appropriate tool to provide management advice for Eastern North Pacific gray whales. It also **agrees** the proposed Makah whaling management plan agreed by the Committee last year remains the appropriate tool to provide management advice for hunts in Washington State, USA, recognising that it must include that the ongoing research programme that monitors the relative probability of harvesting a PCFG whale in the Makah usual and accustomed fishing grounds.

9.3 Bering-Chukchi-Beaufort (BCB) Seas stock of bowhead whale

9.3.1 New information

The Committee received three papers providing information on this stock.

SC/65b/BRG05 described new laboratory methods for measuring D/L ratios of aspartic acid (AAR) in bowhead whale lens nuclei, and reported upon age estimates for 64 BCB bowhead whales, ten of which had been also aged using baleen carbon cycling and/or corpora counting methods. The results strengthened previous evidence suggesting that some animals may live to 200 years or beyond: the oldest estimated age found in this research was 187 years (95% CI (142, 258)) for a 17.7 m male. The results also suggested that the AAR technique provided lower estimated ages than the corpora counting approach. One whale (estimated age 88, 95% CI 66-120 years) had a Yankee whaling projectile point patented in 1879 embedded in it, strengthening previous evidence that the age estimate was plausible. The Committee **welcomes** this study and **encourages** further work on aging studies.

SC/65b/BRG 20 reported on the occasional inadvertent harvest of bowhead whale calves in autumn by Alaskan Eskimos and updates George and Suydam (2006) which had been requested by the Commission.

SC/65b/BRG10 summarised the results of onshore observations of bowhead whales in coastal waters of Chukotka in 2010-2013, and compares them with earlier surveys dating to 1992. These observations provide spatial, temporal and relative abundance information for bowheads in coastal waters. Observations of the spring migration of bowhead whales were made in the northwest Bering Strait region. The Committee **welcomes** this information and **encourages** work in this region.

Citta *et al.* (2013) reported on the analysis of spatial/temporal overlap of satellite tagged bowhead whales and Bering Sea pot fisheries to evaluate which fisheries had the greatest risk of interaction with bowhead whales. This is also discussed under Item 7.1.

9.3.2 New catch information

Harvest data from the Alaskan hunt were presented in SC/66a/BRG08. In 2013, 57 bowhead whales were struck resulting in 46 animals landed. Total landed of the hunt for 2013 was higher than the past 10 years (2003-2012: mean of landed = 40.5; *SD* = 8.7). Efficiency (# landed / # struck) in 2013 was 81%, which was slightly higher than the past 10 years (mean of efficiency=77%; *SD*=7.4%). Of the landed whales, 25 were females and 21 were males. Seven of the 25 females were assumed sexually mature (>13.4 m in length). Four of these were pregnant.

SC/65b/BRG03 reports that in 2013, one bowhead whales was taken in Chukotka, Russia. It was a 41-tonne, 13m male. No whales were struck and lost.

9.3.4 Management advice

The Commission adopted catch limits for a six-year block in 2012, i.e. 2013-2018. The total number of strikes shall not exceed 336 with a maximum of 67 in any one year (with a carryover provision). The Committee has agreed that the *Bowhead Whale SLA* is most appropriate tool to provide management advice for this stock. The Committee **agrees** that these limits will not harm the stock.

9.4 Common minke whales off West Greenland

9.4.1 New information

In the 2013 season, 166 common minke whales were landed in West Greenland and 9 were struck and lost. Of the landed whales, there were 127 females, 37 males and two of unknown sex. Genetic samples were obtained from 106 of these minke whales in 2013. The Committee **welcomes** the additional data and **encourages** the continued collection of samples. It was also pleased to learn that samples from West Greenland were included in the genetic analyses that formed part of the Joint AWMP/RMP workshop on stock structure (SC/65b/Rep4).

Over the years, the Committee has re-emphasised the importance of collecting genetic samples from these whales, and it **welcomes** the new genetic analysis on population structure of common minke whale in the North Atlantic (SC/65b/RMP09), where samples from the West Greenland hunt were compared with samples from the Icelandic and Norwegian hunts. Out of 66 samples from West Greenland analysed for kin relationships, one parent offspring relation was found with a whale caught in the Central CIC sub-area. Witting advised that more samples are soon to be included in this analysis.

9.4.2 Management advice

In 2009, the Committee was able to provide management advice for this stock for the first time. This year, using the Commission's agreed interim approach (IWC, 2009) and last year's revised estimate of abundance (16,100 CV=0.43), the Committee **advises** that an annual strike limit of 164 will not harm the stock.

9.5 Common minke whales off East Greenland

9.5.1 New information (incl. catch data and agreed abundance estimates)

Four common minke whales were landed in East Greenland in 2013, and two were struck and lost. Of the landed whales, there were three females and one male. The Committee is **pleased** to note that samples were collected from all four landed whales and that samples from the East Greenland hunt were included in the genetic analysis (SC/65b/RMP09). Out of 16 samples from East Greenland analysed for kin relationships, one parent offspring relation was found with a whale caught in the Central CIC sub-area (Annex D, Appendix 7). The Committee **welcomes** the new information and **encourages** the continued collection of samples.

9.5.2 Management advice

Catches of minke whales off East Greenland are believed to come from the large Central stock of minke whales. The most recent strike limit of 12 represents a very small proportion of the Central Stock which numbers around 40,000 – see Table 11. The Committee **repeats** its advice of last year that a strike limit of 12 will not harm the stock.

Table 11

Most recent estimates of abundance for common minke whales in the Central North Atlantic by RMP *Small Area*

Small Area(s)	Year(s)	Abundance and CV
CM	2005	26,739 (CV=0.39)
CIC	2007	10,680 (CV=0.29)
CG	2007	1,048 (CV=0.60)
CIP	2007	1,350 (CV=0.38)

9.6 Fin whales off West Greenland

9.6.1 New information (incl. catch data and agreed abundance estimates)

A total of nine fin whales (five females, three males and one of unknown sex) were landed, and none were struck and lost, off West Greenland during 2013. The Committee is **pleased** to note that genetic samples were obtained from all landed fin whales, and that the genetic samples of fin whales off West Greenland are now being analysed together with the genetic samples from the hunt in Iceland. It **encourages** the continued collection of samples.

9.6.2 Management advice

Based on the agreed 2007 estimate of abundance for fin whales (4,500 95%CI 1,900-10,100), and using the agreed interim approach, the Committee **repeats** its advice that an annual strike limit of 19 whales will not harm the stock.

9.7 Humpback whales off West Greenland

9.7.1 New information (incl. catch data and agreed abundance estimates)

A total of seven (four males and three females) humpback whales were landed, and one was struck and lost, in West Greenland during 2013. The Committee is **pleased** to learn that genetic samples were obtained from five of these whales and that Greenland was contributing fluke photographs to the North Atlantic catalogue, both from captured whales and other field studies. The Committee again **emphasises** the importance of collecting genetic samples and photographs of the flukes from these whales.

The Committee also **welcomes** a report that 11 biopsy samples had been collected from West Greenland humpback whales in 2013 and **encourages** continuation of the work and collaborative studies across the North Atlantic.

9.7.2 Management advice

Based on last year's revised and agreed estimate of abundance for humpback whales (2,704 CV=0.34) and the agreed interim approach, the Committee **agrees** that an annual strike limit of 10 whales will not harm the stock.

Furthermore, the Committee **recommends** that the new *Humpback SLA* agreed above (see Item 8.1.2) should be used to provide management advice by the Committee in the future, following completion of the usual final validation/checking process. The Committee **notes** that the *Humpback SLA*, if used now, would provide the same management advice as the interim approach for within this period, i.e. that an annual strike limit of 10 whales will not harm the stock.

9.8 Humpback whales off St Vincent and The Grenadines

9.8.1 New information (incl. catch data)

A total of four humpback whales were landed (three males and one female) in St. Vincent and the Grenadines in 2013 and individual data on these whales (including lengths and sexes) have been supplied to the Secretariat. No lost whales were reported. Skin and/or blubber samples were collected from all four whales. Preliminary information is that these data are being analysed in collaboration with the USA [*to be confirmed before report published*]. The Committee **welcomes** this information from St. Vincent and the Grenadines and **strongly encourages** continued tissue sampling and collection of fluke photographs where possible. Data should be shared with the appropriate databases and catalogues for the North Atlantic.

9.8.2 Management advice

The Committee has agreed that the animals found off St. Vincent and the Grenadines are part of the large West Indies breeding population (abundance estimate 11,570 95%CI 10,290-13,390). The Commission adopted a total block catch limit of 24 for the period 2013-2018 for Bequians of St. Vincent and The Grenadines. The Committee **repeats** its advice that this block catch limit will not harm the stock.

10. WHALE STOCKS

10.1 Antarctic minke whales

The Committee is undertaking an In-Depth Assessment of the Antarctic minke whale, which is focused on whales within the Indo-Pacific waters. Details of the discussions summarised below can be found in Annex G. In addition, during February 2014 the JARPA II Special Permit program was reviewed (SC/56b/Rep02) where research recommendations were made, of which many were referred to in Annex G.

10.1.1 New methods or information

10.1.1.1 BIOLOGICAL PARAMETERS

SC/65b/IA01 described the yearly trend of age at sexual maturity in Antarctic minke whales collected during 1987/88-2004/05 JARPA and 2005/06-2010/11 JARPA II surveys. It is a revised version of SC/F14/J08 presented to the JARPA II Review Workshop taking into consideration some of their recommendations. The results confirmed that the age at sexual maturity of both stocks declined from around 10-12 years for the mid- 1940s cohorts to around 7-8 years for the early 1970s cohorts.

The Committee identified two additional potential methodological issues in SC/56b/IA01 not addressed in SC/56b/Rep02 (the JARPA II review) which could affect the reliability of the long-term trends and suggestions were made to investigate these issues (Annex G item 2.1.1). The Committee **endorses** the suggested workplan in SC/65b/IA01 to address the rest of the JARPA II review panel recommendations.

SC/56/IA02 described the proportion of pregnant animals among mature females (PPF) in Antarctic minke whale catches for two biological stocks using samples collected during 1987/88-2004/05 JARPA and 2005/06-2010/11 JARPA II surveys. The conducted analysis was a revision of SC/F14/J09 which was presented to the JARPA II Review Workshop (SC/56b/Rep02). The PPF of both stocks appeared stable at around 0.9.

In discussion, the Committee first considered how the measured pregnancy rate might be related to the actual birth rate. In response, the authors stated that they will be reporting on results from a feasibility study to examine the possibility of documenting recent lactation by observation of histological samples of the mammary gland to develop a potentially more appropriate index of reproductive success.

The Committee further discussed the possibility that, if birthrate could be inferred, then it would be possible to compare trends and absolute levels of the *per capita* surviving calf production estimates from SCAA estimates of birth and initial calf survival proportions. The difference might be indicative of trends in post-birth juvenile survival. Butterworth and Bravington offered differing views on the utility of and inferences to be drawn from this particular pregnancy dataset in the context of the In-Depth Assessment (Annex G, appendix 2).

10.1.1.2 ABUNDANCE AND DISTRIBUTION

When estimating abundance of Antarctic minke whales in CPII and CPIII, it was presumed that some proportion of the population of Antarctic minke whales was distributed within the sea ice fields, away from where vessels were able to survey. Though the Committee has agreed upon abundance estimates for the 'ice-free' surveyed area, it is still not known what proportion of Antarctic minke whales are in sea ice.

SC/65b/IA15 described Australian supported aerial surveys and subsequent abundance estimates to quantify the proportion of Antarctic minke whales that may be in summer sea ice regions of East Antarctica. Using generalised additive models, model-based estimates of uncorrected abundances and densities (uncorrected for availability bias) were produced. Using 'prorated' abundances from IDCR/SOWER, leveraged on simple estimates of encounter rate from open water north of the aerial survey region, there is some evidence that between 10 and 50% of the minke population can be found within 93-113ºE inside ice during the 2009/10 summer.

SC/65b/IA16 provided an overview of the Antarctic minke whale data obtained from five helicopter surveys conducted from *RV Polarstern* between 2002 and 2013 in the Weddell Sea and around the Antarctic Peninsula in regions of varying ice concentrations. The results show high variability in predicted minke whale numbers over space and time, with a strong relationship to the 15% ice edge and a longitudinal gradient, with more minke whales predicted in the west of the survey area than in the east, around the 0° meridian.

The Committee noted these two studies used different definitions of 'the ice edge'. The authors stated in the future they will use the 3% level which corresponds to the IDCR/SOWER 'ice edge'.

The Committee noted that without some idea of availability bias for Antarctic minke whales, across a range of different sea ice concentrations and types, the ability to judge the true numbers of animals in sea ice areas is limited. After discussion, the Committee strengthened its previous conclusions that there is no reliable basis for quantitatively extrapolating these results to other areas and to the past. Nevertheless, these studies open the possibility of looking at variability in proportions-in-ice as a function of changing ice-coverage.

The Committee noted that currently availability bias for Antarctic minke whales has not been evaluated. To do so the Committee **agrees** that two types of information needed are: (1) information on time-at-depth results across a range of ice conditions; and (2) information on the *visibility* of minke whales from the air as a function of depth and water clarity. The first data need may be met by using satellite-tag information like that in Friedlaender *et al.* (2014), discussed in Item 13. The second data need might be harder to resolve. At least in principle, though, it could be addressed as a gigantic Secchi disk experiment, using a whale-shaped target moored underwater at known depth and over-flights from a fixed-wing, helicopter, or drone aircraft, presumably somewhere close to an Antarctic land base. It might also be possible to derive an estimate of availability bias from forward sighting data. An Intersessional Correspondence group was established to explore these methods and data.

SC/65b/IA14 investigated possible responsive movement of whales to observer vessels by analysing tracks of humpback and Antarctic minke whales conducted from the *RV Polarstern* in the Antarctic.

In discussion, the Committee recalled that the possibility of responsive movement in Antarctic minke whales had been considered several times in the past. Overall, no clear effects had been found. Notwithstanding some of the interpretational difficulties with these data, the Committee **welcomes** the prospect of more data coming from an extension of this paper, accompanied by information on environmental conditions.

The Committee also discussed acoustic detections of Antarctic minke whales as another way that could potentially reveal distribution and possibly abundance information. Risch *et al.* (2014) documented the sound referred to as the 'bio-duck' sound is produced by the Antarctic minke whale. The Committee noted that, now that the bio-duck sound is unmasked, it may be possible to scrutinise past, present and future hydrophone and sonobuoy data for evidence of minke whale distribution and variability, since the frequency range of the calls appears to be detected and recorded with the listening devices.

10.1.1.3 STOCK STRUCTURE

Two papers, SC/65b/SD1 and SC/65b/IA13, contain new genetic information on stock structure in the Antarctic minke whale, where the technical aspects were discussed under Item 11. SC/65b/IA13 presented an integrated approach, by using

genetic and morphometric data, for estimating longitudinal segregation of two populations for Antarctic minke whale. The result indicates that the spatial distribution of the two populations has a soft boundary in Area IV-E and V-W, which depends on year and sex.

The Committee noted (as in previous years) that the results from the SC/56b/IA13 approach should be useful for the In-Depth Assessment, once the model has been embedded in a random-effects framework as the authors intend, assuming that a consistent signal between the two types of data can be shown, and diagnostics are considered. The Committee agreed that it would be reasonable to continue to use the two-stock hypothesis as a default for In-Depth Assessment, although further data might of course change the picture in future.

10.1.2 Consideration of factors that may drive Antarctic minke whale distribution and abundance

SC/65b/IA10 reported relative densities in a spatial context of the circumpolar distribution of baleen whales using the data from CPII and CPIII of IDCR/SOWER. Generalised additive models (GAMs) and available climatological data were used to estimate the relative density. These models suggest that the spatial extents of blue, fin, humpback and southern right whales expanded throughout the time from CPII to CPIII, while that of Antarctic minke whales shrank. The spatial distribution of sei whales was relatively constant between CPII and CPIII, but it was difficult to make any conclusion because of the small sample size.

The Committee **welcomes** this paper, particularly as it will eventually be a contribution to the SOWER Special Volume. In discussion it was noted the difficulty of trying to model relationships between environmental covariates and species distributions, specific issues to be considered were identified in Annex G.

The Committee considered that Additional Variance (AV) should be further explored when trying to explain the inter-survey differences of the Antarctic minke whale abundance based on the IDCR/SOWER CPII and CPIII surveys. Overall, the inter-survey differences are too large to be explained in terms of (i) a single common trend in abundance across the whole Antarctic, and (ii) the intrinsic CV of the estimates; this 'unexplained' variation is known as Additional Variance. The Committee considered that there are really only three plausible causes: (1) Changes in longitudinal distribution from year to year; (2) Changes in the proportion of Antarctic minke whales in the ice (and therefore unavailable to SOWER surveys), both in time and by Area; and (3) 'Area-specific changes'. Ways to address investigate these three possibilities were discussed in Annex G.

10.1.3 Application of statistical catch-at-age (SCAA) models

SC/65b/IA03 updated the Statistical Catch-at-age Analysis (SCAA) for Antarctic minke whales in response to recommendations from the JARPA II review panel. Parameters of the model (annual deviations about the stock-recruitment relationship, changes over time in carrying capacity, density-dependence parameters (productivity and carrying capacity), and parameters which determine growth by stock, age-specific natural mortality by stock, and vulnerability by area and 'fleet') are estimated by fitting the model to data on catches, catch-at-length, conditional age-at-length, and estimates of absolute and relative abundance. This version of the SCAA provided analyses based on updated JARPA and JARPA II abundance indices, included results for three ways to model natural mortality-at-age, explored the sensitivity of time-trajectories of model outputs to assumptions regarding the age-averaged rate of natural mortality, explored the implications of not having the JARPA and JARPA II data, and provided results for a revised reference model which assumed that the updated JARPA and JARPA II indices are absolute rather than relative indices of abundance. The SCAA model is able to mimic all of the data sources adequately and indicates that Antarctic minke whales in the assessed area increased from 1930 until the mid-1970s and have declined thereafter, with the extent of the decline greater for minke whales in Antarctic Areas III-E to V-W than for those further east. The estimates of natural mortality (with asymptotic standard deviations) from the 'new reference case' assessment of SC/65b/IA3 for the I stock for ages <=3, 10-20 and >=40 are $0.077yr^{-1}$ ($0.016yr^{-1}$), $0.048yr^{-1}$ ($0.005yr^{-1}$), and 0.107 ($0.005yr^{-1}$) respectively while the corresponding values for the P stock are $0.074yr^{-1}$ ($0.016yr^{-1}$), $0.046yr^{-1}$ ($0.005yr^{-1}$), and $0.103\ yr^{-1}$ ($0.005yr^{-1}$) respectively. Given that carrying capacity for minke whales is estimated to have changed over time, measures such as population size relative to the (current) carrying capacity are not immediately straightforward to interpret. However, the results of SCAA can be interpreted in the context of trends in abundance. The new reference case model implies that the total 1+ population size increased annually by 1.9% (SE 0.50) (stock I) and 2.1% (SE 0.70) (stock P) per annum between 1945 and 1968. Numbers of 1+ animals were estimated to have declined by 54% (stock I) and 35% (stock P) from 1968 to 2001. SC/65b/IA03 confirms that the ability to estimate trends in abundance and natural mortality rely on the availability of age and length data from the period of both commercial and Scientific Permit catches.

In discussion, the insensitivity of the results of the SCAA to ignoring the JARPA and JARPA II index data was highlighted, noting that previous analyses based on Virtual Population Analysis had indicated that information on trends in abundance are required to distinguish between different values for natural mortality. Reasons for the lack of sensitivity include the fact that the JARPA indices are fairly imprecise, and, when age and length data are included, then the JARPA abundance indices do not convey much extra information about trends.

Some members, noting the estimates above for natural mortality, held the view that this allowed inferences to be drawn concerning minimum values for MSYR for this species, essentially on a similar basis to that used in the MSYR rate review. They added that the results from SC/65b/IA03 would be of particular importance in conditioning *Implementation Simulation Trial*s for these minke whale populations, as well as for further development of multi-species models.

Japanese scientists commented that the analyses of SC/56b/IA03 confirmed that age and length data collected during JARPA and JARPA II had allowed natural mortality for Antarctic minke whales to be estimated satisfactorily, as had been a key objective of JARPA.

Other members commented that, since the SCAA analysis concluded that the value of MSYR could not be estimated by

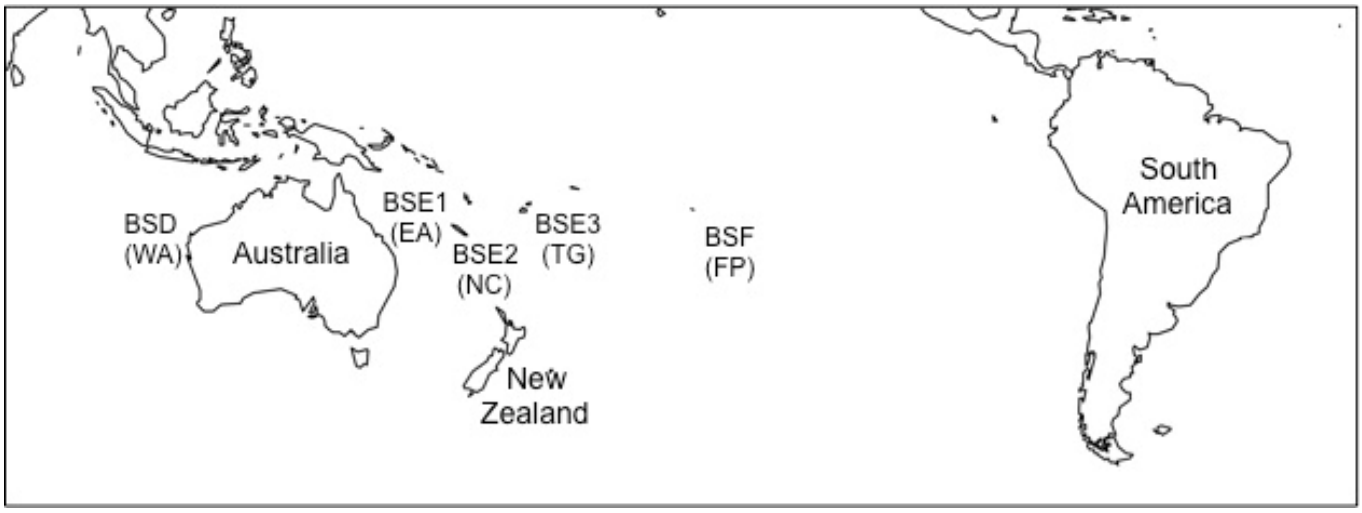

Fig. 1. Distribution of humpback whales breeding stocks grounds BSD, BSE1, and BSO (BSE2, BSE3 and BSF2). Note the following abbreviations: WA = Western Australia, EA = Eastern Australia, NC = New Caledonia, TG = Tonga and FP = French Polynesia.

the SCAA model due to lack of contrast (i.e. a wide range of MSYR values were consistent with the data under this model), it was not valid to attempt to exclude parts of the range of MSYR values from simple inspection of the model results. Therefore, it is not valid to use the SCAA results draw inferences about the level of MSYR or r_{max}.

10.1.4 Future directions for the in-depth assessment

After many years of working towards an in depth assessment of Antarctic minke whales, which has focused on the Indo-Pacific region of the Southern Ocean, the Committee can now provide conclusions and determine what outstanding issues are feasible and/or worthwhile to address in the future. The Committee noted that there were still research issues to complete, but that should not preclude the ability to provide conclusions on the assessment. Because the present In-Depth Assessment of the Indo-Pacific Antarctic minke whale has been so protracted, results are currently scattered across many different volumes of Committee reports. Thus, to complete the In-Depth Assessment of Antarctic minke whales in the Indo-Pacific region of the Antarctic next year, the Committee established an intersessional working group to summarise the state of knowledge.

The situation in the rest of the Antarctic is very different, as it has been decades since the Committee last attempted an assessment of the Antarctic minke whales in those regions. There is less data for other regions than the Indo-Pacific region, so feasibility needs to be considered before undertaking the In-Depth Assessment. It was noted that results from the Indo-Pacific might be helpful in assessing the other regions. An intersessional working group was established to summarise available data and knowledge for these other Antarctic regions.

10.2 Southern Hemisphere humpback whales

The report of the IWC Scientific Committee on the assessment of Southern Hemisphere humpback whales is given in Annex H. The Committee currently recognises seven humpback whale breeding stocks (BS) in the Southern Hemisphere (labelled A to G IWC, 2011e), which are connected to feeding grounds in the Antarctic (Fig. 1). An additional population that does not migrate to high latitudes is found in the Arabian Sea. Assessments of BSA (western South Atlantic), BSD (eastern Indian Ocean) and BSG (eastern South Pacific) were completed in 2006 (IWC, 2007). However, it was concluded at that time that BSD might need to be re-assessed with BSE and BSF in light of mixing on the feeding grounds. An assessment for BSC (western Indian Ocean) was completed in 2009 (IWC, 2010c) and for BSB in 2011 (IWC, 2012c).

10.2.1 Assessment of breeding stocks D, E and F

In 2011, the Committee initiated the re-assessment of BSD in conjunction with assessments of BSE and BSF. As shown in Fig. 1, these correspond to the humpback whales wintering off Western Australia (BSD), Eastern Australia (BSE1) and the western Pacific Islands of Oceania, including New Caledonia (sub-stock BSE2), Tonga (sub-stock BSE3), the Cook Islands and French Polynesia (BSF2). For simplicity, the combination of BSE2, BSE3 and BSF will be referred to herein as Oceania (BSO). These are the last breeding stocks remaining in the Comprehensive Assessment of Southern Hemisphere humpback whales, and their assessments were to be completed as a matter of high priority this year.

10.2.1.1 RESULTS OF MODELS DEVELOPED INTERSESSIONALLY

The Committee had previously recommended that work be carried out intersessionally to facilitate the completion of the assessment. This included: (1) obtaining a minimum bound on the absolute abundance of BSD (see IWC, 2014c) and (2) developing a suite of assessment models.

With respect to (1), the Committee used a preliminary estimate from Hedley. For reasons discussed in Annex H, Item 3.1, the value was considered tentative and requiring future confirmation.

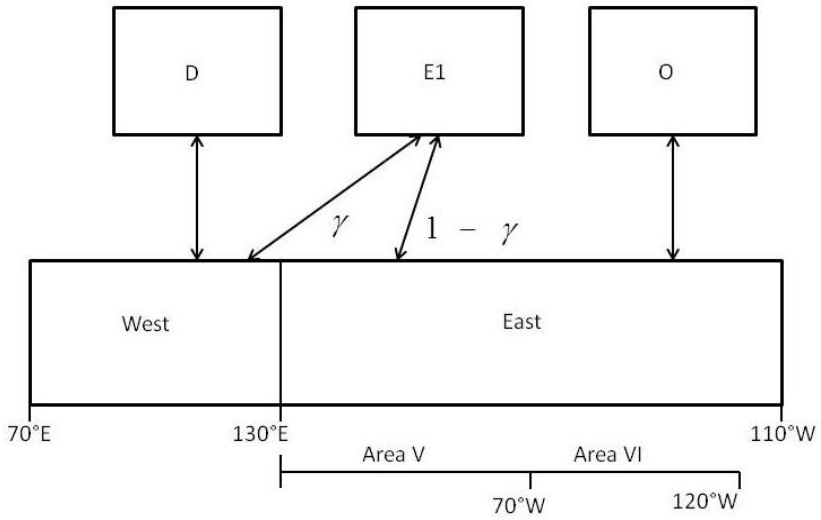

Fig. 2. Diagrammatic representation of the alternative three-stock model used as the base case in the final assessment of breeding stocks BSD, BSE1 and BSO. Antarctic Areas V and VI are shown for reference.

Table 12

Posterior median values of key model parameters for the base case model with 90% probability intervals in brackets.

	BSD		BSE1		BSO	
r	0.090	[0.053, 0.104]	0.105	[0.103, 0.106]	0.091	[0.071, 0.101]
K	21,686	[19016, 29383]	26,133	[21605, 29033]	14,115	[10198, 19651]
γ	-		0.068	[0.007, 0.190]	-	
N_{min}	824	[461, 3685]	237	[203,272]	132	[103, 250]
N_{2012}	19,264	[17,553, 24012]	16,366	[14674, 18034]	5,072	[4456, 6040]
N_{min}/K	0.039	[0.023, 0.128]	0.009	[0.008, 0.011]	0.010	[0.007, 0.014]
N_{2012}/K	0.904	[0.739, 0.984]	0.634	[0.561, 0.729]	0.371	[0.238, 0.535]
N_{2020}/K	0.984	[0.883, 0.998]	0.915	[0.872, 0.950]	0.648	[0.409, 0.846]
N_{2040}/K	1.000	[0.991, 1.000]	1.000	[0.999, 1.000]	0.993	[0.926, 0.999]

With respect to (2), assessment models developed intersessionally included: (1) a single stock model for BSD for a range of choices of the Antarctic feeding ground catches, (2) several two stock models and (3) a three-stock model of BSD, BSE1 and Oceania (BSO). These models are summarised in detail in SC/65b/SH04rev and SC/65b/SH04Addendum.

10.2.1.2 SPECIFICATION AND EVALUATION OF ADDITIONAL MODEL RUNS

The assessment began with a pre-meeting on 10-11 May and continued. It was agreed that a three-stock model (Annex H, fig. 1) best captured the uncertainty in high latitude catch allocations across the three breeding stocks.

Key issues addressed in the pre-meeting included:

(1) While the N_{min} constraint for BSO tended to be problematic intersessionally, the use of 'private' haplotypes (e.g., IWC, 2011, Annex H, appendix 2) resulted in markedly better model fits.
(2) Differences were noted (particularly for Oceania) between the high latitude catch allocations that best fitted the three-stock model and the results of a mixed-stock analysis that allocated high latitude mtDNA samples to low latitude breeding grounds (Annex H, appendix 2). The assessment proceeded by not fitting the model to the genetic data, and future work to address this question was identified.
(3) Whilst the original three-stock model was biologically more plausible than a one or two-stock model, it required estimation of 6 mixing parameters. An alternate (simpler) three-stock model (Fig. 2) resulted in parameters that were relatively well estimated and so it was used as the base case in the final assessment of BSD, BSE1 and BSO.

With agreement reached on the base case model specifications (Annex H, table 1), sensitivity runs were carried out to evaluate the effects of: (1) shifting the Antarctic catch boundaries; (2) modifying the bounds of the BSD absolute abundance estimate; (3) alternative treatment of New Zealand catches and (4) augmenting the Noad *et al.* (2011) relative abundance data for BSE1 with Forestell *et al.* (2011) mark-recapture data in the model fit. The details of these sensitivities are presented in Annex H, item 3.1.2.3.

10.2.1.3 FINAL ASSESSMENT MODEL RESULTS

Final assessment results and sensitivity runs are provided in Annex H, Appendix 3. The results for the base-case model are shown in Table 12. Plots of the median population trajectories for the base case three-stock model are given in Fig 3.

The Committee notes that the results of the model runs did not vary substantially under the different sensitivity scenarios, except if the minimum of the prior for the BSD absolute abundance in 2008 was increased appreciably. Further discussion is provided in Annex H, Item 3.1.3.

10.2.1.4 CONCLUSION AND RECOMMENDATIONS

The posterior median estimate of population status in 2012 relative to pre-exploitation abundance suggests that BSD is approaching pre-exploitation levels (90%, 90% probability interval (PI): 74-98%). However, the results are somewhat sensitive to the lower bound on BSD absolute abundance estimates for 2008, with greater abundance resulting in a slightly greater level of recovery. Given that the available lower bound estimate was preliminary, the Committee **recommends** future work to further refine that value.

A preliminary assessment of BSD was completed in 2006 and had concluded that there had been a substantial increase since protection (IWC, 2007). However, it was agreed at that time that the assessment modelling results should be re-evaluated in the future. It was anticipated then that this would require clarification of the stock structure of Oceania and the extent of mixing at high latitudes, as catch allocation would perhaps be influenced by mixing with BSE1. The three-stock models presented in the current assessment address the concerns expressed previously by allowing for mixing of neighbouring breeding stocks in the Antarctic feeding areas. Although direct comparisons between the two assessments should be viewed with caution due to differences in model inputs and assumptions, the results of the 2006 Fringe model for BSD are very similar to the current base case assessment (Annex H, Appendix 3, Table 2).

The base-case three-stock assessment results for BSE1 and Oceania were not sensitive to the assumption of BSD absolute abundance and suggested recovery towards pre-exploitation levels to be 63% (90% PI: 56-73%) and 37% (90% PI: 24-54%), respectively.

The Committee notes that the current assessment of BSO was valuable in terms of understanding the broader aspects of population status. However, complexities in Oceania require further investigation due to inadequate stock structure definition across the broad area, a lack of population trend data for most of the region, and a lack of resolution and understanding of connectivity in eastern Oceania.

As noted above, there was an inconsistency between the high latitude catch allocations that fit the model best and the mixing proportions of breeding stocks in the Antarctic as suggested from genetic data. Further work on this question would be valuable, although unlikely to alter the outcome of this assessment. For the future, the Committee **recommends** further examination of available genetic data, assumptions and analytical approaches, as described in detail in Annex H, item 3.1.4.

In conclusion, the Committee **agrees** that its assessment of breeding stocks BSD/BSE1/BSO had been completed. It acknowledges the efforts of all those who helped to bring the assessment to a conclusion. This also concludes the Comprehensive Assessment of Southern Hemisphere humpback whales. Noting that this circumpolar assessment took eight years to complete, the Committee **recommends** that assessment results for all Southern Hemisphere breeding stocks be compiled and synthesised for discussion next year.

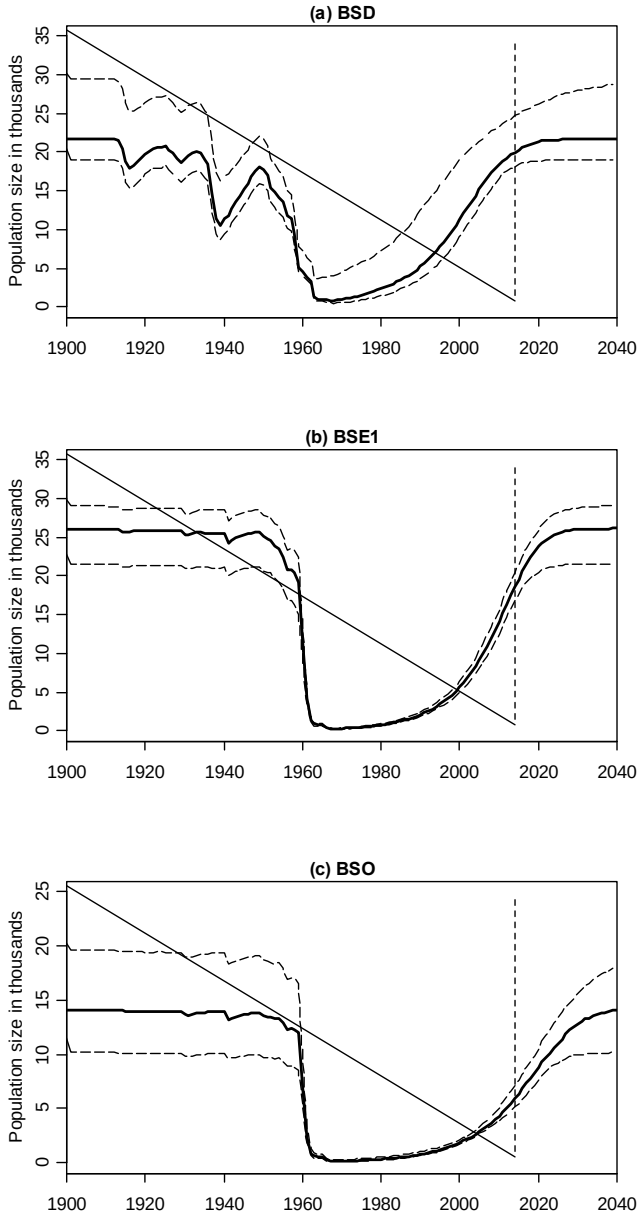

Fig 3. Median population trajectories for the base case three-stock model for breeding stocks BSD, BSE1 and BSO. 90% probability envelopes are indicated by the dashed lines.

10.2.2 Review new information on other breeding stocks

10.2.2.1 BREEDING STOCKS D, E, F

The Committee received four papers with new information on BSD, BSE and BSF, as described below. These papers, and their associated discussion, can be found below and in Annex H, Item 3.2.1. The Committee **welcomes** this new information noting that it remains consistent with the assumptions used in the assessment of breeding stocks BSD, BSE1 and BSO.

Polanowski *et al.* (2014) reported a new epigenetic technique for estimating humpback whale age from skin biopsy samples. The assay has an R^2 of 0.787 (p = 3.04e-16) and predicted age with a standard deviation of 2.99 years. It correctly ordered parent-offspring pairs in more than 93% of

cases. Age was estimated for 63 individuals off East Australia in 2009 and compared results to age profiles for the same population from 1952-1962. Although several caveats were noted, the authors concluded that the high apparent proportion of young animals in 2009 was interesting and warrants further study.

SC/65b/SH07 described a genetic study of humpback whales from Cook Strait, New Zealand. Samples from New Zealand (167 individuals) were compared to Oceania (1,052 individuals) and east Australia (865 individuals). DNA registers revealed six matches (and the least genetic difference) to New Caledonia. Five matches were made to east Australia, but none to any other part of Oceania. Further information is provided in Annex H and the Committee's discussion of the stock structure implications can be found in Annex I.

Orgeret *et al.* (In review) studied the population growth rate of humpback whales at New Caledonia. The results indicated a constant yearly growth rate of 1.15 (1.11; 1.20). This was higher than the maximum rate of increase for humpback whale populations (Zerbini *et al.*, 2010), but the authors hypothesised that it includes a contribution due to immigration from other areas. The Committee **welcomes** this paper and commented that analyses of this nature are important for understanding the effects of animal movement on estimates of population parameters.

SC/65b/SH10 introduced a new crowd-sourcing website, *Match My Whale*, which encourages citizen scientists to score and match humpback whale fluke photos in order to facilitate future cataloguing efforts for BSD and BSE1. The Committee notes the potential value of this project to harness increasing public interest in matching humpback whales online.

10.2.2.2 BREEDING STOCK G

SC/65b/SH15 provided an update on humpback whale research in the Gulf of Chiriqui, western Panama. This is the northernmost breeding area of any Southern Hemisphere humpback whale population, and is also used by whales migrating from feeding areas off California-Oregon-Washington in the Eastern North Pacific. The authors describe the continuation of their long-term monitoring efforts in 2013, which involved greater encounter rates, larger group sizes, and more photo-identification data collected than in prior years. The authors highlighted the importance of continued monitoring to understand population trends and underlying factors.

The Committee **agrees** that genetic studies in this area would be of particular interest given the use of this breeding ground by Northern Hemisphere animals, as well as by individuals from different Southern Hemisphere feeding aggregations.

10.2.2.3 BREEDING STOCK B

Rosenbaum *et al.* (2014) examined the movement of BSB humpback whales and their overlap with anthropogenic activities in the South Atlantic Ocean. This paper reported on the habitat use of three whale cohorts satellite tagged off Gabon and concluded that breeding areas in the eastern Atlantic were extensive and extended north of Gabon late in the breeding season. Also observed, for the first time, was direct migration between West Africa and sub-Antarctic feeding areas. Details can be found in Annex H., item 3.2.4.

10.2.2.4 FEEDING GROUNDS

Two IWC-SORP papers received by the Committee provided data on humpback whales in Antarctic and sub-Antarctic waters. SC/65b/SH05 provided an update of the CETA project which was carried on the continental shelf off Adélie Land in Area V. SC/65b/SH16rev reported on data collected from visual and acoustic observations from the Argentinean vessel *Tango* SB-15 during February 2014. Details of those cruises are provided in Annex H, item 3.2.5.

SC/65b/IA10 described an analysis of the circumpolar spatial distribution of humpback whales based on IDCR/SOWER CPII and CPIII data. A generalised additive model (GAM) was used to examine changes in the abundance of humpback whales among areas, relative to other species and environmental data. Details are provided in Annex H, item 3.2.5.

SC/65b/SH18 reported estimates of abundance and trends of humpback whales in the Magellan Strait off southern Chile. The results suggested an abundance of 88 individuals (95% CI: 81-95) in 2012 with a median population growth rate of 3.2%/year across the study, but close to zero in the past seven years. The authors concluded that this population is likely small and appears to be stable. The potential effect of ship strikes on this population was also examined. The Committee **welcomes** and **encourages** the continuation of this study. Further discussion is provided in Annexes E, H, and J.

10.2.3 Antarctic Humpback Whale Catalogue

SC/65b/SH03 presented the interim report of the IWC Research Contract 16, the Antarctic Humpback Whale Catalogue (AHWC). During the contract period, the AHWC catalogued 761 photo-id images representing 614 individual humpback whales submitted by 21 individuals and research organisations. Matches were made between BSG and the Antarctic Peninsula (18) and between BSG and the Chilean feeding area (3). Within-region re-sightings were identified in BSC3 (2), BSG (18) and the Antarctic Peninsula (7). Two individuals with 28 year sighting histories, the longest in the database, were identified during the contact period, and sixty-eight individuals had re-sightings spanning ten years or more. The fluke photographic collection has approximately doubled in size in the past five years, and now consists of 9,007 photographs of 5,923 individual whales.

The Committee has supported the valuable work of the AHWC in the past and **strongly endorses** its continuation.

10.2.4 Workplan

With the completion of the assessment of humpback whale breeding stocks BSD/BSE1/BSO, the Committee **agrees** that the Southern Hemisphere humpback whale assessment has been concluded. However, given that this circumpolar assessment had taken eight years to complete, the Committee **recommends** a thorough synthesis of assessment results and unresolved questions for discussion in SC/66a.

It further **recommends** that focus on the planning of the future direction of the Sub-committee on Other Southern Hemisphere Whale Stocks is given next year. Topics would include the feasibility of conducting assessments of other Southern Hemisphere species and consideration of future assessments of humpback whales. As foundation, a literature review is **recommended** to identify all new information

produced on Southern Hemisphere humpback whales since the Comprehensive Assessment began in 2006.

The Committee **recognises** the long-term value of photo-identification catalogues to support future assessments and **recommends** that work continue on the Antarctic Humpback Whale Catalogue. Consideration was also given to the importance of evaluating data needs to better inform future assessments. A modelling exercise is **recommended** as one means of informing this question.

Work is also **recommended** to address questions arising specifically from the assessment of BSD/BSE1/BSO. These included work to evaluate (1) the available genetic data, assumptions and analytical approaches for establishing mixing proportions of breeding stocks in the Antarctic and (2) the minimum abundance of BSD, which is only currently available as a preliminary value, but important to the interpretation of assessment results.

10.3 Southern Hemisphere blue whales

10.3.1 Review new information

10.3.1.1 ANTARCTIC BLUE WHALES

10.3.1.1.1 CRUISE REPORTS

SC/65b/SH01 reported on the South African National Antarctic Programme 2013/2014 cruise to the 000˚-020˚E Antarctic coastal region. Based on the relatively high numbers of blue whales sighted, the authors concluded that this region of the Queen Maud Land coast is a hotspot for Antarctic blue whales. The Committee **congratulates** the authors. Discussion held on data sharing and further cruise details can be found in Annex H, Item 3.2.5.

SC/65b/SH05 reported six sightings of Antarctic blue whales at the edge of the continental slope and in the Adélie depression. Three of the animals were individually photo-identified, one of which was re-sighted during the IWC-SORP Antarctic blue whale voyage in the Ross Sea region.

SC/65b/SH16 reported that a single blue whale was seen on one occasion on the Argentinean IWC-SORP Tango cruise in the Scotia Sea near Islas Orcadas del Sur (South Orkney Islands).

10.3.1.1.2 ANTARCTIC BLUE WHALE CATALOGUE

SC/65b/SH20 reported on catalogue comparisons of 52 individual Antarctic blue whales photographed between 2005/2006 and 2012/2013 during JARPA II from IWC Management Areas IIIE, IV and V. Three whales matched individuals in the Antarctic Blue Whale Catalogue with elapsed time intervals of 2 years (for 1 whale) and 7 years (for 2 whales). This brings the total of photo-identified Antarctic blue whales to 354. This work provides data for capture-recapture estimates of abundance as well as information on the movement of individual blue whales within the Antarctic region.

The Committee **thanks** the authors and **recognises** the contribution of this on-going work. It also **recommends** that blue whale research be prioritised in upcoming Japanese Southern Ocean sighting cruises.

10.3.1.1.3 ACOUSTIC STUDIES

The IWC-SORP Antarctic Blue Whale Project (ABWP) reported a number of developments in the use of directional (DIFAR) sonobuoys to give bearing information to baleen whale calls. This has a number of uses including locating animals for further study, such as photo-id, but also for applications related to estimates of abundance derived from acoustic data. DIFAR sonobuoys were used successfully during the 2013 Antarctic Blue Whale cruise to locate blue whales from distances of hundreds of kilometres and hence the steering committee of the ABWP has encouraged their use more widely within the project.

Papers were presented describing software tools to facilitate the use of DIFAR to obtain bearing information in real time (SC/65b/SH06), results of experiments to measure the accuracy and precision of a sonobuoy-based localisation system (SC/65b/SH08), and methods to estimate the drift of sonobuoys (SC/65b/SH09). Most DIFAR sonobuoys send data via VHF radio link back to an aircraft or nearby vessel. While there are some general purpose tools available for working with DIFAR signals, full analysis has required a limited number of bespoke systems, including a more user-friendly software system.

Measurements of the source levels of blue whale calls and propagation loss are important for determining the likely distances over which whale calls may be detected. SC/65b/SH11 presented preliminary estimates of source levels for the first (unit A) 25-29Hz component of Antarctic blue whale 'Z' calls. The authors concluded that with the source levels reported, and under assumed propagation conditions, these calls can be detected from thousands of kilometres away.

Miller *et al.* (2014) explored the Doppler effect as a potential explanation for the long-term linear decline in blue whale calls. Analysis suggested that this was unlikely to fully explain the observations of intra-annual pattern in the frequency of Antarctic blue whale song. Details of this study can be found in Annex H.

Taking these methodological papers as a whole, the Committee notes that the results had confirmed the potential to detect blue whales at over 1,000km in the Southern Ocean. It **recognises** the advancements that these methodologies have made towards improved abundance estimation of Antarctic blue whales and **encourages** the continuation of this important research.

Shabangu and Findlay (2014) described efforts to compile 7,500 sonobuoy acoustic data files from over 700 stations across IWC SOWER Antarctic cruises from 1996/1997 to 2008/2009 in Areas I-VI. Also included were data from three blue whale cruises off Australia, Madagascar and Chile. A total of 1547.76 hours of recordings have been reviewed and blue whale vocalisations have been detected in 55% of the 7,501 recorded files.

Van Opzeeland *et al.* (In press) reported on the SOHN initiative of the IWC-SORP Acoustic Trends Project. This is a long-term program to examine trends in blue whale and fin whale in the Southern Ocean through passive acoustic monitoring. The initiative proposes a circumpolar network of autonomous acoustic recording stations surrounding the Antarctic continent with at least one recording site in each IWC management area. Practical recommendations were also given to increase the efficiency of passive acoustic data collection in Antarctic waters.

10.3.1.4 ABUNDANCE ESTIMATION

Part of the planning process for the IWC-SORP Antarctic Blue Whale Project has been to evaluate how much effort would be required under various survey methods to obtain a precise estimate of circumpolar abundance. The Committee received four papers on such methodological considerations of abundance estimation. The Committee notes that pre-survey analyses such as these are important and are **encouraged**.

SC/65b/SH13 explored the precision of a circumpolar abundance estimate that might be expected from a line-transect survey, and how it might be predicted for varying amounts of survey effort, given population increases. The precision for 6-year research programmes was too low to be considered useful, but the predicted precision of a 12 year program was 27%. The benefits and disadvantages of a line transect approach were discussed.

SC/65b/SH14 predicted the precision and bias of estimates from a hypothetical mark-recapture survey programme. It suggested a precision of the abundance, at the mid-point of the programme, of between 0.2 and 0.3 if passive acoustic tracking were utilised to increase the encounter rate. A 12 year study would be required, but surveys would not necessarily have to occur every year. The authors highlighted that care would be required to ensure that mark-recapture assumptions were met.

SC/65b/SH17 proposed that if parent-offspring pairs could be identified genetically from biopsy samples then these 'recaptures' could be accommodated in an extended mark-recapture model and improve greatly improve precision without any additional survey effort. The model could be made robust against bias arising from un-modelled heterogeneity, without inflating the CV. Precision could be improved further using epigenetic aging techniques (Polanowski *et al.*, 2014) to tell which animal is the parent and which the offspring.

The Committee discussed the relative priority of biopsy and photo-identification sampling to achieve mark-recapture goals, as well as the availability of mark-recapture models that combine genetic identity and photo-ID information. Details can be found in Annex H.

Peel *et al.* (2014) evaluated acoustics as a tool to increase the encounter rate in mark-recapture surveys. Encounter rates were predicted using a discrete-time individual-based simulation of whales and survey vessel. The results suggested that passive acoustics should provide a 1.7–3.0 fold increase in encounter rate of Antarctic blue whales over visual-only methods.

Olsen *et al.* (In press) presents a mark-recapture analysis of Antarctic blue whale photographs taken on 15 IDCR/SOWER cruises from 1991/92 to 2008/09. Circumpolar abundance was estimated at 3,151 (95% CI: 530-24,113) from left side images and 4,286 (95% CI: 1,923-9,802) from right side images, both with large confidence intervals and based on five recaptures. For Area III, the corresponding estimates were 1,318 (95%CI: 514-3,716) from left side images and 939 (95%CI: 421-2,323) from right side images. The Committee **welcomes** this analysis, which provides the first abundance estimates of Antarctic blue whales since Branch (2007). It **agrees** that the authors be invited to the Scientific Committee in the future to discuss this work.

10.3.1.5 PYGMY-TYPE BLUE WHALES

SC/65b/SH02 investigated evidence that blue whales have used the South Taranaki Bight in New Zealand as a foraging ground over the last 10 years. The authors concluded that photo-identification, biopsy sampling; environmental and prey data collection and behavioural observations in 2014 strongly supports this hypothesis, but that more research is needed.

The Committee recommends work to clarify the population identity of blue whales observed off New Zealand, noting that the relationship among pygmy blue whales in different areas of the Southern Hemisphere continues to be unclear and merits further investigation.

Double *et al.* (2014) reported on migratory movements of 11 pygmy blue whales between Australia and Indonesia as revealed by satellite telemetry. Individuals were tracked from between 8 and 308 days and covered an average distance of 3,009 ± 892 km, at a rate of 21.94 ± 0.74 km per day. The Committee notes these results on migratory movements with interest and **recommends** the continuation of this work.

10.3.1.6 CHILEAN BLUE WHALES

Galletti Vernazzani presented an update on efforts to obtain the first abundance estimates from blue whales off Chile based on photo-identification and mark-recapture techniques. The effects of different photograph quality approaches and the impact of a possible transience signal in this population are being investigated. The Committee **welcomes** this update and receiving final results next year.

10.3.2 Southern Hemisphere Blue Whale Catalogue

The Southern Hemisphere Blue Whale Catalogue is an international collaborative effort to facilitate cross-regional comparison of blue whale photo-identification catalogues. It currently includes photo-identification catalogues of researchers from major areas off Antarctica, Australia, New Zealand, Eastern South Pacific and the Eastern Tropical Pacific. These are organised into three major regions, with a regional coordinator appointed for each: (1) Australia/New Zealand/Indonesia (Salgado Kent); (2) Southern Ocean (Olson); and (3) Gulf of California/Eastern South Pacific/ETP (Galletti Vernazzani). Photos are added to the catalogue by region and the regional coordinator appoints a photo-ID expert to perform the matching. Funding is distributed between regions according to the amount of work to be done. A total of 1,101 blue whales are currently catalogued (843 from the right side, 857 from left side and 23 from flukes). The SHBWC has also identified potential improvements in procedures and matching priorities, as described in Annex H, item 5.2.1.

The Committee notes the value of the SHBWC and **recommends** its continuation. Noting that the catalogue had grown in the last few years, discussion focussed on aspects of quality control and matching processes by both the contributing institutions and the SHBWC, as detailed in Annex H. The Committee notes the importance of continued development, reinforcement and communication of SHBWC contributor protocols and terms of reference.

10.3.3 Genetic analyses

Torres-Florez *et al.* (2014) reported on genetic relationships between the whales from southeastern Pacific (SEP) areas of southern Chile, northern Chile and Eastern Tropical Pacific (ETP) and Antarctic blue whale feeding grounds. Significant differences between Antarctica and the other three areas of the SEP were found, but not between the two areas in Chile, nor the ETP. Current analyses support the hypothesis that blue whales sampled in the SEP belong to a unique population, but more data are required. Analyses now underway include eastern North Pacific blue whale samples.

The Committee discussed that, as with many areas, the population identify and structuring of blue whales in the ETP is uncertain. The intermixing of blue whales from the North Pacific, Southeastern Pacific and Antarctica provides challenges that may affect the degree of population structure that can be detected in samples from the ETP. The stock structure implications of this paper were also discussed in Annex I.

10.3.4 Work plan

The Committee **recommends** the continuation of the Southern Hemisphere Blue Whale Catalogue. It also **recommends** efforts to further develop and reinforce SHBWC protocols and to ensure clear communication of the terms of reference of the catalogue to current, pending and future contributors.

The Committee recognises that considerable new information has become available for pygmy blue whales in recent years. It **recommends** that relevant information be synthesised for SC/66a so that regions with adequate data can be identified for a potential future assessment. Further details are given in Annex H, Item 7.2.

10.4 Distribution of baleen and toothed whales in the Antarctic relative to spatial and environmental covariates

SC/65b/IA10 reported circumpolar distribution of six different species of baleen whales using the data from CPII and CPIII of IDCR/SOWER. The main purpose was not to estimate absolute abundance in the survey areas but to show relative density in a spatial context. This paper was discussed in detail under Item 10.1.2 in only the context of the Antarctic minke whale, although the analytical discussion applies to all species.

10.5 In-depth assessment of North Pacific sei whales

10.5.1 Preparations for in-depth assessment

10.5.1.1 ABUNDANCE AND DISTRIBUTION

SC/65b/IA04 provided preliminary abundance estimates for North Pacific sei whales using sighting data collected during the 2010-2012 IWC-POWER surveys. Abundance in the central and eastern North Pacific (north of 40°N, south of the Alaskan coast including both the US and Canadian EEZ between 170°E-135°W), from July to August was estimated as 34,150 (CV=0.27) for the base case scenario. In the sensitivity analysis, abundance estimates ranged from 26,926 (CV=0.205) to 32,843 (CV=0.272).

In discussion, the Committee provided some technical suggestions to improve the analysis, which are detailed in Annex G item 4.1.1. The authors indicated they will update this analysis and also provide a spatial modelling analysis of these data when the data have been validated by the IWC Secretariat.

With the completion of the first trans-Pacific series of POWER surveys north of 40°N and south of the Aleutians, the Committee concluded that there was now a sufficient basis of new abundance data for proceeding with the In-depth Assessment. The Committee **requests** that the POWER data continue to be validated by the Secretariat in the usual way.

10.5.1.2 STOCK STRUCTURE

SC/65b/IA08 reported on the uncertain stock origins of sei whales represented by 71 products purchased in Japanese market from 1997-2009. Of these products, 21 of them showed a phylogenetic affinity with available reference sequences from the Southern Hemisphere rather the expected affinity with available reference sequences from the North Pacific. Possible explanations were explored.

In discussion, (and see Item 11), the Committee **concludes** that the possibility that the market samples reflected additional, previously undetected, genetic diversity within the North Pacific could not be ruled out at this stage and, therefore, **recommends** a direct comparison between market and JARPN II samples to (a) reconstruct phylogenetic relationships, (b) determine if there are significant difference between the market samples and the JARPN II samples and (c) investigate the levels of genetic diversity and the factors explaining possible differences. Two independent proposals were presented to address these questions and are detailed in Annex G, Appendices 3 and 4. The proponents of the two studies agreed that, for the results to be presented next year, they would focus on mitochondrial DNA sequences, because this did not require inter-lab calibration. They recognised that this would not permit individual identifications. Analysis of micro-satellites would also be performed, but not necessarily by next year.

The Committee noted that both studies depend on Data Availability requests being granted under Procedure B of the Data Availability guidelines. Because these results are needed by the Committee for the formulation of stock structure hypotheses under the In-depth Assessment to commence next year, the Committee **endorses** both proposals and **requests** their favourable consideration by the Data Availability Group and the data holders.

The Committee noted that interpretation of the market samples would be aided by knowledge of the geographical and temporal distribution of purchases and thus **requests** that date and location of purchase be included in the data set to be provided for the above studies. Several members considered that more detailed information on the origin of market samples are necessary for a better interpretation of the genetic analysis. This information should include exact location of purchase, date of purchase, labelling and proof of purchase.

The Committee also identified a need for better elucidation of the world-wide genetic structure of sei whales. Pastene reported that a collaborative study is currently underway between the ICR and the University of Groningen, (Palsbøll) to do this using samples obtained from the North Atlantic, North Pacific and Southern Hemisphere. The Committee **welcomes** this study looks forward to receiving results from this study next year.

The Committee concluded that, pending the results of the above studies, it was not yet able to formulate stock structure

hypotheses for North Pacific sei whales. This would be accomplished during the In-depth Assessment.

10.5.1.3 CATCH HISTORY

Allison reported that she had now received the remaining Canadian catches, and that these data, together with the remaining revised Soviet catches, are being entered into the IWC Catch Database. This is expected to be complete within the next 2-3 months. The catch data for North Pacific sei whales is now considered complete.

10.5.1.4 PHOTO-IDENTIFICATION

During the POWER cruises in 2011 and 2012, photo-identification data were collected for all whales that the ship approached for species confirmation and/or for biopsy sampling. Photographs were obtained with sufficient detail to catalogue 27 individual sei whales from the 2011 cruise, and 51 individuals from the 2012 cruise. There were no matches between these two years.

The Committee found these results promising but there was insufficient time to discuss them. The question of how to incorporate photo-id data into sei whale assessments was deferred and submission of a paper encouraged.

10.5.2 Work plan

Given the abundance data from POWER and JARPN II, completed catch history, historical abundance data listed in (IWC, 2013c, p.211) and results expected from the genetic studies, the Committee **agrees** that it can proceed with the In-depth Assessment for sei whales which was expected to last two years (see Annex G item 4.2).

Since the Committee expected to specify assessment runs at the 2015 Annual Meeting, it **recommends** a proposal (Annex G Appendix 5) be funded to develop the appropriate population dynamic models and report(s) documenting the models, their structure, the data used for analysis, results and interpretation of the results to be submitted to the 2016 Annual Meeting.

10.6 Gray whales in the western North Pacific

The discussion of the rangewide workshop is given under Item 9.2.1. That workshop incorporated information from all parts of the North Pacific, including some of the information provided below.

10.6.1 New information

SC/65b/BRG12 provided a summary of sightings of western gray whales near Japan. No gray whales were seen during several cetacean sighting surveys, including JARPN II, from spring to autumn 2013. There was a report of opportunistic sightings of gray whales in the Sea of Japan, just off the estuary of Ohkozu-Bunsuiro diversion channel, Teradomari town in Niigata prefecture in April 2014.

The Committee **welcomes** this information and **encourages** further analysis of the photographs to confirm that there were two whales and whether it was a mother-calf pair. The Committee **strongly recommends** that these photographs be compared with other photographs of gray whales from throughout the range.

SC/65b/BRG12 (also presented to the rangewide workshop) osteologically compared five specimens stranded or entangled off the Pacific coast of Japan between 1990 and 2005 (1 mature and 4 immature animals) with one whale from Ulsan, Korea and one from California, USA, which was reported by Andrews (1914). In 2013, Nakamura and Kato examined five additional California specimens (body length, 9.3–11.7m). The Committee reiterates the view of the Workshop, **welcoming** the results of the work and **encouraging** its continuation. However, it cautions against over-interpretation of any differences between the California, Ulsan, and Japanese specimens until the sample size is increased and factors such as differences with maturity stages are addressed.

The Committee **welcomes** the annual update of the results of the collaborative Russia-US research programme on gray whales summering off Sakhalin Island, Russia (SC/65b/BRG15). The results are discussed in Annex F, item 3.2.1 2014 represents the 19th year of the study.

The Committee also **welcomes** the summary report of the annual study under the Joint Western Gray Whale Monitoring Programme off Sakhalin Island. This is also discussed under Annex F, item 3.2.1.

Although recognising some of the difficulties of sharing data, the Committee again **recommends** that the two programmes off Sakhalin should make every effort to collaborate, especially in sharing photographs and other data. Oil and gas activities are increasing near Sakhalin and the Committee **recommends** that other operators should be involved in studies and monitoring of western gray whales and follow the best mitigation practices (e.g. see Nowacek *et al.*, 2013) to ensure protection of these whales and their habitats off Sakhalin Island.

10.6.2 Other issues

There is substantial concern about interactions between gray whales and coastal fisheries in the western North Pacific. Between 2005 and 2007, four female gray whales in the western North Pacific were unintentionally entrapped and died in set nets (i.e. trap-nets) while migrating off the Pacific coast of Honshu, Japan (Kato *et al.*, 2013).

The Committee **expresses concern** about the possibility of the development of a salmon trap net fishery in the feeding areas of western gray whales off Sakhalin. Last year, the placement of these nets directly overlapped with a core portion of the feeding ground and within critical habitat for mothers with calves. An animal was seen trailing fishing gear that may have originated in this local fishery. Ilyashenko noted that his understanding is that the Russian Federation will prohibit fishing in the feeding areas of gray whales off Sakhalin Island in 2014. The Committee **recommends** that the Russian Federation and local Sakhalin authorities prohibit trap net fishing on the gray whale feeding grounds in the future.

The Committee also received information about *Exxon Neftegaz Limited's* proposed development of a temporary facility to be situated on the eastern shore of Sakhalin Island for the unloading of various modules for oil and gas activities. It **expresses serious concern** over this proposed development project and its possible immediate and cumulative impacts on gray whales, their feeding habitat and prey. The Committee **requests** additional information on the proposed project and **urges** the Government of the Russian Federation to take steps to ensure the maintenance of Piltun Lagoon.

10.6.3 Conservation advice

The Committee again **acknowledges** and **welcomes** the important work of the IUCN WGWAP (Western Gray Whale Advisory Panel) as reflected in the updated report provided to this meeting and **encourages** its continuation. As previously, the Committee again **recommends** that oil and gas development activities (including seismic surveys and on- or near-shore development) in areas adjacent to or used by gray whales be undertaken only after careful planning for mitigation and monitoring. This should include a credible environmental impact assessment process prior to final decision-making. The Committee also **welcomes** the efforts of Japan with respect to the conservation and research on gray whales and **encourages** those efforts to continue.

10.7 Southern Hemisphere right whales

10.7.1 Review of new information

10.7.1.1 CIRCUMPOLAR

SC/65b/IA10 reported circumpolar spatial distribution of southern right whales using the IDCR/SOWER CPII and CPIII data. A Generalised additive model (GAM) was used to estimate the probability of occurrence. Sightings were restricted in Area II and IV both in CPII and CPIII. The abundance estimate from CPIII data in Area IV was *ca* 900.

10.7.1.2 SOUTH ATLANTIC

SC/65b/BRG06 reported on the high mortality rates at Península Valdés, Argentina in 2003, the Southern Right Whale Health Monitoring Program was established by a consortium of NGOs to monitor the health status of this population by post-mortem examinations. A total of 672 dead whales have been recorded on the Península Valdés nursery ground and surrounding areas along the Argentine coast between 2003 and 2013. At least 116 whales died in 2012, which represents the highest number of southern right whale deaths ever recorded in one calving and nursing season. The number of dead whales was 67 in 2013. As in previous years, most of the dead whales were newborn calves (97% of strandings in 2012 and 94% in 2013).

The Committee discussed the increased prevalence of kelp gull attacks at length. The authors confirmed that attacks are most common on calves and, with very few exceptions, the calves are dead before they strand. Not all stranded animals can be examined; search flights occur every 14 to 20 days so some carcases are too decomposed before discovery. However, it is unlikely many calves are stranding outside the search area. The high variability in calf mortality between years has not been explained and is not clearly linked to environmental variation or simply variation is the number of calves born in the region. Notably 24% of the calves that died in 2012-2013 had no gull-inflicted lesions possibly because they died so quickly after birth.

The Committee **expresses concern** over the high calf mortality reported in this population and recommends that the Southern Right Whale Health Monitoring Programme continue as a high priority under the Conservation Management Plan. It also **recommends** that information on the gull control programme is reported to the IWC Workshop to be held in Puerto Madryn, Chubut in August 2014.

SC/65b/BRG7 reported on the fifteen year aerial survey monitoring programme developed by the Marine Mammal Lab. (CENPAT-CONICET). The monitoring area covers waters around Peninsula Valdes in a coastal strip of 620km. Two difference models were used to estimate the trend of the population and in both cases the trend was positive. Also the density is increasing and the range of the whales is expanding. The Committee **welcomes** this report and **urges** that these annual surveys should be continued.

The Committee **welcomes** this study which is valuable in monitoring the recovery of this population together with changes in distribution. Even with estimates of calf mortality there would be a considerable time lag between years of high calf mortality and associated changes in the rate of population growth. High rates of very early calf mortality could explain an increase in the frequency of two-year calving intervals. This would not be anticipated in a population approaching its natural carrying capacity.

10.7.1.3 AUSTRALIA

Bannister outlined the results of a right whale aerial survey off the southern coast of Australia in late August 2013. Funded by the Australian Government through the Australian Marine Mammal Centre, Hobart, the survey, the 21st in an annual series since 1993, covered some 900 n.miles (*ca* 1700 km) close to the coastline between Cape Leeuwin, Western Australia and Ceduna, South Australia, to which the majority of Australian right whales (the 'western' subpopulation) resort in winter/spring. The 2013 cow/calf count (246 pairs) was the highest yet in the series; the calculated population growth rate, 1993-2103 was 7.39% (95% CI 4.55-10.29), and the estimated size of that part of the Australian population to be found in the survey area, based on the number of calving females recorded over the three-year period 2011-2013, is 2756. Given the likely very much smaller number in the 'eastern' Australian subpopulation, the 'Australian' right whale population probably numbers around 3000.

The Committee **welcomes** the report and **urges** that such annual survey work should continue.

10.7.1.4 SOUTH AFRICA

The Committee received a short report on the annual right whale surveys off South Africa and looks forward to a full report next year.

10.7.2 Conservation issues

The Committee received a report on progress under the Conservation Management Plans of the Southwest Atlantic and Eastern South Pacific populations of Southern right whales. The Committee congratulated the teams that have contributed to the actions of the Conservation Management Plans. It stressed the importance and effectiveness of coordinated international action under these Plans given the small number of whales in the right whale population off Chile and Peru and the high calf mortality recorded off Argentina.

10.8 North Atlantic right whales

The Committee **welcomes** SC/65b/BRG14, produced in response to last year's request for an update on the status of the North Atlantic right whale population. A review of the photo-ID recapture database indicated some 455 individually recognised whales known to be alive during 2010. There appears to be a positive and slowly accelerating trend in population size of around 2.8%. From 2007 to 2011, the minimum rate of annual human-caused mortality and serious injury averaged 4.05 per year (annual incidental fishery entanglement, 3.25; ship strike records, 0.8). To reduce ship

strikes, the 2008 US Administrative rule creating speed restriction zones was re-established in 2013 because there was evidence that the rule had been locally effective. To reduce fishery entanglements the National Marine Fisheries Service has implemented rules requiring pot gear to use sinking ground lines in areas seasonally used by right and humpbacks.

10.9 North Pacific right whales

SC/65b/BRG11 reported the sighting summary of North Pacific right whale collected by JARPN and JARPN II from 1994-2013. Right whales were mainly found north of 42°N in the research area (55 schools and 77 individuals; observed mean school size: 1.4); there were records of 10 mother and calf pairs.

The Committee **welcomes** this information provided in response to a request from last year. The Committee **recommends** that a photo-id catalogue be established as soon as possible to compare with existing photographs from the Okhotsk Sea, eastern Bering Sea and other western North Pacific photos held by Japanese and Russian researchers. In addition, the Committee **recommends** that Japanese scientists prepare abundance estimates for right whales in the Okhotsk Sea and off the Kamchatka Peninsula.

10.10 North Atlantic bowhead whales

Shpak reported that in recent years, bowhead whales from the critically endangered Spitsbergen population have been regularly encountered in the waters of Franz-Josef Land (FJL) Archipelago during research vessel expeditions, helicopter surveys and land-based observations conducted by the National Park 'Russian Arctic' and Russian Geographic Society.

In April 2010, 20 bowhead whales were observed in the western part of FJL, in polynyas southwest of George Island (Gavrilo and Ershov, 2010). Gavrilo and Ershov (2010) summarised other past sightings of bowhead whales in the waters of the FJL.

Since 2010, there have been continued sightings of bowhead whales in the waters of FJL. In 2013, during the two visits in the first half of April, 3 groups of at least 9 whales in total were observed in polynya west off FJL (Gavrilo, 2013a). In August, during *Pristine Seas Franz-Josef Land Expedition – 2013*, ca. 40 whales in total were observed in FJL waters (Gavrilo, 2013b). In April 2014, 3 whales were encountered in polynyas (Gavrilo, 2014). Mapping of sightings from 2010-2013 expeditions has allowed (Gavrilo, 2014) to document areas of regular bowhead encounters in the southern part of FJL.

Based on the summarised findings, Franz-Josef Land Archipelago should be considered an important habitat for Spitsbergen population of bowheads for late winter through summer.

The Committee **welcomes** this work, **encourages** its continuation and looks forward to further updates.

10.11 Okhotsk Sea bowhead whales

SC/65b/BRG17 presented new information collected in the Shantar region of the western Okhotsk Sea in 2013. Bowhead whales were encountered in Udskaya Bay in July and October; interviews with locals suggest whale presence in the bay throughout the summer. In Ulbansky Bay, in August, as many as 56 bowhead whales were counted during a single 360-scan from the water with a limited to 2 km visibility, suggesting that the size of the stock observed is much larger.

The Committee **welcomes** this work, **encourages** its continuation and looks forward to further updates.

SC/65b/BRG17 estimated the abundance of bowhead whales in Academii Bay in the Shantar region of the Okhotsk Sea as 328 (SE=125) whales using genetic mark-recapture population estimate methods. The endangered Okhotsk Sea population of bowhead whales face both natural and anthropogenic threats to recovery. Natural threats include killer whale predation which has been observed several times per season in the region. Anthropogenic threats include fishing activities such as salmon net entanglements (two reported cases within past two years) and industrial activities such as the planned construction of terminal for mining in Konstantina Bay (northwestern arm of Academii Bay) and oil and gas development in the northern Okhotsk Sea. The Committee thanked the author for this update on research of the small Okhotsk Sea bowhead population. The Committee **recommends** collaboration of genetic laboratories to allow analysis of all available genetic samples for a population estimate.

10.12 Arabian Sea humpback whales

10.12.1 Review new information

SC/65b/SH19 reported on preliminary results from satellite tracking studies of male Arabian Sea humpback whales (ASHW) at Oman. Three of five tags deployed provided locations for several weeks and the movement results were consistent with a prior spatial modelling study. Further analysis is planned after additional tags are deployed in April 2015 in the Gulf of Masirah. The spatial ecology of this sub-population continues to be poorly understood and the authors proposed that tagging be part of on-going research in the region. It was further reported that the involvement of participants from other ASHW range states in the tagging programme was important to the development of cetacean research programmes in other areas of the Arabian Sea. The Committee notes the value of this work and **strongly endorses** its continuation.

10.12.2 Progress toward the development of a Conservation Management Plan and other conservation initiatives

Willson reported on progress towards a Regional Conservation Initiative. The Committee had endorsed these plans in SC/65a and during the last year, a consortium of NGOs and active researchers in the region developed an agenda to facilitate that work, including a workshop funded by the US Marine Mammal Commission and WWF. This workshop will facilitate capacity building of research personnel and prioritisation of activities toward areas considered to be hotspots. Further assessment of escalating threats will also be evaluated. Priority tasks have been identified including: genetic analysis of existing biopsy samples, field survey training, and preliminary surveys in the Gulf of Kutch on the Pakistan-India border.

The Committee **welcomes** efforts to develop regional cooperation for research and capacity and **recommends** the priority tasks listed above.

The Committee **reiterates** its serious concern about the endangered status and threats facing this distinct population.

A regionally coordinated conservation and research program is **strongly recommended** and the Committee urges the IWC and range states to consider the nomination of the Arabian Sea humpback whale for a CMP, given the benefits that a regional framework would provide. The Committee also suggests that the issue be reviewed by the Conservation Committee, with the continued support of the intersessional Arabian Sea working group.

10.12.3 Work plan

The Committee **recommends** a combination of exploratory surveys and molecular genetics for the Arabian Sea population, as well as the following planned work: (1) the continuation of satellite tagging of humpback whales off Oman; (2) an intersessional workshop in 2014 to facilitate research capacity building, prioritisation of research in potential hotspots and further assessment of escalating threats; and (3) continuation of the Arabian Sea Working Group.

10.13 International cruises

10.13.1 IWC-POWER cruises in the North Pacific

The IWC-POWER programme has been through a thorough planning process by the Committee and the Committee has developed short-, medium- and long-term goals over a number of years based upon a thorough review of data available throughout the North Pacific. The short-term part of the programme is to cover all of the poorly-covered areas of the North Pacific with sufficient coverage to allow the necessary information on distribution, density and abundance (as well as biopsy samples and photo-identification data) to enable the design of a robust medium- and long- term programme that meets the objectives of the IWC-POWER programme. Although the research programme is designed by the Committee, the Committee **acknowledges** the tremendous support of the Government of Japan who provide a vessel and crew for 60-days each year – this is tremendous in-kind support without which the programme could not take place.

This year, the Committee reviewed the results of the 2013 cruise (Item 10.13.2) and report from the Planning Meeting for the 2014 survey (Item 10.13.3) and discussed plans for the 2015 and 2016 surveys (Item 10.13.4), mid- and long-term recommendations (Item 10.13.5), and the archived photographs (Item 10.13.6).

10.13.2 Review of the 2013 IWC-POWER sighting survey

The 4th annual IWC Pacific Ocean Whale and Ecosystem Research (IWC-POWER) was successfully conducted by the Japanese from 12 July to 9 September 2013 in the eastern North Pacific (north of 30°N, south of 40°N, between 160°W and 135°W). Researchers from Japan, Korea and México participated. The cruise had five main objectives (see Annex G, item 5.1). Survey plans had been endorsed by the Committee (IWC, 2014i). The Committee **agrees** that it was duly conducted following the guidelines of the Committee (IWC, 2012f).

Further details of the cruise, including summaries of the sightings made, may be found in Annex G, item 5.1. The Committee thanks the Cruise Leader, researchers, Captain and crew, and the Steering Committee for completing this cruise. The Governments of the USA and Mexico granted permission for the vessel to survey in their respective waters, without which this survey would not have been possible. The Government of South Korea provided one scientist, and the Government of Japan generously provided the vessel and crew. Furthermore, the IWC Secretariat was thanked for providing support. The Committee recognises the value of these data, collected in accordance with survey methods agreed by the Committee, covering many regions not surveyed in recent decades, and addressing an important information gap for several large whale species.

The Committee **welcomes** news that the photographic data had been uploaded into the IWC Secretariat's Lightroom database and **encourages** continuation of this work. Finally, it was noted that for the short-term phase of POWER, surveys will be single-platform, but that double-platform configurations will be evaluated in 2015 and 2016 for possible incorporation into the long-term survey programme if g(0) appears to be less than one for the target species. Other issues concerning this survey programme will be investigated further at the POWER Technical Advisory Group (TAG) Workshop scheduled for September or October 2014 (see also Annex G, Appendix 6).

10.13.3 Planning for 2014 IWC-POWER cruise

SC/56b/Rep01 presented the report of the detailed Planning meeting for the 2014 IWC-POWER cruise, the 5th cruise in the series. The programme is designed by the Scientific Committee and would be impossible without the generous support of the Government of Japan who provide a research vessel, crew and fuel for 60-days (worth some £1m in today's market), as well as the Governments of Japan, USA and Korea who have provided scientists over the period of the programme.

The Committee drew particular attention to the satisfactory resolution of a long-standing problem involving CITES permits. It **expresses** thanks for this satisfactory outcome to the US State Department and the US Embassy in Tokyo, to Brownell, and to Sakamoto (Japanese fisheries Agency), the latter in particular for their persistence in reaching this result.

10.13.4 Recommendations for 2015 and 2016 IWC-POWER cruises

SC/56b/IA11 outlined the line transect sighting survey cruise plan for the 2015 IWC-POWER cruises. It is proposed to be 60 days long mainly in July and August 2015 and conducted in the central north Pacific between 170°E and 160°W, from 20°N to 30°N. Photo-id and biopsy experiments are also planned. It was agreed that a feasibility experiment will be implemented to determine whether $g(0)$ for Bryde's whales is likely appreciably less than one. Improvements of methods for distance and angle estimation experiment will be considered at the TAG meeting with the aim of trialling improved methods for this cruise. Information collected from the survey would contribute valuable information on blue whales, sperm whales and Bryde's whales in a poorly covered area. The data and report of this survey would be submitted to the Committee meeting soon after the cruise.

The plans for the 2016 IWC-POWER cruise are outlined in Annex G, Appendix 6. The Committee **agrees** that this survey be conducted either in a block surrounding the Hawaiian Islands or in the Bering Sea, depending on (a) the level of coverage of previous surveys that are in the block surrounding the Hawaiian Islands; and (b) permitting issues for the Russian zone of the Bering Sea. The Bering Sea was suggested because the entire Bering Sea has been poorly

covered and would also assist in discussions *inter alia* arising out of the Commission workshop on Arctic impacts. Since the short term goal is to cover all poorly-covered areas of the North Pacific, if previous abundance surveys have already sufficiently covered the Hawaiian Island block, then it is not necessary for the IWC-POWER programme to once again conduct a survey in that area. Thus, if the Planning Meeting determines the previous coverage around Hawaii is sufficient, the Bering Sea will be proposed to be covered. The Committee during the 2015 Annual Meeting will finalise this decision.

The Committee noted in discussions there may be a possibility of including the collection of passive acoustics data, with equipment such as towed-arrays. The Committee **thanks** the Government of Japan yet again for its generous offer of providing a vessel for this survey. The Steering Group for the IWC North Pacific Planning meeting that was appointed last year was re-established and will be convened by Kato. Matsuoka was assigned responsibility for IWC oversight for both the 2015 and 2016 surveys.

10.13.5 Mid- and long-term recommendations for the IWC-POWER cruises

SC/56b/Rep09 presented the report of the TAG (Technical Advisory Group) to the IWC-POWER, who met in Tokyo prior to the 2013 Planning Meeting. The TAG focussed on beginning to review the information obtained thus far in order to begin to develop the medium-term programme. The TAG addressed six issues and a number of recommendations for further analyses, improvements to procedures and information requests were made.

The Committee was asked to establish intersessional correspondence groups to examine the following issues:

(1) Collaborative efforts should be made to develop an effective and efficient onboard electronic system for the medium-term programme in the light of existing systems and the shared interest in improving such systems in other national and international cetacean survey programmes (e.g. SCANS III, T-NASS etc.).

(2) Upgrade the old IWC-DESS system to a fully functional relational database to enable efficient storage of the several kinds of data collected and to facilitate analyses of the data (including a more effective mapping option). Data include that from IWC-POWER, IDCR/SOWER, and other national programmes. These should be linked to the extensive photographic database being developed by the IWC Secretariat.

Reports related to the onboard electronic system development and the potential for the use of passive acoustics on POWER cruises will be submitted before the TAG meeting in September/October 2014. In discussions it was noted that the distribution of sei whales may be driven by environmental factors, such as gyres, and that it might be possible to design surveys to inform on these relationships. The Committee **thanks** all the members of the POWER Steering Committee and TAG for reporting back from the respective meetings. The Committee **endorses** the TAG report, and **encourages** collaboration from other countries, recognising the contributions of Japan, Korea, Australia and the USA thus far.

10.13.6 Archiving IWC-POWER photographs

Donovan reported that data continue to be added to the the Secretariat Lightroom database. All POWER photographs from 2010-2012 have been added, geo-referenced and coded as previously described in last year's paper (Taylor and Donovan, 2013) and references to associated record sheet numbers added. All of the digitised SOWER records have been incorporated and the process of digitising the negatives from the earlier cruises is underway. A user's guide to the database is complete apart from final checking. Finally, a database of biopsy records from SOWER is almost complete and will be sent to Japan and SWFSC to ensure that the record numbers for samples can be cross-referenced. POWER records are being added. The Committee **welcomes** this news and **recommends** continuation of this work.

10.13.7 Progress on IDCR/SOWER volume

Last year, the Committee noted that preparation of the volume was underway. The contents will include an introduction to SOWER and the fieldwork; distribution and movement of species encountered; their taxonomy and population structure; acoustics; species abundance; conclusions and lessons for the future.

As convenor of the Editorial Board, Bannister reported that a deadline for texts of 31 December 2013 had been set, but that progress had been slow. Only six texts of a total of 26 (excluding the introduction and conclusions) had been received so far; a further five can be expected shortly. There is still some way to go, but the Board will continue its efforts to encourage authors to produce texts as soon as possible.

The Committee also **welcomes** the news that the Secretariat Lightroom database now incorporates all of the digital photographs from the more recent cruises and that efforts are now being made to digitise all of the negatives from the earlier cruises. It **recognises** the great value of this dataset and **recommends** continuation of this work.

The Committee thanked Bannister and the Editorial Board, and looked forward to an update next year.

10.13.8 DESS database for IWC IDCR/SOWER data

The Committee had been informed during the development of the abundance estimates for Antarctic minke whales that Bravington and Hedley had found some errors in the IDCR/SOWER data. The database should of course be as accurate as possible and Secretariat has agreed to correct any errors when they are passed on. To date the Secretariat has not received the necessary information and the Secretariat has encouraged provision of this as depending on its nature, this may also require alterations to the existing validation algorithms being used which is important for future datasets as well as past ones. The Committee **recognises** the difficulties of time constraints for the researchers involved but also the need to correct errors and improve validation algorithms. It has therefore formed an intersessional working group to assist in this process.

10.13.9 IWC-SOWER sonobuoy data

The South African Blue Whale Project applied for and received the acoustic recordings from sonobuoys deployed during several IWC Antarctic and low latitude cruises (Shabangu and Findlay 2014). This resulted in some 7500 acoustic files from over 700 stations across cruises from 1996/1997 through to 2008/2009 in Areas I-VI, and the three

blue whale cruises off Australia, Madagascar and Chile. A total of 1547.76 hours of recordings had been initially reviewed and blue whale vocalisations (either Z or D calls) have been detected on 4155 (55%) of the 7501 recorded files.

The Committee **welcomes** the processing of these valuable data. Now that the 'bio duck' sound has been positively identified as an Antarctic minke whale, the Committee **recommends** this database be interrogated to identify the bio duck sound to investigate the spatial temporal distribution of the Antarctic minke whale.

10.13.10 Review of other cruises

10.13.10.1 REPORT OF JAPANESE CETACEAN SIGHTING SURVEYS IN THE NORTH PACIFIC IN 2013

SC/65b/IA06 presented a systematic vessel-based sighting survey that was conducted in 2013 by Japan to examine the distribution and abundance of large whales in the western North Pacific. A total of 3,470.1 n.miles was searched, where eight species including seven baleen whales were sighted. Photo-ID photographs and biopsy skin samples were also successfully collected.

The Committee **welcomes** this report and looks forward to receiving abundance estimates arising from these data. The Committee thanked Matsuoka for overseeing this survey on behalf of IWC.

10.13.10.2 PLANS FOR JAPANESE CETACEAN SIGHTING SURVEYS IN THE NORTH PACIFIC IN 2014

SC/65b/IA07 presented a plan for a systematic vessel-based dedicated sighting survey in the North Pacific for 2014 by Japan as a part of the Japanese Whale Research Program under Special Permit in the western North Pacific (JARPN II). The main objective is to examine the distribution and estimate the abundance of Bryde's whale for management and conservation purposes. In addition to sighting survey data, biopsy samples and photo-identifications will be collected. A report will be submitted to the 2015 Committee meeting.

The Committee **endorses** the proposal and Matsuoka was appointed to provide IWC oversight.

10.13.10.3 REPORT OF CETACEAN SIGHTING SURVEYS IN THE ANTARCTIC IN 2013/14

SC/65b/IA09 indicated that a dedicated sighting survey for abundance estimations in the Antarctic in the 2013/14 austral summer season was unable to be conducted due to external violent interferences by an anti-whaling group. This situation has now continued over three seasons, starting from the 2011/12 survey.

The Committee **expresses** its regret that the actions of an anti-whaling NGO had prevented the sighting survey. Following the cessation of the IDCR/SOWER programme in 2009 (and notwithstanding smaller-scale national projects to collect sightings data in particular regions), surveys such as this provide the only dedicated cetacean sightings that are synoptic over a wide area, and as such are extremely valuable for the work of the Committee.

10.13.10.4 PLANS FOR CETACEAN SIGHTING SURVEYS IN THE ANTARCTIC IN 2014/15

SC/65b/IA12 presented a plan for a systematic cetacean sighting survey for abundance estimation for the 2014/2015 austral summer season in the Antarctic to be operated by Japan. The research area comprises Areas IV, V and VIW between 70°E and 145°W, south of 60°S from December 2014 to March 2015, where up to four research vessels may be used using survey procedures used in the IWC/SOWER surveys. Photo-identification and biopsy studies will also be conducted. International researchers will be able to apply to participate in the cruise, but they will do so at their own cost. A cruise report will be submitted to the 2015 Committee.

The Committee **commends** the researchers for recording killer whale ecotypes as recommended in SC/65b/Rep02. The Committee **endorses** the proposal. Matsuoka was appointed to provide IWC oversight.

10.14 Sperm whales

Last year, an intersessional e-mail group was established to consider the feasibility of a future assessment of sperm whales. Its terms of reference were to evaluate data availability and work required on the following topics: (1) population structure within ocean basins; (2) population size within ocean basins and abundance in smaller areas; (3) catch history; and (4) consideration of the development of a new assessment model (IWC 2014). Brownell and Bannister met in Bled to consider four working papers on the above subjects and a number of published papers on sperm whales and had discussions with other members. For the purposes of those discussions sperm whales were divided into two broad groups: (1) North Pacific and (2) Southern Hemisphere.

It is clear a lot of preparatory work is required before undertaking a sperm whale assessment in either the North Pacific or the Southern Hemisphere. However, based on recent and ongoing research (catch histories, population size, genetic sampling, population structure, acoustics) on sperm whales in the California Current, the available data could be used for the development of a new assessment model. At the present time in the Southern Hemisphere, highest priority could be given to conducting survey[s] with acoustics to resolve the current status of the sperm whales off southern Western Australia where a 2009 aerial survey found no evidence of increase since whaling ceased in 1978.

The high priority given to the assessment of humpback whale breeding stocks BSD/BSE1/BSO left inadequate time to consider this agenda item. However, Brownell and the intersessional e-mail correspondence group will continue to develop the ideas canvassed above, perhaps with others, for report to the 2015 Annual Meeting.

10.15 Overview of workplan

The Committee's workplan for items related to whale stocks is summarised in Table 13.

11. STOCK DEFINITION

This item has been handled since 2000 by a Working Group (hereafter the SDWG). The Terms of Reference for SDWG were changed in 2012 to reflect the evolving needs of the Committee. During the present meeting, the SDWG continued to develop guidelines for preparation and analysis of genetic data within the IWC context (see Item 11.1), provided the Committee with feedback and recommendations concerning stock structure related methods and analyses presented to other sub-committees (see Item 11.2), and continued in their efforts to develop a reference glossary of stock related terms, to aid consistent definition of 'stocks' in a management context for the Committee (IWC, 2014f, pp.287-8). The Report of the SDWG is given as Annex I.

Table 13

Overview of the workplan as it relates to whale stocks

Species / area	SC66a 2015	SC66b 2016
Antarctic minke whales	Review information collated intersessionally (see Annex J, item 9) to try to finalise the in-depth assessment with a focus on the Indo-Pacific region	Finalise if not completed at SC66a and [consider how to] address the remainder of the Antarctic
Southern Hemisphere humpback whales	Undertake thorough review (collated intersessionally) and synthesis of the completed 8-year circumpolar assessment. Begin to evaluate data requirements and process for future assessments.	Complete evaluation and determine future workplan
Southern Hemisphere blue whales (including pygmy blue whales)	Review available existing and new information on stock structure abundance etc. and determine feasibility of conducting area-based assessments with an associated workplan	Depends on workplan developed in 2015
North Pacific sei whales	Begin in-depth assessment	Complete in-depth assessment
North Pacific gray whales	See detailed workplan provided in Annex F	Continue and possibly complete
Southern right whales	The most recent assessment was completed in 2012. The focus will thus be on reviewing new information, e.g. with respect to matters related to CMPs	Continue to review new information and develop workplan with respect to future updated assessments
North Atlantic right whales	The last assessment was completed in 2000 and since that time the Committee has reviewed new information on abundance, trends, anthropogenic mortality etc. Consideration of when to undertake a new assessment will be given and a workplan developed.	Depends on outcome of discussions in 2015.
North Pacific right whales	New information (and hopefully abundance estimates) is expected from the Sea of Japan/Kamchatka region. Consideration will be given to whether sufficient information is available to conduct an assessment and a workplan developed.	Depends on outcome of discussions in 2015.
North Atlantic bowhead whales	Continue to review new information.	Continue to review new information and develop a workplan towards and eventual assessment.
Okhotsk Sea bowhead whales	Review new information expected on abundance and stock structure.	Continue to review new information and develop a workplan towards and eventual assessment.
Arabian Sea humpback whales	Review new information expected from several research initiatives. Continue to assist in efforts to develop a CMP.	Depends on outcome of discussions in 2015.
Sperm whales	Review information and report from an intersessional group and develop a workplan	Depends on outcome of discussions in 2015.

11.1 Guidelines for DNA data quality and genetic analyses

Two sets of reference guidelines have been developed and endorsed by the Committee (IWC, 2014e, pp.248-9) and form 'living documents' that can be updated as necessary[15]. The first set addresses DNA validation and systematic quality control in genetic studies. The second set provides guidelines for some of the more common types of statistical analyses of genetic data used in IWC contexts, and contains examples of management problems that are regularly faced by the Committee. One section of the data quality guidelines will be updated intersessionally. During the present meeting, appendix sections of the genetic analysis guidelines were added; this document will be completed intersessionally (see Item 11.5). Both guidelines will also be published in the peer-reviewed literature.

Several papers were discussed that present new methodologies of relevance for the DNA data quality and genetic data analysis guidelines. These included (1) evaluation of data quality in studies using next generation sequencing technologies, (2) development of an epigenetic assay which uses known-age humpback whales to estimate age in humpback whales of unknown age, and (3) development of a suite of computational tools that allow the exploration and visualisation of spatial patterns in genetic diversity using data from individual-based, long-term cetacean studies.

The Committee welcomes the developments in epigenetic ageing methods. It noted that this approach can be applied to increase the power of the close-kin mark recapture by identifying the inter-generational relationships within parent-offspring pairs.

11.2 Statistical and genetic issues related to stock definition

A number of Committee stock related papers were discussed by the SDWG. These were submitted to the following sub-committees: Revised Management Procedure (Annex D), Bowhead, Right and Gray Whales (Annex F), In-Depth Assessments (Annex G), Other Southern Hemisphere Whale Stocks (Annex H), Small Cetaceans (Annex L) and Review of Special Permit Proposals (Annex O). Technical comments on these papers are given in Annex I.

The development of close-kin mark recapture methods for a number of species, including North Atlantic minke whales (Annex D item 3.3.1) and Antarctic blue whales (Annex H item 5.1.1.4) was also discussed (Annex I, item 3.1). This

[15] DNA data quality guidelines are available from http://www.iwcoffice.org/sci_com/handbook.htm#ten. Genetic data analysis guidelines are anticipated to become available before the 2015 Annual Meeting.

approach has broad utility for the work of the Committee as it can increase the stock structure-related information content available from existing sample collections. The Committee **encourages** the continuation of this developing methodology and further reporting to the 2015 Annual Meeting.

Another useful development was the concerted attempt to discover why different studies of common minke whales in the North Atlantic have led to different conclusions about stock structure. Some studies suggest substantial levels of differentiation between areas, and others identify little to no differentiation. Evaluating why these differences exist is complicated, as differences in sample size, areas sampled, years sampled, marker types, and potentially laboratory protocols exist between studies. To better understand these differences, locus-specific differentiation (F_{ST}`) values were compared across five datasets, and revealed that the same markers varied substantially in $F_{ST}$` between studies (Adjunct 3 of Annex D). It was noted that the loci in Adjunct 4 of Annex D were non-focal (i.e., heterologous; developed in one species but utilised in another species) which may contribute to the inconsistencies seen; though see Appendix 2 of Annex I. Factors thought most likely to contribute to these differences were ranked (Item 3.3.3 of Annex D), and continued analysis to identify the cause of these differences continues intersessionally (Annex D of Item 3.7). The Committee **expresses** strong appreciation for these efforts to combine allozyme and microsatellite datasets together for a locus-specific reanalysis. It is of importance to the ongoing North Atlantic common minke whale assessment to resolve what factors may be contributing to the lack of concordance among these studies as this will allow simplification of the number of hypotheses to be considered. In addition, determining the factors underscoring the different levels of differentiation between these datasets may have wider implications for other studies of interest to the Committee. In most cases, multiple datasets are not available for such direct comparisons of results, thus discordant signals such as those seen in this locus-specific F_{ST}` analysis (Adjunct 3 of Annex D) could be present but unrecognised in other studies.

This year, there was extensive discussion of SC/65b/BRG02 (see author's summary in Item 3.1.2 and discussion summary in Appendix 2 of Annex I). SC65b/BRG02 reports results of a meta-analysis of microsatellite diversity and standardised F_{ST} across populations of whales, dolphins, porpoises and sharks. This analysis finds that whale and dolphin studies have been based on a significantly lower proportion of focal loci than porpoises or sharks. The authors also find significantly lower allelic diversity in whales and dolphins than in sharks and porpoises. This reduced allelic diversity is also associated with higher estimates of population differentiation (using standardised F_{ST}). The authors of SC/65b/BRG02 therefore strongly recommend that the use of non-focal microsatellites to estimate F_{ST} should be avoided in future studies since this might lead to inflated estimates of F_{ST} that are potentially statistically significant.

The potential implications of the main conclusions in SC/65b/BRG02 are far reaching, and resulted in extensive discussions (see Appendix 2 of Annex I). This particularly focuses on the author's argument that the higher measures of F_{ST} found for non-focal loci could lead to the over-diagnosing of stock structure. This inference has ramifications for the many studies based on non-focal loci in cetaceans and more widely in the field of molecular ecology. If the authors' assertion was correct, this would call into question the conclusions of those studies and the consequent recommendations agreed by several IWC sub-committees. In discussion, many argued that the conclusion from SC/65b/BRG02 about the over-diagnosing of structure was based on a methodological misconception. The essential reasoning is as follows (see Appendix 2 of Annex I for further details). F_{ST} has two components: locus-specific effects, and population-specific effects. While highly diverse loci may not reflect a sufficient proportion of the population-specific effects to detect real population structure, it is not conversely true that markers of low variation will detect non-existent structure. Indeed, if this was the case, commonly used low diversity markers such as allozymes and SNPs would routinely, artificially detect population structure, and this is demonstrably not the case. Regardless of the specific magnitude of F_{ST}, a statistical assessment determines significance with a controlled magnitude of type I error.

In summary, the Committee **requests** that the authors provide the data used in the meta-analysis be made available to the SDWG so that it can better understand the associations identified in SC/65b/BRG02. This will allow examination of alternative explanations for the results, which is needed before drawing conclusions for the Committee.

11.3 Testing of Spatial Structure Models (TOSSM)

The aim of the TOSSM project that was developed by the Committee, is to facilitate comparative performance testing of population structure methods intended for use in conservation planning. From an IWC perspective, the TOSSM software package allows evaluation of methods for detection of genetic structure, in terms of how well the methods can be used to set spatial boundaries for management. It is available for all to use and simulated datasets exist for three of the five stock-structure Archetypes previously proposed by the Committee (see IWC, 2010b, p.51). There was no progress on Testing of Spatial Structure Models to report this year. Progress continues to be made on the work items suggested in IWC (2013b) for the Pacific Coast Feeding Group (PCFG) of gray whales and will be presented next year. The Committee **agrees** to form an intersessional email group to further advance the use of TOSSM, with the primary intent that TOSSM be used to provide general guidelines for setting sub-area boundaries for assessment processes, with particular reference to populations that pose management challenges to the Committee. It was noted that the use of particular examples, such as the ongoing work on the PCFG gray whales, was a great motivator for use of TOSSM and was helpful in making its relevance to the Committee clear.

11.4 Terminology and unit-to-conserve

Defining and standardising the terminology used to discuss 'stock issues' is still a long standing objective of the SDWG, in order to help the Committee report on these issues according to a common set of terms (see Appendix 5, IWC, 2014f, pp.287-8). This year, the SDWG decided further work was needed to (1) agree the definition for 'mixtures of stocks', as well as (2) align the terms used in SDWG with terminology already in use by the sub-committee on Small Cetaceans and make additions to the developing glossary where needed. An intersessional email group was formed to complete this task.

11.5 Workplan

The Committee **agrees** to the overall workplan given in Table 14; details are given in Annex I.

Table 14

Overview of the workplan as it relates to stock definition

Topic	SC66a 2015	SC66b 2016
Terminology review and unit-to-conserve	Continue to work on this issue with a focus on examining terms used for small cetaceans. Try to finalise an initial list for use by the Committee.	Finalise if not completed at SC66a.
Updates to genetic data analysis and DNA data quality guidelines (annual)	This is part of maintaining an online and evolving set of guidelines.	Review to see if updates are required
Statistical and genetic issues concerning stock definition	Continue to review technical issues regarding papers submitted to all sub-groups of the Committee.	Continue.
Testing of Spatial Structure Models (TOSSM)	Examine the future application of TOSSM datasets to new cetacean examples of interest to the Committee; advance the use of TOSSM to provide general guidelines for setting subarea boundaries for assessment, including those for the RMP and AWMP.	Continue based on discussions at 2015

12. ENVIRONMENTAL CONCERNS

The Commission and the Scientific Committee have increasingly taken an interest in the environmental threats to cetaceans. In 1993, the Commission adopted resolutions on research on the environment and whale stocks and on the preservation of the marine environment (e.g., IWC, 1996a; 1997; 1998a; 1999a; 1999b; 2001). As a result the Committee formalised its work by establishing a Standing Working Group that has met every year since.

12.1 State of the Cetacean Environment Report (SOCER)

The SOCER provides an annual update, as requested by Commission Resolutions 1997-7 (IWC, 1998a) and 1998-5 (IWC, 1999a), on: (a) environmental matters that potentially affect cetaceans and (b) developments in cetacean populations/species that reflect environmental issues. The 2014 SOCER (Annex K, Appendix 4) focused on the Atlantic Ocean, Caribbean and Gulf of Mexico. Details of this year's SOCER can be found in Annex K, item 6.

The Committee thanked the SOCER editors for compiling this year's report and **encourages** participation in the upcoming version. The focus of the SOCER at SC/66a will be on the Pacific Ocean region; at SC/66b, it will be focused on Arctic and Antarctic regions.

12.2 Pollution

12.2.1 Update on Pollution 2020+ progress

SC/65b/E13 reviewed microplastics in the marine environment and their potential impacts on cetaceans. Microplastics have a global distribution; do not biodegrade and are only partially removed by sewage treatment. The toxicological consequences for marine life range from mechanical hazards to leaching toxic chemicals. Analysis of cetacean faeces may provide information on the assimilation and excretion of microplastics. The Committee **thanks** the authors for this comprehensive report.

The IWC Pollution 2020 Steering Group Meeting report (SC/65b/Rep05) noted that the last 4 years have seen the completion of Phases II and III of the Pollution 2000+ initiative, which has included the finalisation of an individual-based model that can be used to investigate the effects of pollution (particularly polychlorinated biphenyl or PCB) exposure on cetacean populations (Hall *et al.*, 2013). The major points identified were that: (1) the model should include the ability to change the annual accumulation over time, as this would better reflect the gradual decrease in environmental PCBs; (2) the vital rates used to parameterise both the dolphin and the humpback model may need to be updated; (3) a major source of uncertainty in the model relates to the parameters that control the offloading of PCBs from mothers to their calves; and (4) currently, there is no uncertainty incorporated into the model around the relationship between immune function and reduced survival probability. Work on prioritising current contaminants of concern for cetaceans remains important to the SWG and efforts to complete this task should be continued.

The Committee **commends** this work and recognises that the development of a practical modelling tool provides an important step in the Committee's ability to quantify the effects of chronic threats to cetaceans. The Committee **endorses** the steering committee advice and **recommends** the addition of leachate and adsorbed chemicals from microplastics to the questionnaire that will be circulated among experts for input on chemicals of concern. In addition, the Committee **recognises** that continued investigation into the effects of chemicals adsorbed to microplastics, on cetaceans, is needed.

12.2.2 Oil spill impacts

12.2.2.1 UPDATE ON DEEPWATER HORIZON OIL SPILL

An update on the 2010 Deepwater Horizon oil spill investigation on the injuries and impacts to cetaceans in the Gulf of Mexico was provided. Health assessments of bottlenose dolphins in Barataria Bay, Louisiana (an area that received heavy and prolonged oiling) and Sarasota Bay, Florida (control site) were conducted in 2011 (Schwacke *et al.*, 2014). Barataria Bay dolphins showed evidence of hypoadrenocorticism, consistent with adrenal toxicity and were five times more likely to have moderate to severe lung disease. Additional assessments and are planned for the region of concern.

An Unusual Mortality Event (UME) started in February 2010 in the northern Gulf of Mexico and was ongoing as of 14 May 2014. Most of the strandings (87%) were bottlenose dolphins. From results received to date, the cause of the UME is unlikely to have been due to *morbillivirus*, marine biotoxins, or *Brucella*. The Deepwater Horizon oil spill has not been ruled out as a possible contributing factor. Details of the discussion on these papers may be found in Annex K, item 7.2.1.

The Committee **commends** this work and **recommends** that these studies continue. It also **recommends:**

(1) that baseline data from populations at risk be collected and knowledge about exposure and impacts following spill events maximised;
(2) that analytical methods for oil spill-related compounds be standardised; and
(3) that pre-planning begin for an oil spill workshop to inform the Committee on the impacts of oil, dispersants, and spill response on cetaceans and the methodological tools for the assessment of impacts to cetaceans after a spill.

12.2.2.2 OTHER OIL SPILL INFORMATION

The report 'Responding to oil spills in the US Arctic Marine Environment'[16] was discussed. It noted that response actions will have to deal with the remoteness, limited infrastructure and capacity, and might have to deal with sea ice, low temperatures, and days with very little or no sun light. The report includes recommendations about all of these topics. Details can be found in Annex K, item 7.2.2.

The Committee again **stresses** the importance of baseline information on both marine mammals (and other wildlife) and their prey. It was noted that the injury assessment process is difficult to complete without this type of data available for comparisons. In addition, the Committee **recognises** the importance of subsistence species to local communities.

The 2013 *Community Oil Spill Response in Bering and Anadyr Straits* workshop report was briefly summarised (Wildlife Conservation Society, 2013). The workshop specifically focused on: (1) the role of communities in these policies and planning processes; (2) the location and role of emergency response equipment in the region; and (3) examples of how other communities in Alaska and elsewhere engage with prevention, planning, and response needs. Participants identified several key themes during this exercise including the need for oil spill response training, equipment, funding and effective local and cross-border communication plans (see Annex K; Item7.2.2).

Further to discussions about oil spills, the Committee **agrees** that absolute priority should be given to preventing oil spills in the highly vulnerable Arctic region. However, the Committee noted that even when preventative measures are taken, oil spills may still occur. Responding to an oil spill, especially a large one in a polar area, is hindered because of limited capacity particularly due to infrastructure. In addition to abundance and distribution, baseline data should include: health assessments; contaminant levels; biomarker measurements; and habitat/prey quality. It was noted that cetaceans in other countries are also under threat of both oil and gas development and increased shipping. The Committee **recommends** that Committee members: (1) enhance the collection of baseline data related to abundance, health assessments, prey, and habitat of cetaceans for an improved capacity for injury assessment and monitoring recovery in the event of a spill; and (2) build capacity for responding to an oil spill in polar regions or other vulnerable or at risk areas. The Committee also **recommends** that the Commission seeks observer status at the Arctic Council for improved communication and coordination of Arctic issues related to cetaceans, including issues related to shipping oil and gas activities (and see Item 10.2.1 and Item 7.2.2).

12.2.3 Other pollution information

An update on the 2011 Fukushima Nuclear Accident was provided. Monitoring efforts to determine levels of radionuclides in environmental samples have increased since the disaster. Radioactive isotopes of iodine and caesium were detected in air, water, milk and food samples collected across the entire northern hemisphere and also southern hemisphere, including New Guinea and Fiji but radiation levels were very low and did not pose a risk to the public. A report has been published on the potential impacts and monitoring efforts being conducted[17].

The Committee noted that the Government of Japan has measured Fukushima-associated radionuclides in more than 45,000 seafood samples collected from various coastal waters of Japan[18]. Modelling efforts have projected the input of Fukushima-associated radionuclides into marine waters of eastern North Pacific and the levels in some areas could approach those reported in the 1950-1960s, i.e., a period during nuclear testing and activity in the region. The Committee **expresses** concern about this new information; the impact that radionuclides released as a result of the Fukushima accident might have on wildlife and humans remains unclear.

12.3 Cetacean emerging and resurging diseases (CERD) and mortality events

12.3.1 Update from the CERD intersessional group

The Cetacean Emerging and Resurging Disease (CERD) Group was created in 2008 in recognition of the increased need to address disease issues in cetaceans at an international level, including information on emerging diseases and the fact that for most cetacean species there is insufficient information on diseases, particularly those with potential anthropogenic drivers, to evaluate the risks to populations (IWC, 2008c).

12.3.2 CERD website and database

In 2012, the CERD working group proposed to develop a website that provides information on infectious and non-infectious diseases, as well as nutritional disorders and biotoxins (IWC, 2013a). The CERD will advertise internships to assist with data validation and input into the CERD web framework. In recent years, standardisation of the data that will be used for the CERD website has begun and the proposed format was presented to the Committee.

12.3.3 Strandings and mortality events

SC/65b/E03 provided information on an Unusual Mortality Event (UME), with increased numbers of bottlenose dolphin strandings documented from New York to Virginia beginning in July and August (> 1,200 dolphins stranded). This was determined to be a *morbillivirus* outbreak. Other stranded cetacean species testing positive by PCR (polymerase chain reaction) for cetacean *morbillivirus* included humpback, fin and pygmy sperm whales and striped dolphins. The impacts of dolphin *morbillivirus* on these species remains unknown (see Annex K, Item 8.3 for details). The Committee

[16] www.nationalacademies.org
[17] See: http://marinedebris.noaa.gov/sites/default/files/Japan_Tsunami_Marine_Debris_Report.pdf
[18] see www.jfa.maff.go.jp/e/inspection/index.html

encourages continuation of the investigation of the *morbillivirus* outbreak, further international collaboration and looks forward to additional information as it becomes available.

SC/65b/SM03 reported the first mass stranding of seven Longman's beaked whales in New Caledonia on 16-17 November 2013. Samples were collected from 5 animals. Low concentrations of elements associated with mining activity in New Caledonia were found in the tissues, suggesting that industrial extracting activities do not represent a significant source of contaminants for this species. Cetacean *morbillivirus* was identified in one of the individuals via PCR analysis. Details can be found in Annex K, item 8.3.

On 1 April 2014, an atypical mass stranding of 6-10 Cuvier's beaked whales occurred along the coasts of south and southwest Crete, Greece, Mediterranean Sea, inside the 'area of special concern for beaked whales', discussed in Item 12.4.4. The mass stranding comprised several stranding events in three different locations/areas. At the time of the Crete atypical mass stranding event, the 'Noble Dina' naval exercise, involving Greek, US and Israeli navies, was taking place in Greek offshore waters.

In discussion, it was noted that atypical mass stranding events such as this have previously been associated with anthropogenic sound from military sonar. The Committee **recommends** that this event be investigated by marine mammal veterinarians and the findings reported next year.

12.3.4 Other health-related activities

SC/65b/E04 evaluated marine *Brucella* infections in cetaceans in the United States (see Annex K, item 8.4 for details). Manifestations of infection in cetaceans include late-term abortions and lesions in lungs, reproductive organs, bones and the brain. Collaborative work in the US over the last four years has identified more than 120 cetaceans testing positive for marine *Brucella*, many with clinical signs of brucellosis. Brucellosis due to marine *Brucella* has been found in four human cases worldwide and the wide presence of the marine *Brucella MLST 27* in cetacean cases has raised the most concern for public health, as this was the type implicated these *Brucella* infections. Based on concerns for both cetacean populations and human health, the Committee **recommends** that the development of a reliable serological assay for the detection of marine *Brucella* antibodies be given high priority. It also **recommends** further research into virulence mechanisms, transmission pathways, pathogenesis and co-morbidity factors in cetaceans. The Committee **recognises** and **encourages** the work on *Brucella* in the Southern Hemisphere and welcomes initiatives that would allow cetacean *Brucella* types to be identified and compared. In addition the Committee **recognises** the concern about the potential risk that the marine types may pose to humans, including stranding response workers, subsistence consumers and fishermen, and **recommends** that particular attention be given to elucidating the frequency and routes of transmission of the marine *Brucellas* to humans.

SC/65b/E05 described information on a pilot project called Marine Mammal Health Map for tracking heath data obtained from marine mammal strandings, mortality events, and health assessments during live capture release programs. The ultimate goal of the Marine Mammal Health Map is to share marine mammal health and disease information on a national and international scale and evaluate potential impacts on populations. The Committee **expresses** interest in the health mapping technology and **encourages** updates on this work, as well as further development and potential application to CERD.

SC/65b/E06 summarised information on skin lesions in southern right whales from the Península Valdés area. Over the past ten years, there has been an increase of skin lesions in whales in this population. As a result of analysis of samples obtained during 2012 and 2013, the presence of poxvirus in skin lesions of southern right whales was confirmed, and several bacteria (e.g. *Erysiphelotrix spp., Staphylococcus epidermidis*, and *Streptococcus spp*.) were isolated from wounds caused by kelp gulls.

The Committee **commends** Argentina for conducting skin lesion research on Southern right whales, especially the recent investigations of pathogens that may be expressed in the lesions and **recommends** that they continue the work on skin lesions given the prevalence and continued problems with kelp gulls. Further information on this work was discussed in Annex F, item 4.1.

Information on pathological findings of subsistence-harvested bowhead whales by Alaskan Eskimos during 2013 was presented to the Committee (see SC/65b/BRG08).

Di Guardo and Mazzariol (2013a) described some of the host and viral factors driving dolphin *morbillivirus* infection with particular emphasis on striped dolphins in the Mediterranean. An expansion of the host range has recently been observed in the Mediterranean with infection in fin whales and a captive harbour seal.

Di Guardo and Mazzariol (2014) presented a commentary on two papers recently published regarding cetacean *morbillivirus* in the Southern Hemisphere. The authors noted that data are needed on the genetic composition of the new strains and emphasis should be placed on the host and agent-related factors that drive the complex *morbillivirus* cetacean interaction dynamics.

Of note was the number of new cases of *morbillivirus* globally which may be a cause for concern. Princeton University is hosting a workshop on marine *morbilliviruses* in August 2014 and the Committee looks forward to a report at SC 66a.

Di Guardo and Mazzariol (2013b), reported that striped dolphins stranded in 2007 and 2008 showed evidence for *T. gondii* in association with brain lesions. They suggested that an 'open sea' life cycle involving this and other pelagic cetaceans should not be ruled out.

12.4 Effects of anthropogenic sound on cetaceans and approaches to mitigate these effects

12.4.1 IWC/IQOE workshop report

A two-day workshop was sponsored by the Commission, the International Quiet Ocean Experiment (IQOE) and others, to discuss regional and ocean-basin scale underwater sound field mapping techniques to provide support for decision makers seeking to characterise, monitor, and manage the potential impacts of chronic or cumulative anthropogenic noise on marine animals. Many different soundscape monitoring and modelling programs have been developed

(see Annex K, item 9.1). However, while these programmes are an excellent start, they are not standardised in their measurement or modelling parameters, making it extremely difficult to compare products across regions. In addition, they are largely focused on US and European waters, while management concerns for marine organisms are far wider ranging. The Workshop recommended identifying acoustic measurement and modelling protocols that if implemented world-wide would greatly add to the value of local and regional studies by allowing data to be combined and integrated at larger scales.

To support further development of sound modelling tools, it was proposed that the Committee should consider its management needs and designate high priority areas for the next steps in this work. Possible areas that were highlighted during workshop discussions for further evaluation by the Committee included the Arctic, Southern Ocean Sanctuary, South Atlantic, Mediterranean, North Sea, and Gulf of Mexico-Caribbean waters.

The Committee **commends** the IWC/IQOE workshop participants for their efforts, and **recommends** continuation of this effort and further work to implement the recommendations contained in the workshop report. The Committee **endorses** the recommendations from the workshop report. In order to advance this work, the Committee **recommends** conducting the two predictive sound field mapping studies in high priority areas as described in Annex K, Appendix 2. In addition, the Committee **recommends** the collection of empirical data (e.g. acoustic recordings) to assess baseline acoustic conditions in these high priority regions (particularly where rapid industrial or environmental change is occurring), and the expansion of efforts where data collection is currently limited. The Committee **recommends** continued international collaboration on the issue of underwater anthropogenic sound, and planning of additional workshops or projects with various regional management agencies, industry, and organisations.

12.4.2 New information on the effects of anthropogenic sound

Simmonds *et al.* (2014) is a history of marine noise pollution and explained how it came to emerge as a 'significant mainstream issue,' taking note of the role that the IWC has played in this effort and concluding that over the last two decades or so, significant progress has been made acknowledging this issue, especially in the USA. The authors call for enhanced international cooperation and the expeditious sharing of information from marine renewable energy devices (which has emerged as a new issue) and stress that temporal and spatial separation should be the primary mitigation approach.

12.4.3 Update on new tools, approaches or efficacy of mitigation of effects of anthropogenic sound on cetaceans

SC/65b/E11 describes a simulation framework to evaluate the efficiency of using Marine Mammal Observers (MMOs) for mitigation of sound-related injury. Without an adequate quantified assessment of the risk reduction, mitigation measures may often be applied inappropriately or result in regulators granting approval for activities on the basis of measures that do little to reduce risk. The Committee **thanks** the author and encouraged publication of his findings.

SC/65b/E09 discussed the real-time mitigation measures based on the detection of animals close to airguns and other sources and, in particular, the role that MMOs play. SC/65b/E09 raised questions about the work of MMOs covering issues including: increasing distances of monitoring from sound sources required, complex multispecies requirements, the authority and independence of MMOs, their training and assessment, numbers of observer required to be effective and data availability.

The Committee noted that addressing such issues was important in ensuring that MMOs were effective and noted that an independent assessment of MMO practices does not exist. Hence, the Committee **agrees** that this issue would be a suitable focus for its consideration at a future Committee session in which MMOs and their associations would be represented.

SC/65b/E08 provided a brief overview of the various options available to reduce anthropogenic ocean noise. The overarching recommendations are: (i) governments around the world should phase in increasingly strict noise level standards for all noise-producing activities; and (ii) governments, industry and NGOs should seek ways to address and reduce the underlying demand for noise producing activities. For more specific recommendations see Annex K, item 9.3.

In SC/65b/E07, Environmental Impact Statements or Reports were examined to determine whether the focus on reducing Level A 'takes' under the US Marine Mammal Protection Act (i.e. a predicted level of sound that could result in physical injury or death) is sufficiently protective and effective by comparing the numbers of Level A with Level B takes (i.e. a level of sound that results in behavioural disturbance). Spatio-temporal mitigation (time-area closures) and quieting alternative technologies, such as marine vibroseis (which exposes only 1-15% of animals to higher noise levels compared with airguns), in contrast to safety zones and ramp-up, can dramatically lower both Level A and B takes. For discussion details see Annex K; item 9.3. In summary, it was considered that more animals are affected by noise, and as such the impacts to cetaceans are greater, than currently estimated.

The Committee **thanks** the author for presenting these findings, **recommends** that further consideration should be given to examining behavioural effects and possible population level effects. It looks forward to receiving additional information from studies such as this.

A German study about the development of noise mitigation measures in offshore wind farm construction was presented to the Committee.[19] The aim of this study was to describe technical noise mitigation measures that can be applied during pile driving of offshore wind turbines, as well as alternative low-noise foundation concepts and to analyse their applicability. Additionally, it was noted that, in Germany, an 'underwater noise concept' for the North Sea has been in place since September 2013, which is applied to protect

[19] http://www.bfn.de/0314_meeresnaturschutz-berichte.html.

harbour porpoises from underwater noise from pile driving activities.

The Committee welcomed the study and **stresses** the importance of sound mitigation measures. With respect to the Baltic Sea, the Committee **strongly encourages** the relevant governments in the area to apply appropriate measures to protect the highly endangered harbour porpoise subpopulation of the Baltic proper from negative effects of underwater noise through pile driving and other anthropogenic activities.

In recognising the pervasive nature of underwater sound in the marine environment and the inherent difficulties in assessing the behavioural impacts that such inputs may cause, the Committee **agrees** that increased efforts should be made to avoid, minimise and mitigate the adverse effects of anthropogenic noise on cetaceans. In particular the Committee **recommends** that Governments should promote and facilitate the adoption of noise-reducing technologies by industry including shipping noise, exploration for fossil fuels and pile-driving. The Committee also **encourages** the completion of appropriate assessments for marine activities to help ensure harm is not caused to cetaceans, including giving consideration to the development of noise exposure limits as, for example, used in Germany with respect to pile driving. The Committee **encourages** industry (and other noise producers such as the military) to release data about its noise generating activities (both completed and where possible, planned), including but not limited to activity, location, source characteristics, duration, in order that the cumulative implications for cetaceans of all activities can be assessed.

The Committee also **stresses** the importance of utilising temporal and spatial management of noise generating activities and encouraged the identification of sensitive areas in which noise would be strictly managed.

Nowacek *et al.* (2013) dealt with a responsible approach to minimising disturbance to cetaceans from seismic surveys. The authors identified a number of principles and steps that would have common application even though the final mitigation and monitoring programmes would differ (see Annex K, item 9.3) This is a feedback process with a primary objective that the monitoring and mitigation plans improve over time and the monitoring component is integral part of any programme not merely an optional extra.

The Committee thanked Donovan for presenting this paper on behalf of the authors and **recommends** the process described in this paper. It also **endorses** the approaches described in the other papers presented in this section.

12.4.4 Other anthropogenic sound issues

The Committee received a brief summary of the findings of the 2008 mass stranding of melon-headed whales in northwestern Madagascar undertaken under the auspices of the IWC and others. The full report and supplementary information can be found on the IWC website.[20] While seismic surveys and other factors were systematically excluded or deemed unlikely it was found that the use of a12-kHz Multi-Beam Echosounder System to be 'the most plausible and likely behavioural trigger for animals initially entering the lagoon system.'

The Committee noted that the investigative process described in this report could serve as a model for investigating the cause of mass stranding in other areas

The Committee drew attention to the fact that this is a new sound source to be associated with cetacean mass strandings and **recommends** that high intensity multi-beam echosounder systems be considered in addition to military sonars as possible threats to cetacean populations. The Committee **thanks** the Government of Madagascar, the US government as well as the IWC for their support in the investigation of this mass stranding event.

Di Sciara presented the work of the Scientific Committee of the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS), on the location of critical habitats of Cuvier's beaked whales in the Mediterranean in order to support appropriate mitigation measures. The ACCOBAMS Committee developed a map of 'areas of special concern for beaked whales' – based on a combination of modelled beaked whale habitat and locations of all known mass stranding events, surrounded by a 50 nautical mile buffer zone – showing areas that naval exercises involving sonar use should avoid.

The Committee **commends** the ACCOBAMS Scientific Committee for addressing the conservation of Cuvier's beaked whales in the Mediterranean through the identification of the species' critical habitat, and **recommends** that efforts to map Cuvier's beaked whales' habitat in the Mediterranean should be continued and improved.

12.5 Impacts of climate change on cetaceans

12.5.1 Progress on climate change

An overview of IWC work on climate change and a summary of recent relevant publications were provided in SC/65b/E12. It noted Doney *et al.* (2012) which discussed impacts of climate change on marine ecosystems structure and dynamics, and how species might adapt; Lambert *et al.* (2014) recognised limitations of current scientific understanding of cetaceans, when attempting to model future distribution under climate change scenarios; and Poloczanska *et al.* (2013) compiled a database of 1,735 marine biological climate-related changes from the literature.

In addition, the recent Intergovernmental Panel on Climate Change (IPCC) summary for policy makers (IPCC 2013) predicted continued ocean warming, higher rates of sea level rise, greater sea ice loss and ocean acidification.

During discussion, it was noted that approximately half of the members of the SWG on Environmental Concerns are currently engaged in or indirectly working on issues related to climate change. In addition, the Committee indicated that other bodies have been considering the issue of climate change and conservation (e.g. ACCOBAMS, CMS). The Committee **agrees** that an intersessional steering group should meet to develop a plan for climate change work by the Committee over the next few years.

[20] http://iwc.int/2008-mass-stranding-in-madagascar.

12.5.2 Other climate change information

Information on a recently published review of the distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in the Arctic (Reeves *et al.*, 2014) was presented to the Committee. The results showed extensive overlap between areas inhabited by the whales and areas of increasing interest for shipping and hydrocarbon exploration and development. For details of the paper, see Annex K, item 10.2.

12.5.3 Arctic impacts workshop

A summary of the 'Workshop on Impacts of Increased Marine Activities on Cetaceans in the Arctic' (Anchorage, Alaska on 6-7 March, 2014) was presented to the SWG. It focused on shipping and oil and gas activities and involved a wide range of stakeholders who discussed number of relevant aspects of the issue, including: current and past research conducted; implementation of management measures; knowledge gaps and concerns; and information the IWC can provide to assist managers in preparing for these impacts (see Annex K, item 10.2.1 for further details and recommendations)

The Committee **commends** the workshop participants for their work and looks forward to the final report. The Committee **reiterates** that two of its recommendations are independently in accord with those arising out of the Arctic workshop: (1) that the Commission pursue stronger links with other important international organisations (e.g. the Arctic Council, IMO), range states, local authorities and industry; and (2) that IWC member nations enhance the collection of baseline data related to health assessments, prey, and habitat of cetaceans for an improved capacity to detect impacts from or recovery after oil spills or to detect changes due to other human activities.

12.6 Habitat-related issues

12.6.1 Cetaceans and marine debris

12.6.1.1. UPDATE ON PLANNING FOR THE 2ND MARINE DEBRIS WORKSHOP

The first IWC workshop on marine debris, sought to define and understand the adverse impacts of marine debris on cetaceans (IWC, 2014b, pp.521-39). A second marine debris workshop under the auspices of the Conservation Committee will be held in Hawaii in the first week of August 2014 and a report will be forthcoming in 2014 (see Annex K, item 11.1.1).

12.6.1.2 NEW INFORMATION ON MARINE DEBRIS IMPACTS ON CETACEANS

Information collated on rates of marine debris ingestion and associated mortality rates, as well as recommendations regarding reporting debris interactions to the IWC was presented in SC/65b/E02. Debris ingestion has been documented in 48 cetacean species, with rates of ingestion in necropsied stranded carcasses as high as 74% in some areas. A key recommendation of the first IWC workshop on marine debris was that information on rates of debris interactions should be reported annually by country to the IWC. SC/65b/E02 made recommendations for information that should be included in such reporting.

The Committee **thanks** the authors of SC/65b/E02 for providing the information and **notes** that there was a need to develop monitoring tools to quantify the relevance of marine debris ingestion to the incidence of strandings and mortality, with the ultimate aim of extrapolation to cetacean mortality rates. The Committee **agrees** that information on marine debris ingestion should be included in national Progress Reports submitted to the IWC. For details on fields see Annex K, item 11.1.2.

The Committee **recommends** discussions with the *ad hoc* Progress Report group and Secretariat with the aim of adding agreed fields for inclusion of such records in the online submissions portal.

A plan for the analyses of the quantity and distribution of marine debris in German waters, collected via aerial surveys, as well as an assessment of marine debris impacts on marine mammals was described in SC/65b/E10.

Summaries of SC/65b/SP02-05 and SC/65b/J22 were presented to the Committee (see Annex K, item 3 for statement on these papers). During the 2013 JARPN II offshore survey, debris was detected in stomachs of 33 of 100 sei whales sampled and 2 of 28 Bryde's whales. Plastic was the most abundant type of (<15cm). No obvious signs of illness that may have been caused by debris ingestion were detected. Marine debris on the sea surface was recorded during the sighting surveys (1987/88-2010/11; SC/65b/J22). A total of 70 pieces of marine debris and objects other than prey were found in the stomachs of Antarctic minke whales (n=10,041), including feathers, stone, wood, plastic and others. The authors noted that given the low indices, the effect of marine debris on whales in the Antarctic is expected to be limited at the present time.

12.7 Other habitat-related issues

Rosenbaum *et al.* (2014) provided information on the movement of Southern Hemisphere humpback whales from Breeding Stock B and the overlap with anthropogenic activities in the South Atlantic Ocean. The extent of overlap with anthropogenic activities makes it difficult to implement effective mitigation measures over their entire range.

Rosenbaum presented information on the assessment of vessel strike risk for large cetaceans in the Bering Strait region. The conclusions were that significant overlap between whales and vessels does occur, and these interactions are likely to increase and this is an area of key concern.

SC/65b/SH19 presented preliminary information that indicated 3 satellite-tracked Arabian Sea humpback whales exhibited spatial and temporal overlap with shipping traffic, oil and gas activity and planned fast ferry routes along the coast of Oman, and all three whales passed through the main approach channels to major ports.

The Committee **thanks** the authors of the papers for presenting their findings and **encourages** the continuation of similar work.

12.8 Conservation Management Plans

This is considered under Item 21 as well as in Annex K (item 12).

12.9 Workplan

The two-year overview of the Committee's workplan for matters related to environmental concerns is given as Table 15. The workplan itself is discussed in detail under Annex K, item 13.

Table 15

Overview of the workplan as it relates to environmental concerns

Topic	SC66a 2015	SC66b 2016
POLLUTION 2020	Refine population modelling approach; finalise priority contaminants list for future studies.	Continue to refine modelling approach; in utero transfer analyses and modelling
Oil spills	Review new information	Plan for an oil spill workshop
Contaminant threat information	Focus sessions on regional trends and POPs in cetaceans	Data integration and mapping
CERD	Pre-meeting to develop workplan. Data input and website management	Improved communications on disease issues
Strandings and mortality events	Plan intersessional workshop and finalise agenda; review new information	Receive the report of the intersessional workshop; review new information
Anthropogenic sound	Continue work on soundscape mapping including next steps and priorities; plan for 'masking' focus at SC65b. Review new information	Continue work on soundscape mapping; focussed sessions on 'masking'; plan for 'stress and sound' workshop; focus session on effectiveness of marine mammal observers in mitigation
Climate change	Receive report from intersessional meeting and agree workplan	Depends on progress at SC66a

13. ECOSYSTEM MODELLING

The report of the Working Group on Ecosystem Modelling is given as Annex K1. The Ecosystem Modelling Working Group was first convened in 2007 (IWC, 2008b). It is tasked with informing the Committee on relevant aspects of the nature and extent of the ecological relationships between whales and the ecosystems in which they live.

Each year, the Working Group reviews new work on a variety of issues falling under three areas:

(1) reviewing ecosystem modelling efforts undertaken outside the IWC;
(2) exploring how ecosystem models can contribute to developing scenarios for simulation testing of the RMP; and
(3) reviewing other issues relevant to ecosystem modelling within the Committee.

This year the Working Group focused on a review of competition among predator species and the work of CCAMLR on krill and its dependent predators.

13.1 Review of ecosystem modelling efforts undertaken outside the IWC

13.1.1 Competition among baleen whales: how can we measure and model it?

Friedlaender gave a presentation reviewing published and unpublished data related to baleen whale foraging ecology, energetics and competition, including Friedlaender *et al.* (2013). This issue was first addressed by Clapham and Brownell (1996), who discussed criteria necessary to demonstrate if, in fact, direct competition[21] among cetaceans exists. Although the potential for some direct competition may exist, the influence of any such interaction on depleted and recovering whale populations in the Antarctic is difficult to assess, given the paucity of appropriate data for analysis (Clapham and Brownell, 1996). Nonetheless, Clapham and Brownell (1996) postulate that competition is unlikely between Antarctic baleen whale species due in part to probable resource partitioning mediated by food preferences and, potentially, the biomechanics of body size.

Until recently, logistical constraints limited our ability to test many of the ecological criteria to determine direct competition between cetaceans. Work off the western Antarctic Peninsula by Friedlaender and collaborators shows that sympatric humpback and minke whales appear to partition resources vertically at broad spatial scales. Humpback whales also appear to be distributed primarily in relation to their prey, while minke whales are more strongly associated with sea ice and secondarily to prey, which may indicate lower likelihood of competition via evolved means to partition resources. Tagging studies also show that minke and humpback whales feed at very different rates, in direct relationship to the anatomical scaling of their feeding apparatuses as predicted by recent biomechanical models for rorquals. Integrated with prey data, these models can also be used to predict minimum prey density thresholds, feeding rates and energetic intake across species.

In discussion, it was noted that data obtained by these tagging studies only provided the number of lunges as a measure of feeding success, and that the amount of food consumed by the animals could not be estimated based only on data obtained by the tags. However, it was also noted that when tagging data is accompanied by simultaneous measurements of prey density, such estimates of food consumption are possible.

The Committee agrees that there is a critical need for species-specific, fine-scale data on cetacean feeding and prey to provide parameters for individual-based models of competition between baleen whales. There is also an urgent need to develop the analytical and modelling tools to scale from individual-based whale foraging scales to broad spatial scales across species and ecosystems, using information about baleen whale energetics and feeding functional forms, as well as existing satellite tag, spatial and temporal data. The development of competition models should be conducted in parallel with data collection because the models can inform data collection and experimental design, and vice versa. In light of this, the Committee recommends that further work be carried out to collect the data identified above to inform the further development of ecosystem models.

13.1.2 Update from CCAMLR's Ecosystem Monitoring and Management Programme (WG-EMM) on krill and its dependent predators

The Committee held a joint workshop with CCAMLR in 2008 (IWC and CCAMLR, 2010). Since then, the Committee has identified significant knowledge gaps in aspects such as

[21] Direct completion occurs when two predators are present in the same area as a prey species, and may interfere with each other's access to the prey. When the two predators occur in different parts of the area of prey distribution, indirect competition may occur because the prey's production is limited so that consumption by the one predator limits the production available for the other, and *vice versa*.

spatial variability and trends in prey species, on the relationships between predators and prey, and on the effects of environmental variability on predators. Seeking closer collaboration between IWC/SC/EM and SC-CCAMLR's WG-EMM, in 2013 the Committee established communication with SC-CCAMLR and obtained a formal invitation for an IWC Scientific Committee observer to attend the annual meeting of the SC-CCAMLR WG-EMM. At this year's meeting, the Committee nominated Watters to take on this role and asked him to bring IWC Scientific Committee priorities to CCAMLR for future joint discussion. The Committee **views** the appointment of Watters as important for the development of a continuous and long-term relationship between IWC SC/EM and SC-CCAMLR WG-EMM. In addition, the Committee noted that Currey is now SC-CCAMLR observer to IWC SC and recommended his appointment to the obverse role of IWC SC observer to SC-CCAMLR in place of Kock. The Committee **agrees** to make this collaboration its primary emphasis for 2015 and 2016, and formed an intersessional correspondence group under Currey to facilitate communications that the Committee **expects** will lead to a joint IWC-CCAMLR intersessional workshop in 2016.

Watters also gave a presentation to the Committee on the development of minimally realistic ecosystem models to evaluate management strategies for the Antarctic krill fishery, based on work by Plaganyi and Butterworth (2012) and Watters *et al.* (2013). These models are relevant to the consideration of (both direct and indirect) competition among baleen whale species, but he noted that the specific effects of competition are conditional on the various structural assumptions (e.g. the spatio-temporal overlaps of predators and prey) and parameters that are estimated or fixed (e.g. the shapes of functional responses). Watters also noted that although time series of krill biomass and predator abundance are necessary to 'condition' the models, these time series might not be sufficient to discriminate among competition hypotheses. Thus, he concluded that it seems most robust to use multiple models for making inference about the effects of competition.

The Committee **agrees** that in order to successfully model indirect competition between baleen whales there is a need to collect data on the energetic demands and foraging behaviour of individual species across a range of scales from large regional or global scale, through defined management units, to spatially confined, fine-scale situations. Moreover, an important requirement of a competition model is for it to be able to inform strategic management advice, and this requires the ability to:

(a) Change state variables to address particular management concerns; and
(b) Maintain open communication and feedback between modellers and management bodies to ensure reciprocal familiarity, understanding and acceptance of the priorities, scientific process and proffered advice.

13.2 Explore how ecosystem models contribute to developing scenarios for simulation testing of the RMP

At last year's meeting, De La Mare (2013) presented a modelling framework that uses spatially resolved individual based energetics models (IBEMs) to determine reproductive success and mortality in an environment where food has a patchy spatial distribution. These models can be used to generate population dynamic scenarios for evaluation in the RMP context (IWC, 2014g, Annex K1, p.333). Among the issues that could usefully be explored using these IBEMs, the Committee accorded highest priority to the characterisation of yield curves for populations in stochastic environments, and to exploring the relationships between $MSYR_{1+}$ and $MSYR_{mat}$ and between K and $MSYR$.

SC/65b/RMP03 and SC/65b/RMP04 reported progress on using the IBEM to explore the relationships between $MSYR_{1+}$ and $MSYR_{mat}$ and to incorporate it into the RMP testing software framework. The Appendix of SC/65b/RMP03 provides the details of the model, including energetics and prey dynamics. The Committee noted that it was not immediately clear what were the main drivers of the results and that an emulator could be usefully developed to better understand the model's properties, although this would require considerable work. Further discussion of these papers is given under Items 5.1 and 5.2.

13.3 Review of other issues relevant to ecosystem modelling within the Committee

13.3.1 Update on Antarctic minke whale body condition analyses

For the last four years the Committee has discussed suggested declining trends in blubber thickness and body condition in Antarctic minke whales (Konishi *et al.*, 2008) over the 18 years (1987/88-2004/05) of the JARPA special permit programme (IWC, 2011c; 2012d; 2013d; 2014g). This item is relevant to ecosystem modelling because the findings have implications for energetics, reproductive fitness, foraging success, and the prey base itself, all of which are important as input in models. A number of concerns have been raised and addressed on the statistical methods that were used to derive these trends.

At last year's meeting (IWC, 2014g), the Committee recommended the use of mixed-effects linear models with different interaction terms as possible random effects and the inclusion of a new binary variable (near or far from the ice edge). The Review Panel at the JARPA II Review Meeting raised additional issues regarding the treatment of the time trend in body condition, the correlation among covariates, the procedure for model selection from the full model, and the diagnostics for the best model (SC/65b/Rep02). The Review Panel also recommended consideration of additional interaction terms, as well as additional variables that could potentially be included as random effects (SC/65b/Rep2).

SC/65b/EM02 presented analyses that included the recommended interaction terms for 'Date and longitude', 'Year and Latitude' and 'Year and Ice' (although these adjustments did not result in any change in model selection in terms of BIC in the cases investigated). The procedure for model selection was done with the recommended stepwise selection, and the requested correlation matrices and diagnostic plots for the best model were also included. In discussion, the Committee indicated that further clarity was required about what the full and reduced models were, including the explicit identification of a 'maximal biologically plausible model'. A small group was formed to

address this issue and the complete results are presented in Appendix 2 of Annex K1.

Konishi *et al.* (2014) reported a decreasing time trend in the weight of stomach contents from Antarctic minke whales taken during the JARPA and JARPA II programmes, and SC/65b/EM03 provided a revision of this paper following the JARPA II Review Panel recommendations (SC/65b/Rep2), but restricted to data from the JARPA period. The authors applied similar regression analyses as in SC/65b/EM02 for body condition and obtained similar results, including an indication that it was not necessary to consider year as a categorical variable. In discussion, the Committee identified similar problems to those of SC/65b/EM02, and asked that the small group tasked with addressing those issues also include SC/65b/EM03. The Committee further noted that a model with a constant time trend and with a random effect for the variation around this trend could potentially be better suited. In addition, in light of the highly skewed distribution of the residuals, they were asked to revisit model's distributional assumptions.

The results of the work of the small group are included in Appendix 2 of Annex K1. In discussion of these further analyses, the Committee **agrees** that the analyses which it had requested last year, and those requested by the Review Panel, had been satisfactorily completed. Given the results, the conclusion followed that a decline in blubber thickness and in fat weight that was statistically significant at the 5% level had occurred during the JARPA period. The Committee **agrees** that the implications of these results, together with indications of no further decline after the JARPA period, should be discussed further at next year's meeting. In particular, this will address whether a change of biological importance had occurred or not in the Southern Ocean ecosystem during the JARPA period. The Committee also **agrees** that the model presented in Appendix 2 of Annex K1 would benefit from extension to determine whether the trends identified showed any indication of change over time. It was noted that, even if not statistically significant at the 5% level, estimates of changes in trends would ultimately be important to take into account in fitting multi-species models.

Finally, the Review Panel at the JARPA II Review Meeting also recommended that a paper be presented at this meeting with details of a work plan to incorporate uncertainty in the estimates of prey consumption rate by Antarctic minke whales based on JARPA and JARPA II data (SC/65b/Rep2). SC/65b/EM01 was written as a response to these recommendations, indicating that over the next 1-2-year period the authors will implement Monte Carlo simulations for the estimation of uncertainty in the following parameters: *r* (the ratio of low/high feeding intake), the length of the feeding season and the extent of night feeding. The Committee had no further comments on this paper.

13.3.2 Case studies of the effects of long-term environmental variability on whale populations

The Committee briefly considered the types of information that should be compiled for analysing the effects of environmental change on cetaceans, for a fuller discussion next year. These analyses require decadal-length time series of cetacean demographic parameters and/or abundance together with relevant environmental variables for the same time periods and regions. An initial list of potential data sets was identified, and an intersessional correspondence group was appointed under Cooke to continue advancing this objective.

13.3.3 Other, if new information is available

Palacios *et al.* (2013) presented an evaluation of current statistical modelling efforts applied to predict marine mammal species distributions, commonly referred to as habitat models or species distribution models. These efforts have primarily relied on correlative approaches, and the authors argued that their limited explanatory power is due fundamentally to the omission of critical environmental and behavioural processes that directly affect marine mammal distributions. Palacios *et al.* (2013) outlined field studies targeted at that the elucidation of such processes, and the subsequent incorporation of this information into habitat models, as a way forward to significantly improve our ability to predict species' distributions. Finally, the authors note a convergence between probabilistic (stochastic) and deterministic approaches as a potential solution to the incorporation of the processes of interest into species distribution models.

The Committee **welcomes** this summary and noted the paper provides a timely contribution to discussions within the Committee on methods in species distribution modelling. Given the complexity and rapid development of this field, the Committee appointed an intersessional correspondence group under Murase to develop guidance and best practices to further applications of species distribution and habitat modelling within the Committee. Appendix 3 in Annex K1 was compiled as a basis for this work.

13.4 Workplan and budget requests

The detailed workplan and Budget Requests are detailed in Annex K1. The overall two-year workplan is summarised in Table 16.

Table 16

Overview of the workplan as it relates to ecosystem modelling

Topic	SC66a 2015	SC66b 2016
Co-operation on ecosystem model development	Discuss how best to further the long-term scientific exchange between IWC SC/EM and SC-CCAMLR WG-EMM (and receive report from observer at 2014 WG-EMM meeting)	Receive results of Joint CCAMLR-IWC Workshop and continue
Processes in ecosystem model development	Receive results of IWC funded project to use tagging data to incorporate into models (especially with respect to competition, resource partitioning and total prey consumption)	Review progress and continue
Ecological change in the Southern Ocean	Review new analyses of the minke whale body condition and stomach content data to further examine temporal trends	Continue if necessary
Effects of long-term environmental change	Review work of intersessional group to determine suitable long time datasets and determine workplan	Depends on discussions at SC66a
Modelling species distribution	Build upon previous and intersessional work to develop guidelines and recommendations for modelling steps	Depends on discussions at SC66a

14. SMALL CETACEANS

14.1 Review of status of small cetaceans in the eastern Mediterranean and Red seas

This year, the priority topic given the location of the meeting, was to review the current status of small cetaceans in the eastern Mediterranean and Red Seas (fig. 1 of Annex L). The Committee noted the importance of co-operation with ACCOBAMS in this region.

Relatively little information was received on the eastern Mediterranean Sea and several areas in the region remain poorly known with respect to the status of small cetaceans. The available information was primarily for the Adriatic and Aegean seas, Libyan waters and the Levantine Basin.

14.1.1 Adriatic Sea

SC/65b/SM20 provided a general review of cetacean species in the Adriatic Sea. The common bottlenose dolphin is the only species that occurs throughout the basin and it appears to have a continuous distribution over the continental shelf area. The striped dolphins are more abundant but limited to the southern Adriatic Sea which also seems important for Cuvier's beaked whales and Risso's dolphins. The common dolphin, once abundant, is now extremely rare (Bearzi and Notarbartolo di Sciara, 1995; Genov *et al.*, 2012; Rako *et al.*, 2009). Two recent aerial surveys have covered the entire Adriatic basin and provide important new information on summer distribution and abundance[22]. Surveys confirmed the general distribution of cetaceans and generated preliminary abundance estimates uncorrected for availability and perception bias (Fortuna *et al*. 2011 and unpublished data). Details on available information on genetic structure of populations, interaction with fisheries and other existing threats can be found in Annex L.

The Committee **thanks** Holcer and colleagues for providing this valuable summary.

The Swiss NGO OceanCare provided an inventory[23] of the seismic offshore explorations for oil and gas in the Mediterranean since 2006, many in the Adriatic Sea. There is a concerning geographical overlap with areas thought important for cetaceans. The Committee **welcomes** this information and reiterates previous Committee concern over the difficulty of obtaining information of where and when seismic surveys are taking place (see Nowacek *et al*., 2013). Additional discussion on beaked whales and anthropogenic noise was carried out in the joint session with the SWG on Environmental Concerns (see Annex K, items 8.3 and 9.4).

The Committee also **thanks** Genov for providing information on the bottlenose dolphins that occur year round off Slovenia and in the Gulf of Trieste (northern Adriatic Sea), that have been monitored since 2002 (Genov *et al.*, 2008). All details are provided in Annex L.

In conclusion, the Committee **recommends** that monitoring programmes in the Adriatic Sea should be coordinated among the neighbouring countries to enable regular basin-wide surveys of populations and monitoring of threats especially within the mandatory activities needed under the EU Marine Strategy Framework Directive (*Directive* 2008/56/EC). The Committee also **recommends** that ongoing studies in the region, particularly in offshore areas of the southern Adriatic, be continued (e.g. to improve the knowledge on beaked whale).

14.1.2 Aegean Sea

Frantzis (2009) summarised the present status of knowledge on small cetaceans in Greek waters, and more recent publications (Bearzi *et al.*, 2011; Bonizzoni *et al.*, 2014) complement that information. Five species of small cetaceans are present year-round in Greek waters: striped, common bottlenose, short-beaked common and Risso's dolphins and Cuvier's beaked whales. The harbour porpoise has been recorded in the northern Aegean Sea (they are not genetically isolated from those in the Black Sea (Rosel *et al.*, 2003; Tonay *et al.*, 2012; Viaud-Martínez *et al.*, 2007) and there have been opportunistic sightings of harbour porpoises in the straits between the Aegean and Black Seas. The rough-toothed dolphin has been recorded in the central Ionian Sea. False killer whales are occasionally recorded. The common bottlenose and striped dolphins are the most common species. Cuvier's beaked whale is present along the Hellenic Trench from Corfu to Rodos Island, and over steep depressions of the Aegean plateau. Abundance estimates are very scarce and apply to limited areas (Bearzi *et al.*, 2008a; Bearzi *et al.*, 2008b; Bearzi *et al.*, 2011; Bonizzoni *et al.*, 2014). Details on threats in this area can be in Annex L.

Explosives are still used illegally to fish and the Committee **expresses concern** and **requests** the Greek authorities to stop the illegal use of explosives.

SC/65b/SM15rev provided a review of current knowledge on small cetaceans in the Mediterranean waters of Turkey, including the Aegean Sea. Information for this large area, particularly on abundance and population structure, is limited by funding and research capacity. Nine species of small cetaceans have been recorded from the area. The short-beaked common dolphin, common bottlenose dolphin, striped dolphin, Risso's dolphin and Cuvier's beaked whale are considered common based on sighting and stranding data whereas the long-finned pilot whale, the false killer whale and beaked whales are considered rare. All cetacean species are protected by national legislation. Additional information can be found in the paper.

The Committee **thanks** Öztürk and colleagues for preparing this useful overview.

SC/65b/SM04 summarised information from the summer 2013 Song of the Whale survey of the Aegean and Levantine Seas (Ryan *et al.*, 2014). Harbour porpoises were encountered for the first time in over 20 years north of Thasos Island and west of Alexandropoulos (Greece) and in Saros Bay (Turkey). Common bottlenose dolphins were most common in the Aegean Sea and striped dolphins in the Levantine Sea. Common dolphin sightings were limited to the northern Aegean Sea, primarily the Thracian Sea. Rough-toothed dolphins were observed twice in the Levantine Sea, south of Cyprus. Seven acoustic detections (no sightings) of beaked

[22] Carried out by the Italian National Institute for Environmental Protection and Research (ISPRA) and Blue World Institute (Croatia) within the framework of two projects (Italian monitoring of bycatch under EU regulations and EU IPA Adriatic NETCET project).

[23] Still not exhaustive as the information about these surveys is not readily accessible.

whales were recorded, one in the Ikaria Basin, an area thought to be important for deep-diving species, and the rest along the Anaximander Seamount, south of Turkey.

The Committee **endorses** the recommendation from local scientists that Turkey develops a Conservation Action plan for small cetacean species in its waters which incorporates public awareness as well as research elements.

14.1.3 Libyan waters

SC/65b/SM16 provided a brief summary of the status of small cetaceans in Libyan waters, which occupy 40% of the southern Mediterranean coast. The cetacean fauna of Libya is little known, with seven species expected to occur. A long-term photo-identification study in Cyrenaica suggests the presence of a resident bottlenose dolphin population distributed between two areas. There is growing concern over both habitat degradation and unregulated fisheries, including the use of explosives. There are some reports of bycatch, consisting mostly of striped dolphins and common bottlenose dolphins in seasonal trammel net fisheries in the west of the country.

The Committee **encourages** relevant authorities in Libya to more strictly regulate fisheries and stop the illegal use of explosives.

14.1.4 Levantine Basin

SC/65b/SM9 presented a review of the present knowledge on small cetaceans in Mediterranean Israeli waters. Very few surveys have been conducted, but densities of all species (common bottlenose, stripes, common, Risso's and rough-toothed dolphins and Cuvier's beaked whales) appear to be relatively low. Strandings data collected between 2000 and 2010 indicate almost 30% of dead bottlenose dolphins were trapped in the safety line of bottom trawls. Entanglement in gill nets is apparently rarer (6%). The presence of large groups of short-beaked common dolphins (up to 100 individuals) off southern Israel is noteworthy. SC/65b/SM9 also contains some information on observed and potential threats, including gas and oil explorations. More details are given in section 6.1.4 of Annex L.

Discussion focused on the status of rough-toothed dolphins in the eastern Levantine basin, an area of apparent importance for the species. The species appears absent from the western Mediterranean and the Red Sea. Genetic information suggests the Levantine animals are a relict population of Atlantic origin with little if any recent exchange with other populations. Differences in behaviour and diet are suggested compared to other areas. Kerem encouraged analyses of an as yet unanalysed dataset from surveys conducted by IFAW (2013).

The Committee **thanks** Kerem and his colleagues for information on a poorly known region and **encourages** publication as soon as practicable. It also **recommends** that (1) that a preliminary analysis to define the amount of effort needed to obtain robust abundance and distribution data in Israeli waters be conducted and (2) that Israel develop Conservation Action plans for small cetacean species incorporating scientific elements and public awareness.

14.1.5 General recommendations for the eastern Mediterranean

Noting the various threats identified for small cetaceans in the eastern Mediterranean region, the Committee **recommends** that further research be conducted to investigate their effects on the long-term viability of populations. Specifically the Committee **reiterates its previous recommendations** that:

The large-scale survey known as the 'ACCOBAMS Survey Initiative' be carried out as soon as possible in order to obtain information on cetacean distribution and abundance for the whole Mediterranean, including the eastern sub-region.

It also **recommends** that:

(1) Systematic sub-regional surveys be implemented;
(2) Research be undertaken to define management units, at least for the most common species (e.g. the common bottlenose dolphin and the striped dolphin), through multidisciplinary approaches (including genetics, isotopes, biomarkers and photo-identification) to evaluate the effects of anthropogenic mortality (e.g. bycatch) at population level;
(3) The nature and extent of cetacean-fisheries interactions (including bycatch, depredation and competition/overfishing) be investigated. This could include enlarging the scope of existing fishery monitoring programmes (e.g. by collecting data on cetaceans bycatch and other interactions on a regular basis), including those for IUU (illegal, unreported and unregulated) fisheries;
(4) Research be conducted on the extent and effects of oil- and gas-related activities;
(5) Cooperative research with oil and gas industries be developed for sharing information on cetacean distribution and to develop models to identify areas of high density or high importance to small cetaceans;
(6) Conduct research on the effects of boat traffic on small cetacean local populations, especially in harbours and other areas of high activity and potential overlap;
(7) A research project be developed in the eastern Mediterranean Sea to gather data on rough-toothed dolphins in order to assess their degree of isolation and their conservation status under IUCN criteria. This assessment should make use of existing acoustic and genetic data.
(8) Regional cooperation on science and policy for conserving/managing shared populations/species (e.g. common research/monitoring programmes, common mitigation actions) should be implemented (e.g. in the Adriatic Sea under the Marine Strategy Framework Directive);
(9) Capacity building actions should be implemented (university, local authorities) throughout the region.

14.2 Review of status of small cetaceans in the Red Sea

SC/65b/SM13 summarised existing knowledge on cetaceans in the Red Sea based on a literature review and the authors' direct observations. Eleven species of small cetaceans are thought to occur in the Red Sea of which eight (*D. c. tropicalis*, *G. griseus*, *P. crassidens*, *S. plumbea*, *S. attenuata*, *S. longirostris*, *T. aduncus* and *T. truncatus*) are thought to occur regularly.

SC/65b/SM23 summarised the results of a dedicated survey to estimate abundance of delphinids in a portion of the southern Egyptian Red Sea (10,651 km^2). Abundance estimates are provided in Annex L, item 6.2. *Stenella* species were encountered throughout the study area. Bottlenose dolphins were present at low densities, with an apparent

concentration of *T. truncatus* in offshore areas and *T. aduncus* in southern coastal areas. Within the study area *G. griseus* occurred mainly south of 23°N. Offshore reefs in the southern part of the study area appear to be used as resting areas by at least three species; this is also an area where fishing and tourist activities are concentrated. The authors stressed the need to gather more information about these zones, since similar resting areas are known to be heavily affected by tourist and fishing activities in the northern part of the study area. They also urged that there be more research effort in the southern coastal areas frequented by two coastal species (*T. aduncus* and *S. plumbea*), where unregulated fishing is conducted regularly from the main village (Shalatin) and where there are two large active Egyptian naval bases.

Despite low human densities along the region's desert coasts, observed increases in tourism and coastal development, fishing, shipping, and hydrocarbon exploration and extraction (particularly in the northern portion of the region) suggest the need for increased cetacean research efforts. Dedicated research projects and surveys should include investigations of ecology, potential threats and conservation status. Such actions could be facilitated by PERSGA, the Regional Organisation for the Conservation of the Red Sea and Gulf of Aden.

The Committee **agrees** on the importance of gathering additional detailed information on the distribution and abundance of cetaceans, particularly in the least known portions of the region (e.g., Gulf of Suez, waters of Saudi Arabia, Sudan, Eritrea and Yemen), and promoting regulation of dolphin watching in Egypt.

The Committee **encourages** the authors to publish their review in a peer-reviewed journal as soon as practicable.

14.3 Report on the Voluntary Fund for Small Cetacean Conservation Research

Fortuna presented a summary of projects funded by the Voluntary Fund for Small Cetaceans. Approximately £350,000 has been disbursed since 2010 and 16 projects have been funded (Annex L, Appendix 2). Projects were awarded through two calls for proposals (2011 and 2013). Proposals are selected through a rigorous review process by the Small Cetacean Conservation Research Fund Review Group (http://iwc.int/sm_fund). All details of funded projects were available through the Secretariat and final results will be made available on the IWC website.

The Committee **recognises** the importance of this fund and the work being accomplished and **welcomes** the most recent voluntary contributions received after the last Commission meeting in Panama (June 2012) by Italy (£12,300), the Netherlands (£19,324), the United Kingdom (£30,000), the USA (£6,320), Italian National Institute for Environmental Protection and Research (£12,132), Oceancare (£998), World Society for Protection of Animals (£3,000) and World Wildlife Fund (£1,295).

14.3.1 Update on 2011 awarded projects

SC/65b/SM21 reported progress on the 'Ecology, Status, Fisheries Interactions and Conservation of Coastal Indo-Pacific Humpback and Bottlenose Dolphins on the West Coast of Madagascar'. Interview surveys with fishers in the northwest indicated that directed hunting on coastal dolphins is not as prevalent as in the southwest, but by-catch, particularly of *T. aduncus*, is prevalent and there is some evidence for 'directed by-catch' that may indicate a progression towards hunting. In the southwest where hunting has been documented, a model of community-based conservation has been successfully implemented; local associations for the protection of marine mammals have been established, education and outreach commenced, local traditional laws (Dina) are being developed and ratified, and alternative livelihood options (ecotourism) are being tested. Additional details on this project can be found in item 7.1 of Annex L.

In discussion, it was noted that in the southwest the overt presence of meat in markets had decreased since the project's inception (1999) and that fishers were benefiting from alternate sources of cash generated through seasonal whale watching ecotourism activities (developed in 2004). The number of local operators and clients was increasing in the Anakao area and the spatial extent of conservation work was expanding in the wider southwest region (Anakao to Andavadoaka). Continued effort was planned but requires additional funding.

The Committee **emphasises** that this project represented another good example of the important contribution made by the Small Cetaceans Conservation Research Fund.

14.3.2 Update on 2013 awarded projects

SC/65b/SM26 provided a progress review of the project entitled 'Defining the units of conservation and historic population dynamics for two small cetacean species affected by directed and incidental catches in the North Pacific' (Principal Investigator: Chen). Ten animals confiscated in PingDong Taiwan from an illegal take (from unknown locations) were investigated to confirm species identity. They had been identified as Fraser's dolphins by the Taiwanese authorities. Genetic analysis suggested that the confiscated samples were not Fraser's dolphin but more likely of a species in the genus *Stenella*, possibly *S. longirostris*. Further analyses and sequencing is planned to resolve this question. These results were presented at regional meetings in Taiwan and Japan and a report on the status of these species for Taiwanese authorities in in preparation. A final report will be submitted to the IWC in June 2014.

In discussion it was noted that although the results were preliminary, they served to emphasise the lack of reference sequences for many genes. The Committee **commends** the work by Chen and Hoelzel and **emphasises** the efficient use of a relatively modest grant.

Porter provided an update on an ongoing project entitled 'A Pilot Study to Identify the Extent of Small Cetacean Bycatch in Indonesia using Fisher Interview and Stranding Data as Proxies'. Recent activities include a workshop (November 2013) where participants were trained to identify evidence of bycatch in strandings events. Interviews of fishers (50 per site) were completed at two sites: Paloh and Adonara. The Paloh area fisheries focus on coastal areas using gillnets as the main fishing gear and interviews suggest that the species most effected are the finless porpoise and the Indo-Pacific humpback dolphin (*Sousa chinensis*). The Adonara fisheries operate both inshore and offshore with pole and lines and purse seine as the main gears utilised. The cetacean species most effected were noted to be the bottlenose dolphin (*Tursiops spp*), the spinner dolphin (*Stenella longirostris*),

some unidentified 'black fish' (and sperm whales). Data analyses are still underway and the final report will be submitted by the first week of June 2014.

In discussion Porter clarified that dolphins were actively targeted for consumption in some areas but were opportunistically used at other sites when landed. The use of terminology associated with catches was also discussed, with the need for care and consistency emphasised. It was suggested that the term 'takes' and not 'bycatch' be used in this context.

14.4 Progress on previous recommendations

14.4.1 Vaquita

Great concern over the status of this species has been expressed for many years by the Committee. At last year's meeting the Committee was (1) advised that the best 2013 abundance estimate for the critically endangered vaquita, long a topic of this Committee, was 189 animals and (2) commended Mexico's establishment of a new Advisory Commission of the Presidency of Mexico for the Recovery of the Vaquita (CAP). Rojas-Bracho reported that CAP held its fourth meeting in April 2014 where Advisory Commission members were advised of a recent dramatic escalation of illegal fishing and trade of totoaba (*Totoaba macdonaldi*), a critically endangered CITES Appendix I species, in the Upper Gulf of California. This fishing involves the use of large-mesh gillnets which have a high entanglement risk for vaquita. Demand is driven by the high price of totoaba swim bladders in Asian markets. The actions by the Mexican Government to combat this fishery were presented and discussed during the CAP meeting as were further measures to replace gillnets with alternative light trawl gear and to strengthen enforcement.

The Committee also received information on the Second Meeting of the Steering Committee of the Vaquita Acoustic Monitoring Program, which met in Ensenada in April 2014, to review and evaluate technical aspects of the passive acoustic monitoring project and to review results to date. The monitoring array performed well and acquired sufficient data to detect a 4%/year increase in over a 5-year interval were such an increase to occur. Alarmingly, mid-project results indicate a substantial decline in vaquita numbers since 2011. Raw data indicate declines of 7.5% and 14.9% from 2011 to 2012 and from 2012 to 2013, respectively. Assuming a 14.9%/yr decline, from the 2013 estimate of 189 individuals, the population could be reduced to fewer than 100 individuals in the next two years. The Steering Committee agreed that these estimated annual rates of decline from 2011 to 2013 are so severe and the vaquita's status so serious that immediate action is essential to save this species. To confirm its findings, the Steering Committee is planning an immediate review of the data, analyses and preliminary findings by a small group of experts before the next CAP meeting in July 2014.

The Committee **reiterates** that the situation for the vaquita is extremely grave and is especially exacerbated by the totoaba fishery. It **expresses grave concern** that the resurgence of illegal totoaba fishing with large mesh gill nets is driving the vaquita more rapidly toward extinction. The Committee **supports** the actions taken and recommendations made by the CAP at its Fourth Meeting and **recognises and commends** the efforts being made by the Mexican Government to combat the illegal fishing of totoaba.

Recalling Committee recommendations from 1991, the Committee **recommends** that further action be taken to stop vaquita entanglement by fully enforcing the closure of the totoaba fishery and that immediate action be taken to stop the illegal shipment of totoaba across the US border.

The Committee **recommends** that the Governments of Mexico and the United States consult on this continuing illegal international trade in CITES Appendix I totoaba and, as necessary, raise it to CITES and its Party government to highlight the effect of this trade in causing additional losses of the critically endangered vaquita, with the goal of enhancing enforcement efforts and awareness.

The Committee **emphasises** that immediate implementation by the Government of Mexico of its strategy to replace gillnets with alternative fishing gear, as required by NOM-002-SAG-PESC-2013, is **extremely urgent**, particularly given the recent major expansion of illegal totoaba fishing and the preliminary results of the acoustic monitoring program, which indicate a rapid decline in vaquita abundance.

The Committee also **reiterates** its previous recommendations (IWC, 2011a; 2012a) to continue research on technologies to replace gillnetting for finfish or otherwise to remove all gillnets from the vaquita's entire range (IWC, 2008d; 2009c; 2010d; 2011d; 2012e; 2013e; 2014h).

The Committee **encourages** the Government of Mexico to maintain and, as necessary, refine or expand the acoustic monitoring programme as the only feasible way of evaluating the effectiveness of the recovery plan contained in the federal Action Program for the Conservation of Vaquita (PACE-Vaquita). The Committee **strongly endorses** and **applauds** the work of the team (Coordinación de Investigación y Conservación de Mamíferos Marinos) at CONANP for the field work and data analysis and of the steering committee for the review and evaluation of the monitoring programme.

14.4.2 Hector's dolphin

Currey provided a summary of the Government of New Zealand Ministry for Primary Industries (MPI) science and management actions for Hector's (*Cephalorhynchus hectori*) and Maui's (*Cephalorhynchus hectori maui*) dolphins. The decline of Maui's dolphin is demonstrated by multiple methods. Both the East Coast of the South Island (ECSI) and West Coast South Island (WCSI) Hector's dolphin populations are probably also in decline, although evidence is inconsistent and trends not entirely clear. Since 2008 there has been a substantial reduction in set net effort on the WCSI, while on the ECSI fisheries interactions have declined following the extension of set net area closures. The population of Hector's dolphins along the South Coast of the South Island is small and genetically isolated, but the trend in abundance is unknown.

The Committee **respectfully requests** that the New Zealand government provide updates of the MPI report on a regular basis.

Annex L provides details of criticism by Slooten of aspects of the report relating to abundance and distribution.

Mackenzie and Clement (2014) reported the results of an aerial survey program to estimate the abundance and distribution of the ECSI population of Hector's dolphins between Farewell Spit and Nugget Point and offshore to 20

nm (covering ~42,677 km^2). The estimates suggest substantially higher numbers in both inshore and offshore areas than previously thought. The discrepancy is more likely attributable to differences in survey methodology (i.e., boat versus aerial surveys) and increased survey effort in offshore areas, rather than to an increase in population size or a change in distribution.

The Committee **agrees** that this matter deserves closer scrutiny than was possible in the time available at this year's meeting. Next year the sub-committee will make provision to ensure appropriate evaluation of abundance estimates.

14.4.2.1 MAUI'S DOLPHIN

SC/65b/SM8 presents estimates of the effectiveness of the extensions to protected areas for Maui's dolphin implemented in 2012 and 2013 in terms of reducing bycatch. An 'Expert Panel' of scientists, convened by the New Zealand government in 2012, estimated that five Maui's dolphins were killed each year in trawl and gillnet fisheries (Currey *et al.*, 2012). The level of trawl mortality is unchanged and continued dolphin deaths in gillnets are due to a lack of protection in some areas and incomplete protection in others. The estimated number of bycatch events has decreased from 5 per year to 3-4 per year, reducing the total level of bycatch from >75 to >54 times the safe level estimated using a PBR (Potential Biological Removal). Detailed information on strategies to reduce bycatch below PBR are given in the document and summarised in Annex L.

SC/65a/SM11 recognised the efforts of the Government of New Zealand to date, but provided a critique of the current protection measures stating that they are insufficient. Detailed information is given in the document and summarised in Annex L.

In discussion it was noted that the current management situation falls short of that required to reverse the Maui's dolphin decline. Since the publication of the Expert Panel report (Currey *et al.*, 2012) the New Zealand Government had closed additional fisheries, and a reduction in the number of predicted fisheries interactions is expected. It was noted that bycatch numbers would not be reduced to zero even with the most recent increased area closures.

The Committee **commends** the New Zealand Government for maintaining initial and interim protection measures for Maui's dolphin, and adding an additional 350 sq. km set net restriction. However, the Committee **emphasises** that these measures fall significantly short of those previously recommended (IWC, 2013a; 2014c). The Committee **reiterates** its **extreme concern** about the continued decline of such a small population as the human-induced death of even one dolphin would increase the extinction risk for this subspecies. It also **reiterates** that rather than seeking further scientific evidence it is of highest priority to take immediate management actions that will eliminate bycatch of Maui's dolphins. This includes full closures of any fisheries within the range of Maui's dolphins that are known to pose a risk of bycatch of small cetaceans (i.e. set net and trawl fisheries).

The Committee **re-emphasises** that the critically endangered status of Maui's dolphin and the inherent and irresolvable uncertainty surrounding information on small populations, require the implementation of precautionary measures.

Ensuring full protection of Maui's dolphins in all areas throughout their habitat, together with an ample buffer zone, would minimise the risk of bycatch and maximise the chances of population increase. The Committee **notes** that the current range of Maui's dolphins comprises the area from Maunganui Bluff in the north to Whanganui in the south, offshore to 20 nautical miles and including harbours. This range reflects all available sightings and strandings data for Maui's and Hector's dolphins along the West Coast of the North Island. The Committee **notes** that data from Hector's dolphins off the South Island, with most sightings in waters less than 100 m deep and less than 20 nm offshore support our understanding of the offshore distribution of Maui's dolphins and the recommendation that within this defined area, fishing methods other than set nets and trawling should be used.

The Committee **urges** the New Zealand Government to **commit** to specific population increase targets and timelines, and **respectfully requests** that reports be provided annually on progress towards conservation goals.

14.4.3 Beaked whales

SC/65b/SM01 provided a short review of strandings of Gervais' beaked whale (*Mesoplodon europaeus*) in the Atlantic Ocean collected since 1995 and SC/65b/SM02 presented stranding records in European waters of Sowerby's beaked whale (*Mesoplodon bidens*) since 1825.

See Annex L, item 6.1 for new information on Mediterranean beaked whales. See also the relevant discussions on beaked whales and anthropogenic noise in Annex K, items 8.3 and 9.4.

14.4.4 White whales[24] of the Okhotsk Sea

SC/65b/SM14 provided information on recent and expanding captures of white whales in the western Okhotsk Sea (Russia). Recent studies have identified separate demographic units within the Western-Okhotsk population, including the summer aggregation in Sakhalin-Amur region (details on abundance are provided in item 8.4 of Annex L) with Potential Biological Removal (PBR) estimated as 42 (SC/65a/SM23).

Last year (IWC, 2014c), the Committee agreed that the current management scheme for live-capture of white whales in the Sea of Okhotsk was very likely to lead to unsustainable levels of removals, placing at least the Sakhalin-Amur summer aggregation in Sakhalinsky Bay at high risk of depletion.

The Committee **expresses strong concern** given the estimated PBR of 42, that the removal of 81 living white whales, with an additional 12 confirmed and over 30 suspected deaths in summer of 2013, is unsustainable for this local summer aggregation and **reiterates** that removals should be reduced to at least a level that is consistent with available scientific data and that the four summer aggregations in the North-Okhotsk subzone should be managed separately through separate quotas for Sakhalin-

[24] 'White whale is the official IWC common name but the species is also known as 'beluga' or 'belukha' in some parts of the Arctic.

Amur region, Ulbansky Bay, Tugursky Bay and Udskaya Bay (IWC, 2014c).

The Committee also **supports** the continuation of the white whale research projects conducted by the A.N. Severtsov Institute and the Marine Mammal Council and **recommends** expanding research efforts into all areas of potential beluga removals.

14.4.5 Killer whales

14.4.5.1 RUSSIAN FAR EAST

SC/65b/SM07 provided information on killer whales in the Russian Far East, including details of recent captures. Six killer whales were live-captured in different areas of the Russian Far East from 2002-2011 and seven more were reported captured in the western Okhotsk Sea in 2012-2013. Two of these were transported to China for public display and another two are suspected to be in Moscow; the fate of the remaining three animals is unknown.

The Committee discussed its concern about these captures, particularly the uncertainty of ecotype identification. There is evidence that resident and transient killer whales belong to reproductively isolated populations (SC/65b/SM15, Filatova *et al.*, 2014; Ivkovich *et al.*, 2010), mirroring the situation in the eastern North Pacific (Ford *et al.*, 1998; Saulitis *et al.*, 2000). Based on genetic data similar to that reported in SC/65b/SM07, 'Resident' and 'Transient' killer whales are currently recognised as unnamed subspecies by the Society for Marine Mammalogy Committee on Taxonomy (List of marine mammal species and subspecies. Society for Marine Mammalogy)[25] and some have suggested that these ecotypes qualify as full species (Morin *et al.*, 2010a).

No reliable abundance estimates are available for either ecotypes in the Okhotsk Sea but the available information (e.g. SC/65b/SM07) raises concern that local stock size is fairly small and that only transients have been live-captured in this region. Different killer whale ecotypes are not officially recognised in Russia, and consequently they are not treated as different management units. Currently, the total allowable take for 2014 is zero, but this will likely be reviewed before the 2014 season.

The Committee **reiterates** its longstanding recommendation that no removals of small cetaceans (live capture or deliberate killing) should be authorised until a full assessment of sustainability has been completed and **recommends** transient and resident killer whales be managed as distinct units and that studies in the western Okhotsk Sea be continued and be expanded.

14.4.5.2 ANTARCTIC KILLER WHALES

Six papers where presented on six ongoing projects (including SORP) on Antarctic and sub-Antarctic killer whales. All details are provided in the Annex L, item 8.5.2.

The Committee was also informed that Italian National Antarctic Research Programme (PNRA) will conduct research on killer whales in Terranova Bay (Ross Sea) to assess the role and dynamics of killer whales in this highly productive local marine ecosystem.

The Committee **recognises** the importance of these projects on Antarctic and Sub-Antarctic killer whales, **encourages** their continuation and **recommends** any further studies consider any impacts of tagging as part of their ongoing work.

14.4.5.3 CARIBBEAN KILLER WHALES

A recent paper on killer whales in the Caribbean Sea (Bolaños-Jiménez *et al.*, 2014) summarises records there and indicates their widespread and year round occurrence. Preliminary morphological analysis suggests that Caribbean killer whales exhibit both characteristics typical of Type 2 killer whales in the North Atlantic and those typical of 'offshore' killer whales in the northwest Pacific.

14.4.6 Irrawaddy dolphin (Mekong and Ayeyarwady dolphins)

An update was provided on Irrawaddy dolphins in the Mekong and Ayeyarwady Rivers based upon two meetings organised by WWF-Cambodia in March 2014. The number of dolphins in the Mekong River has declined to well below 100 and their survival is very much in doubt. The most recent reported counts in the Ayeyarwady River have been in the order of only 70 individuals and mortality appears to have increased in the last few years. Bycatch in gill nets remains the most serious problem. The construction of any large hydropower projects in the Mekong basin, especially mainstem dams, will have very serious impacts on the population of Irrawaddy dolphins. The proposed Don Sahong Dam is of immediate concern because Lao PDR has announced it will begin construction of the dam in the near future. A WWF-Cambodia risk assessment found that the extinction risk posed by the Don Sahong dam to the trans-boundary sub-population – the last remaining dolphins in Lao PDR– is 'very high' and the risk to the overall Mekong population is 'high' (Ryan *et al.*, 2014).

The Committee again **re-emphasises** that the situation in Laos and Cambodia is of **serious concern** and that without urgent intervention in the trans-boundary pool, and the surrounding area, the dolphins there will be eradicated.

Effective enforcement of gillnet fisheries ban is essential to the survival of dolphins throughout their remaining Mekong River range and the Committee **recommends** that the governments of Cambodia and Laos give the highest priority to effective enforcement of existing dolphin conservation laws. The Committee **notes with concern** the assessment of the risk of the Don Sahong dam to the transborder sub-population and the Mekong River population as a whole, and **calls** for full and transparent assessment of the environmental impacts of this and other less destructive hydropower options.

The Committee will receive a further update on the ongoing management actions put in place to mitigate threats, including widespread electro-fishing practices next year.

14.4.7 Yangtze finless porpoise

SC/65b/SM22 provided recent information on the Yangtze finless porpoise (*Neophocoena asiaeorientalis asiaeorientalis)*, red-listed by IUCN as a Critically Endangered subspecies endemic to Yangtze River system in China. The population in the mainstem of the Yangtze (Yichang to Shanghai) is estimated to have declined from more than 2,500 in 1991 (Zhang *et al.*, 1993) to 505 now (Mei *et al.*, 2014); data suggest a reduction by more than half between 2006-2012 with an estimated probability of

[25] http://www.marinemammalscience.org consulted on 25 May 2014

extinction in the next 100 years of 86%. Bycatch is considered the main cause of the decline. Ship strikes have also increased in recent years. Lack of enforcement of regulations as well as a lack of awareness among fishermen are considered major obstacles to success of conservation measures. The authors emphasised the need for immediate *in-situ* conservation actions to save 'seed populations', increased *ex-situ* conservation efforts, and strengthened national protective legislation.

The Committee **is concerned** that given the scale of anthropogenic pressures from *inter alia* bycatch, vessel traffic, sand mining and pollution, preventing the extinction of this subspecies will be a daunting challenge. Our concern is heightened because the same decline was witnessed with the decline and extinction of the baiji. Support from government officials at the highest levels, regional and national, is essential. Current conservation measures include reserves that are not appropriately designed or not adequately enforced.

Given its **grave concern** about the rapid, ongoing decline of Yangtze finless porpoises throughout their range, the Committee **recommends** that stronger measures be taken immediately, beginning by upgrading the subspecies to State I Protected status in Chinese legislation and implementing a national action plan with the necessary policy and financial support.

The Committee further **recommends** that all effort be made to protect Yangtze finless porpoises in their natural habitat. These include: (a) identifying river and lake segments with the highest porpoise concentrations, enforcing appropriate protection measures (including fishing bans) there year-round; (b) vigorously enforcing basin-wide prohibitions on electro-fishing and other fishing activities known or suspected to threaten porpoises; (c) vigorously enforcing regional and seasonal closures of sand-mining; (d) strengthening pollution control measures and (e) ensuring that before any further modification of the natural flow regime (or other natural features) of the Yangtze ecosystem are allowed to take place, the implications for finless porpoises are investigated and taken into account.

The Committee **recommends** that the Secretariat send a letter to the appropriate Chinese Government authorities, drawing their attention to these recommendations.

14.4.8 Franciscana

The franciscana is endemic to the eastern coasts of Brazil, Uruguay and Argentina, and is regarded as one of the most threatened small cetaceans in South America due to high bycatch levels as well as increasing habitat degradation, especially in the inshore and estuarine portions of its range.

SC/65b/SM18 reports on 9 days of helicopter experiments partially funded by the IWC Small Cetacean Research Fund to evaluate availability bias in franciscana observations made from an aerial survey platform. Results showed that availability bias is underestimated when using data from surface platforms, resulting in overestimation of abundance. The Committee **recommends** that estimates of availability bias derived from aerial, rather than surface platforms be used when analysing aerial survey data for abundance estimation.

Cunha *et al.* (2014) (also discussed in Annex I, item 3.1.1) suggests that there is substructure within each of the four existing Franciscana Management Areas (FMAs, Secchi *et al.*, 2003). The paper recommends division of these areas into smaller management units as data indicate very limited movement of franciscanas between sub-areas and raise concerns over the effects of localised bycatches.

The Committee **expresses its concern** regarding the increase of reported franciscana entanglements in sub-regions within FMA I. The Committee **recommends** that the impacts of bycatch and human-related mortality on franciscanas within sub-regions be assessed and mitigated It further **recommends** the assessment of finer-scale management area boundaries and that FMA definitions be supported to the greatest extent possible by analyses of both nuclear and mitochondrial markers and other indicators. The Committee **agrees** that the goal of species conservation is to maintain viable Franciscana populations in all areas where they occur.

The Committee **reiterates** its previous recommendations:

(1) on the need to gather additional basic data on demography and life history, so that the status of each management unit can be evaluated and appropriate conservation measures designed and implemented;
(2) the need for bycatch to be estimated in additional areas and for assessment of other possible threat factors, such as underwater noise, chemical pollution from coastal development and industrial and human waste discharge, oil and gas exploration activities and vessel traffic; and
(3) the need for international collaboration to continue and expand the investigations into population structure and to assess its implications for conservation, especially the strengthening of the regional collaboration between Argentina, Uruguay and Brazil to implement conservation management actions that address bycatch and other threats.

14.4.9 Amazon River dolphins: boto and tucuxi

SC/65b/SM24 provides an update on more than 15 scientific expeditions conducted by regional NGOs between 2006 and 2014 in the Amazon River. These have recorded sightings of the three species recognised (*I. geoffrensis, I. boliviensis, S. fluviatilis)*, as well as the recently described but not yet evaluated Araguaia dolphin (*Inia araguaiaensis*) over 5,700 km of the wider Amazon basin. The authors encourage strengthening of regional collaboration to manage direct threats, such as mercury contamination associated with mining and the hunting of dolphins for use as bait in the piracatinga (*Calophysus macropterus*) fishery.

SC/65b/SM10 summarised recent efforts by the Brazilian government to limit the illegal use of river dolphins as bait in piracatinga traps. Piracatinga are distributed throughout the Amazon Basin, occurring in Brazil, Bolivia, Colombia, Peru and Venezuela, highlighting legal, enforcement and institutional challenges and approaches. See Annex L, item 8.9 for additional details. Additional attention was drawn to dolphin watching and hand feeding tourism activities in Brazil as described in SC/65b/WW1 (see Annex M, item 5).

The Committee **commends** the Government of Brazil for responding to the current situation, **noting** that emerging cooperative efforts amongst the range states of the Amazon basin present a cause for optimism and that the Brazilian Ministry of Foreign Affairs could play a role in encouraging cooperation with other governments.

The Committee **encourages** further coordination between governments as a means to strengthen the effectiveness of conservation actions. The Buenos Aires Group was recognised as a useful caucus for discussions on conservation actions for the Amazon River dolphins.

The Committee once again **reiterates** its **serious concerns** about the potential population implications of the intentional killing of both botos and tucuxis for use as bait in the piracatinga fishery. It expresses **support** for the priority actions to assess and mitigate the capture of dolphins for bait contained in the Brazilian National Action Plan for Small Cetaceans and **reiterates its previous recommendation** that an international scientific workshop be organised involving scientists and managers from the range states, with the goal of addressing research and conservation priorities, standardising methodologies and planning long- term strategies.

In particular, the Committee **calls upon** the relevant authorities in each range state to continue and strengthen their efforts to:

(1) Assess and monitor the impact of intentional and incidental river dolphin capture relative to the density of local populations;
(2) Evaluate and monitor the use of botos and tucuxis as bait in fishing for piracatinga; and
(3) Test alternative baits (e.g. slaughter house waste products) for use in piracatinga fishing.

The Committee **encourages** the presentation of a report next year on progress in the development and implementation of an inspection plan to combat the targeted catch of Amazonian dolphins for bait.

14.4.10 Harbour porpoise

SC/65b/SD4 that describes population differentiation of Baltic Sea harbour porpoises using RAD-tag genotyping. Full technical details can be found in the report of Stock Definition Working Group (Annex I, item 3.2.1). Participants noted that this is a promising method for the future.

14.4.11 Humpback dolphins

An expert workshop on 'Sustainable Fisheries and the Conservation of the Critically Endangered Taiwanese White Dolphin (TWD) (*Sousa chinensis*)' in Taiwan (April-May 2014) conducted an assessment of TWD population status, using three approaches, each of which suggested the TWD population is declining. The workshop made a number of recommendations and welcomed the recent decision of the Government of Taiwan to designate 'Major Wildlife Habitat' along a stretch of the dolphins' known current range in the nearshore waters of the west coast of Taiwan, but also highlighted the need to implement its recommendations beyond the proposed area of protection. The workshop suggested a management target of recovering the population to 100 dolphins by the year 2030.

The Committee **endorses** the following recommendations by the workshop:

(1) immediate banning of all gill and trammel nets within the entire known habitat of the Taiwanese white dolphin;
(2) compensation for fishers willing to engage in alternative livelihoods;
(3) compensation to aid in the transition to alternative fishing gear that is both sustainable and dolphin-friendly, such as handlines;
(4) a strict enforcement of the existing inshore (inshore of 3nm) trawler ban.

The Committee also discussed three candidate wind farms planned for the Eastern Taiwan Strait, one of which overlaps with the northernmost range of the Taiwanese white dolphin. Such threats were a global concern for coastal small cetaceans and agreed that future meetings of the sub-committee should consider the impact of offshore renewables and land reclamation on small cetaceans. It **recalls the advice** provided by the Committee with respect to marine renewables provided in IWC (2013a) and **commends** this to the appropriate authorities.

The Committee received a summary of a report from a recent workshop on Marine Protected Areas (MPAs) for the Indo-Pacific humpback dolphin (*Sousa chinensis*) in the East Asia Ecoregion (January 2014). This workshop focused on the usefulness of establishing an East Asian network of MPAs. The Committee **welcomes** the positive steps taken at this workshop towards better protection for populations of *Sousa chinensis* which are under pressure from a multitude of threats associated with resource competition, coastal development and habitat loss throughout the East Asia region. The Committee **highlights** the critically endangered status of Taiwanese white dolphin and stressed the need for expediency in MPA designation and other management strategies.

The question of taxonomy is dealt with under Item 26.

14.4.12 Japanese drive fishery

In 1975, 1980, 1990, 1992, 1993 and 1996 the Commission passed resolutions on the Japanese drive fisheries in general or specifically on actions to better assess and prevent further depletion of striped dolphins taken in these fisheries. Those resolutions were based on the discussions and concerns related to the drive fisheries raised in the sub-committee. Last year, the Committee re-iterated a number of recommendations (IWC, 1992; 1993; 1998b) including the that (a) up-to-date assessments of these exploited populations be undertaken, including studies of population structure and life-history; (b) up-to-date data on struck and lost rates, bycatch rates, directed hunting effort, stock identity and reproductive status and age composition of catches be collected and made available; (c) catch limits take into account struck and lost bycatch rates and be based on up-to-date population assessments, and be sustainable with allowance for population recovery.

There is no struck and lost rate problem in the drive fisheries. However, there is an important related issue of the total removals in the drive fisheries. These concerns relate to the long holding period before the remaining dolphins that are not ultimately removed are released. This long holding period will lead to cryptic mortality (unobserved, unrecorded deaths) including the following: (1) stress caused by holding the animals for extended periods prior to release, (2) serious injury while held captive, (3) disruption of reproduction during the drive and during holding and/or handling (e.g. abortions caused by stress and mother/calf separation leading to the death of the calf) (Kita *et al.*, 2013) and (4) post-release deaths (e.g. due to pneumonia). These types of cryptic mortality are not estimated or counted against annual catch

limits or included in assessments of the effects of drive fisheries on the dolphin populations. Further information is provided in Annex L.

The Committee **agrees** the issue of total removals in the drive fisheries needs to be more critically examined and incorporated into population assessments. Based on detailed information provided in Annex L concerning live captures of bottlenose dolphins during the Taiji hunt and export to *inter alia* China (Zhang *et al.*, 2012), the Committee **also agrees** that the issue of live removals in drive fisheries must also be taken into account in assessments and notes the lack of current data on either stock identity or stock size for the bottlenose dolphins in waters the off Taiji. Finally, the Committee noted that stress experienced during long processing time of captured animals (up to 5 days) will increase the likelihood of post-capture mortality (see Annex L).

Based on the foregoing information, the Committee **reiterates its previous concerns and recommendations** that there is an **urgent need** for an up-to-date assessment of the targeted populations. This is especially needed for the common bottlenose dolphins subject to exploitation in the Japanese drive fisheries and live captures. Any new assessment must include, as indicated above, explicit consideration of cryptic mortality and subsequently consider the sustainability of removals for international trade.

Regarding the concerns about cryptic mortality in the drive fisheries in Japan, Kishiro noted that at least the animals found to have died during the period prior to release were actually counted, and included in the number of catch against the catch limit in the drive fishery, even though these animals were not directly killed and landed.

14.5 Takes of small cetaceans

14.5.1 New information on takes

The Committee received from the Secretariat the summary of catches of small cetaceans in 2013 extracted from this year's online national Progress Reports (see Annex L, Appendix 3, table 1).

14.5.1.1 DIRECT TAKES

Funahashi presented a table of direct takes of small cetaceans in Japan from 2002 to 2012, together with the catch limits for each species from 2007 to 2013 (Annex L, Appendix 3, table 2). The figures were obtained from websites of the Government of Japan. The catch limits given in the table are by season but the catch numbers are by calendar year.

The Committee **reiterates** its long standing recommendation that no small cetacean removals (live capture or directed harvest) should be authorised until a full and complete assessment has been made of their sustainability.

SC/65b/SM17 reports on small cetacean landings recorded in Dixcove Port (Ghana) in 2013-14. Details are given in Annex L. This information raises serious concern for these populations. Animals were mostly captured in large-mesh gillnets of the primary artisanal fishery. There was also evidence of at least occasional directed captures. The products was traded for human consumption, as previously reported (Debrah *et al.*, 2010). The authors stress that sampling has to be improved, possibly by providing support to biology/fisheries faculty students trained to photograph and sample landings. The proportion of total catches the figures in the paper represented are unclear but the authors state that there are many deficiencies in the current monitoring system, including focal instead of national coverage and discontinuous monitoring effort over time. The Committee **thanks** the authors for this important information and **expresses serious concern** over the threat to these populations.

The Committee **welcomes** received new information on the release of three Indo-Pacific bottlenose dolphins in 2013 in Jeju-do, Korea. The animals appear to be interacting successfully with wild population. The overall population size was estimated at 104 and the population is thought to be stable.

14.5.1.2 ACCIDENTAL TAKES

SC/65a/SM05 documents the ongoing threat from illegal large-scale driftnetting to cetacean populations in the Mediterranean. Illegal driftnetting continues in Albania and Tunisia, at a potentially significant rate, with unconfirmed indications of illegal activity in Italy. The authors recommend further research in order to better understand the threat from driftnetting, including that (i) methods be developed and applied to estimate driftnet-related mortality of cetaceans in the Mediterranean and the impact on populations, giving special attention to areas where driftnetting overlaps with known concentrations of cetaceans; (ii) scientists and other stakeholders collaborate to conduct a regional examination of the impacts of European small-scale driftnet fisheries on cetacean populations; and (iii) researchers and relevant national and international agencies collaborate to examine the extent of regulation and impacts of large-scale driftnetting within EEZs globally. Additional information on this issue can be found in Annex L, section 9.1.2.

The Committee **welcomes** the recent improvements in the implementation of the ban and **expresses concern** over the ongoing illegal driftnetting and **recommends** that countries increase enforcement capacity and penalties for any illegal, unreported and unregulated (IUU) fishing. In addition to existing EU legislation, all Mediterranean countries are party to the General Fisheries Commission for the Mediterranean (GFCM) which bans the use of large pelagic driftnets (>2.5 km long and mesh size >10 cm).

The Committee **agrees** that improving the identification of ports and areas affected by the illegal driftnet fishery was of considerable importance and should be pursued further.

From the progress reports, the Committee noted that the bycatch of finless porpoises in South Korean waters was still high. Acknowledging previous recommendations, the Korean Government has started a monitoring and mitigation programme on the stow net fisheries which are responsible for 95% of finless porpoise bycatch. The Committee **looks forward** to results of the programme next year.

14.5.2 Follow up on the proposal for a Workshop on 'poorly documented hunts of small cetaceans for food, bait or cash'

Limited progress had been made on this standing agenda item in the intersessional period. The sub-committee decided to pursue this further by producing a scaled down agenda from that proposed last year with the intention that this may provide a structure for a series of regional workshops, including South East Asia, Africa and South America.

New research in Southeast Asia, some of which has been supported by the Small Cetacean Voluntary Fund, has led to an opportunity to organise the first workshop there (Annex L, Appendix 4). Members of the steering group will work to formalise a list of attendees and a detailed agenda. The Committee **welcomes** this new development.14.6 Work plan

14.6 Update on proposed joint workshop on monodontids
Bjørge reported that the proposal for a global review of Monodontids was discussed at the NAMMCO Council meeting in February 2014. The Council decided to convene a workshop to undertake a global review of narwhal and beluga. This will not be an IWC workshop. The workshop will be convened in connection with the meeting on Marine Mammals of the Holarctic in Russia in 2016.

14.7 Conservation and Management plans
This is considered under Item 21.

In addition, the Committee **agrees** to trial a new intersessional approach for situations that are considered high priority from a conservation perspective at the species or population level, especially where the indications are that time is short and no mitigation actions are in place. An intersessional 'task team' of appropriate experts will be identified from the sub-committee on small cetaceans. Task teams would undertake a thorough review of the situation, consulting with local research groups, authorities and others as appropriate, provide written information to the relevant authorities (through the chairs of the sub-committee and Committee in consultation with the Secretariat) if required, and provide scientific or mitigation advice as appropriate. Task Teams would report back to the sub-committee on progress at its next meeting. It was suggested that budgetary needs could be evaluated by the existing Small Cetacean Conservation Research Fund Review Group (http://iwc.int/sm_fund). Work will continue intersessionally to better define this task team approach.

14.8 Other information on small cetaceans
SC/65b/SM12rev describes two unknown beaked whale FM pulse types (Antarctic BW29 and BW37) recorded during the 2014 IWC-SORP-ABWP South American Consortium voyage.

SC/65b/SM3 provided information on seven Longman's beaked whales (*Indopacetus pacificus*) that stranded in New Caledonia during November 2013, the first mass stranding recorded for this species.

SC/65b/SM27 reviewed the information on cetacean strandings and mortality in Venezuela between 1988 and 2014.

14.9 Workplan and budget requests
Last year, two previously identified priority topics, a review of Southern Hemisphere Ziphiids and an assessment of *Tursiops* systematics and associated conservation issues were deferred. The Committee **agrees** that the former remains a priority that should be addressed when the Scientific Committee next meets in the Southern Hemisphere.

There was considerable discussion over whether the *Tursiops* review was an appropriate priority topic for next year as discussed in detail in Annex L, item 14.9. It was decided to advance the discussion intersessionally.

Recognising that the venues for the 2105 and 2016 Annual Meetings are not yet known, Table 17 presents a tentative two-year workplan for small cetacean work.

Table 17

Overview of the workplan as it relates to small cetaceans

Topic	SC66a 2015	SC66b 2016
Main topic to be decided by December 2014	*Tursiops* systematic or regional assessment of the status of small cetaceans	Depends on what happens in 2015 and the venue for 2016
Voluntary fund for small cetaceans conservation research fund	Continue	Continue
Review of previous recommendations (priority will be given to vaquita, Hector's and Maui's dolphins, franciscana, beluga, river dolphins)	Continue	Continue
Review on takes of small cetaceans.	Continue	Continue

15. WHALEWATCHING

The report of the Committee on whalewatching is given as Annex M. Scientific aspects of whalewatching have been discussed formally within the Committee since a Commission Resolution in 1994 (IWC, 1995). The Commission also has a Standing Working Group on Whalewatching that reports to the Conservation Committee (e.g. see Item 15.3.3).

15.1 Assess the impact of whalewatching on cetaceans
SC/65b/WW01 described inter- and intraspecific behaviours of pilot whales (*Globicephala macrorhynchus*) from the Canary Islands, Spain, where their behaviours when interacting with swimmers were recorded, and of botos (*Inia geoffrensis*) in Amazonas state (Brazil), where tourists feed and interact but do not swim with the animals. Behaviour was categorised based on *a priori* ethograms and the risk they posed for physical harm to either humans or cetaceans.

Roughly a quarter of the pilot whales reacted neutrally or avoided swimmers; the others initiated one or more interspecific behaviours. Pilot whales were assumed to be disturbed by human swimmers to some extent, although their overall reaction was interpreted as 'indifferent'. The Amazon botos (all males), were attracted to people. This is an unnatural association, as they are generally solitary. The dolphins performed risky behaviours during all encounters and initiated agonistic behaviours towards conspecifics, which could compromise their health and increase stress as well as pose health risks to humans at the provisioning sites. Licensing of operators and regulation of feeding is being experimentally implemented. The authors' recommendations are listed in Annex M, item 5.

The Committee welcomes this information and requested that Ritter report back on the implementation of regulations and licensing of boto feeding operations in Brazil. Discussion of the paper is found in Annex M, item 5, including consideration of the subjectivity of assigning behaviours to categories such as 'risky' and 'not risky'. The Committee

agrees that researchers conducting impact studies with specific species should work to standardise ethograms to ensure comparability of results.

Last year, the Committee had recommended that an international scientific workshop be organised involving scientists and managers from the boto range states, with the goal of addressing research and conservation priorities, standardising methodologies and planning long-term strategies (IWC, 2014c). Given concerns expressed in SC/65b/WW01, which could make the animals more susceptible to hunting, the Committee **reiterates** this recommendation.

SC/65b/WW02 summarised three papers addressing the impacts of whalewatching on cetaceans: Luis *et al.* (2014) documented the vocal responses of dolphins in a control setting (no vessels) and in the presence of different vessel types, including dolphin watching vessels, in the Sado Estuary, Portugal; Christiansen *et al.* (2013) evaluated the energy budgets for Icelandic common minke whales, using both field observations and a step-wise modelling approach; and Perrtree *et al.* (2014) showed that begging and other abnormal behaviour can persist more than 20 years after banning food provisioning, strongly suggesting that this activity could have long-term detrimental behavioural impacts on cetaceans.

In 2012, the Committee expressed concern over the impacts of ineffectively managed dolphin watching in Bocas del Toro, on the Caribbean coast of Panama, and recommended continued monitoring of the impacts of dolphin watching activities on this population (IWC, 2013f). This recommendation was 'strongly' reiterated at SC/65a (IWC, 2014i). The resident bottlenose dolphin population in the entire archipelago of Bocas del Toro is probably less than 250 dolphins of which some 105 frequent Dolphin Bay, where dolphin watching activity is concentrated.

SC/65b/WW06 presented data collected by boat-based surveys monitoring dolphin behaviour in the presence and absence of dolphin watching boats. There were significant differences in dolphin reaction to the research (86% neutral) and dolphin watching boats (80.6% neutral). 'Negative' reactions to boat presence increased four-fold as the number of dolphin watching boats increased from one to more than three. When multiple boats were present, a significant positive correlation was found between diving frequency and boat presence. In contrast, foraging and social behaviours were significantly negatively correlated with an increase in boat presence.

The Committee **welcomes** this update on the situation in Bocas del Toro and **reiterates its continued and extreme concern** regarding the lack of enforcement of regulations (IWC, 2013f; 2014i). It noted with concern that the boat presence (up to 39 boats on one group) reported in SC/65b/WW06 was in the tourist low season; in high season, boats can number up to 100 or more. In addition, in the last three years (2012-2014), 10 dolphins have died in Dolphin Bay due to boat strikes.

The Committee **emphasises** that situations of extreme concern like Bocas del Toro, where recommendations need to be directly communicated with governments, need a more focussed mechanism to bring them to the attention of the Standing Working Group on Whalewatching and the Conservation Committee, than a simple presentation of the Scientific Committee report.

The Committee **endorses** the following recommended mitigation measures from SC/65b/WW06, which are consistent with the IWC Guiding Principles (see SC/65b/WW04): (1) licensing should be limited and license issuance should be regularly re-evaluated; (2) operator training workshops and a certification program for best dolphin watching practises should be developed and implemented; (3) a maximum of two dolphin watching boats should follow a single group of dolphins at one time; (4) new boats arriving and encountering a dolphin group should remain outside a 'waiting zone' of 300m, and allow a 30min 'resting time' before approaching dolphins after a previous interaction; and (5) arriving boats should either stop in the 'waiting zone' if other boats are already present, or move to other parts of the bay to look for a different group of dolphins. The Committee also **agrees** that speed restrictions and propeller shrouding can reduce collision risk and severity between dolphin watching boats and cetaceans.

The Committee **agrees** that responsible whalewatching operators from other areas, using best practises and making efforts to be sustainable in their operations, should attend Bocas (and other area) training workshops, where they could be helpful advocates for encouraging sustainable dolphin watching practises. All stakeholders, (e.g. hotel operators, airlines) should be involved in workshops to help ensure the widest possible buy-in to any management regime.

Further discussions are detailed in Annex M, item 5.

15.2 Review whalewatching in the Mediterranean and Red Seas

Annex M, table 1 is a summary from O'Connor *et al.* (2009) on worldwide tourism and expenditure on whalewatching.

It was noted that in general, the response to requests for input on whalewatching in the region of the Committee's meeting was insufficient for a comprehensive and up-to-date review. The Committee therefore **agrees** that the process would be improved if individuals are tasked in advance with compiling a basic review of the industry in the region of the next year's meeting. The review should be widely distributed (see Annex M) for comment and revision in advance of submission as a document for the Committee; the Conservation Committee could be approached for help with this distribution. Kaufman, Weinrich, and Alisa Shulman-Janiger volunteered to draft the review for the 2015 Annual Meeting should the northeastern Pacific be the appropriate region.

15.3 Review reports from intersessional working groups

15.3.1 Modelling and Assessment of Whalewatching Impacts (MAWI) steering group

SC/65b/WW08 summarised the progress with MAWI, established last year, to date. The group was tasked to define specific research questions and hypotheses that would best advance understanding the impact of whalewatching, identify whalewatching locations that would be most suitable and amenable for targeted studies addressing these questions, and summarise the current modelling tools available to analyse the data that will be collected.

Suitable locations should be in accessible areas where: the potential for whalewatching exists; has not yet started or is in

its infancy; control areas can be established; there is an elevated site in near proximity allowing for land-based observations; and some data on the target species exists. See Annex M, item 7.1 for details.

A variety of data collection methods have been used when analysing the impacts of whalewatching vessels on cetaceans. The variety of statistical approaches used to estimate the effects of whalewatching on cetaceans appear to have been determined by the researchers' skill sets, the question under consideration and/or the nature of the data collected. The approaches can be divided into roughly four categories: (1) comparison of groups; (2) regression methods; (3) Markov-chains; and (4) modelling and simulation. The approaches are detailed in Annex M, item 7.1.

The MAWI steering group will be presenting a symposium and small workshop at the 2014 International Marine Conservation Congress in Glasgow (18 August 2014), to receive input and feedback from the wider marine conservation community. The Committee **welcomes** this paper and looks forward to further discussion at the 2015 Annual Meeting.

15.3.2 Background document for Guiding Principles
SC/65b/WW04 reported on the intersessional working group on Guiding Principles development. The group was tasked to develop a 'background document' to annotate the Guiding Principles, with an explanation of their origin and evolution, as well as definitions of terms and other explanatory background. Details on annotations and discussions are noted in Annex M, item 7.2.

15.3.3 Five-Year Strategic Plan Whalewatching Handbook
Rojas-Bracho presented an outline of the Handbook. A chapter involving significant input from the Committee will be on the Role of Science. This chapter will be amongst the longest in the Handbook and will focus on a number of overlapping themes aimed at providing advice on threats and mitigation measures, and evaluating whether measures are working or are likely to work. It will highlight strengths and weaknesses of various management approaches by operation type and circumstances, as well as species.

The chapter on Management, although not within the Committee's remit, still will be based on the best available science and therefore will require the Committee's input. It will include the Guiding Principles, developed at the 2015 and 2016 Annual Meetings. See Annex M, item 7.3 for discussion.

There was a general desire expressed by the Committee for clarification of the relationship between the Commission and the Committee regarding the development of the Handbook. The Whalewatching Sub-Committee Co-Convenors will work with the chair of the Conservation Committee to address this concern. The Committee **agrees** that a budget request for assistance with developing the Handbook should be forwarded to the Standing Working Group on Whalewatching for consideration and submission to the Commission.

15.3.4 Swim-with-whale operations
SC/65b/WW03 updated earlier work using web-based searches in English for swim-with-whale operations. Commercial operations increased from 67 as compared to 44 in 2005 and 21 in 2003. Sources of positive and negative bias in data collection, plans for future reviews of swim-with-whale operations and general discussion are in Annex M, item 7.4.

15.3.5 In-water interactions
A study is underway in Dominica focusing on sperm whale swims and additional work on ethograms is being undertaken.

15.4 Consider information from Platforms of Opportunity of potential value to the Scientific Committee
SC/65b/WW05 reported on *Whale and Dolphin Tracker* (WDT), a web-application for recording cetacean sighting data in real-time. It presented the occurrence of encounters with several cetacean species from data collected on platforms of opportunity using WDT from tour vessels off Maui, Hawaii. This customisable web-application was developed in-house by the Pacific Whale Foundation. Preliminary results indicate that WDT can be a cost-effective web-based data management system providing a large amount of good quality data (including effort). Details and discussion are in Annex M, item 8. The Committee **thanks** the authors for this paper and the work done on WDT.

SC/65b/WW07 proposed guiding principles for data collection from platforms of opportunity, to be hosted by the Commission website, to help ensure a higher standard of data from whalewatching vessels. Basic parameters any data collection system should include were listed, along with explanations on why these parameters are important to record. It also addressed multi-layered data quality control, an important aspect of citizen science. Details and discussion are in Annex M, item 8. The Committee **agrees** that the guiding principles presented in SC/65b/WW07 should be refined and then added to the website. It also **recommends** that the final data collection guiding principles be added to the Handbook. The Committee **agrees** to establish an intersessional working group whose task would be to finalise the guiding principles for SC/66a, with Rose as convenor and a diverse composition, including at least one operator and one researcher who uses data from platforms of opportunity (see Annex M, table 2).

15.5 Review whalewatching guidelines and regulations
Carlson noted that the 2014 update of the Compilation of Worldwide Whalewatching Regulations would be submitted for inclusion on the Commission's website by September 2014.

SC/65b/WW02 summarised Dimmock *et al.* (2014), a study of the perspectives of two stakeholder groups (resource managers and commercial whalewatching operators) in relation to industry knowledge and information exchange. See Annex M, item 8.

SC/65b/WW09 evaluated the level of whalewatching guideline compliance and the effects of compliance, or lack thereof, on dolphin behaviour in Bocas del Toro (and see Item 15.1). A total of 63 dolphin encounters were recorded from June through September 2013. During all of the dolphin encounters where dolphin watching boats were present, Panama's 100m minimum distance regulation was violated at least once. Operators violated other regulations regularly. Results of the study and levels of non-compliance are detailed in Annex M, item 8.

The authors noted that sustainable tourism and training workshops for the community and boat operators are urgently needed in Bocas del Toro and recommended that all dolphin

watching vessels place the regulations in a visible location on board their vessels, so tourists can be aware of the regulations. In accord with its recommendation under Item 15.1, the Committee **endorses** these recommendations and **agrees** that research on dolphin watching impacts and community engagement in Bocas del Toro is important and should continue identifying funding sources should be a priority.

15.6 Consider emerging whalewatching industries of concern

15.6.1 Review of workshops in Oman

Last year, the Committee received an update on the development of whalewatching guidelines, an effort undertaken as a multi-stakeholder initiative by Environment Society of Oman (ESO) and funded by the Commission. The initiative included a series of workshops held over the past year focusing on delivering and demonstrating whale and dolphin watching guidelines and on-water training sessions. Several ministries were consulted during the process and the team visited with operators in Muscat, Salalah and Dhofar. Continued funding support is requested to consolidate this work, including development of an Oman Whalewatchers' Association.

The Committee thanked Wilson for a further update and greatly **welcomes** the positive nature of developments in Oman, which were partially in response to the recommendation of the Committee (IWC, 2013f). Continuation of training workshops is especially urgent in areas where operators are targeting Arabian humpback whales and local populations of *Sousa*. The Committee **recommends** that this work continues and be funded for at least the next two years and **agrees** to keep this as a standing item on the agenda.

15.7 Other issues

The Committee considered several strategies that might make Committee recommendations more visible and effective, especially urgent statements involving highly endangered or isolated cetacean species/populations (see also Annex M, item 5). These include: extracting and combining recommendations in a separate short document, enabling follow-ups by introducing a new agenda item ('progress on previous recommendations') on the agenda of the sub-committee on whalewatching, and establishing intersessional groups with terms of reference related to promoting recommendations beyond the Commission.

The Committee **agrees** to add 'progress on previous recommendations' to the agenda (see Annex M, item 12). In discussion at plenary, the Committee noted that a model highlighting and progressing recommendations on particular issues of concern had been discussed by the Small Cetaceans Sub-committee (Annex L, item 8) and would be a useful model. The Committee **agrees** that an intersessional group to discuss highlighting and progressing recommendations be formed, using Bocas del Toro as an example, to report back to the Committee at the 2015 Annual Meeting.

Funahashi presented information that in June 2014, local whalewatching associations, operators, guides and industry-related personnel will form the Japan Whale-Dolphin Watching Council from seven areas, to promote a responsible, sustainable whalewatching industry in Japan.

The Committee **welcomes** this information and **endorses** the formation of the Council. The Committee **recommends** that the council expand its membership by contacting established operators in other regions of Japan. It was also suggested that the council contact established operators in other countries. Funahashi agreed to draft a document describing the council and its goals for global distribution via Committee members.

Carlson updated Robbins' work to identify data sources from platforms of opportunity of potential value to the Scientific Committee. There have been delays in its development, but it should be online in the near future.

Attention of the Committee was drawn to a new publication for which several members of the Committee are chapter authors and/or editors. Details can be found in Annex M, item 11.

15.8 Workplan

The detailed workplan is given in Annex M, item 12. Table 18 provides a short overview

Table 18

Overview of the workplan as it relates to whalewatching

Topic	SC66a 2015	SC66b 2016
Assess the impacts of whalewatching on cetaceans	This is the ongoing and primary aspect of the work on this topic.	Continue
Review progress on the Commission's five-year strategic plan including the Handbook	Review the work of an intersessional working group. As the Handbook is an online 'living' document then it is anticipated that this will be ongoing work although the initial work will be the most intense.	Continue
Review work of intersessional steering groups	These are listed in Annex M, table 2	Continue
Review whalewatching in the region of the meeting	The next meeting venue is unknown but this is an ongoing item	Continue
Consider information from platforms of opportunity	Finalise standard elements and guidelines including data collection items to be hosted on the IWC website	Review progress and modify if required
Review whalewatching guidelines and regulations	Ongoing work –the most recent compilation is submitted to the IWC Secretariat and included on the IWC website	Continue
Emerging whalewatching industries of concern	Ongoing work	Continue
Progress on previous recommendations	Ongoing work	Continue

16. DNA TESTING (DNA)

The report of the Working Group on DNA is given as Annex N. This particular agenda item has been considered since 2000 in response to a Commission Resolution (IWC, 2000).

16.1 Review genetic methods for species, stock and individual identification

SC/65b/DNA01 was prepared in response to a recommendation from the JARPA II Review Workshop that

a revised paper be submitted that explains in more detail how far the IWC guidelines for DNA data quality control were able to be followed (SC/65b/Rep2 p.15). SC/65b/DNA01 presented a full description of the protocol used by the Institute of Cetacean Research for the genetic analyses in the context of the IWC guidelines. The Committee **welcomes** this document and **agrees** that it responds appropriately to the recommendation.

SC/65b/BRG04 presented an estimate of the genome size of the bowhead whale using flow cytometry. The mean genome size (C value) was estimated to be 2.93 picograms (2.87 gigabases, Gb). This was the first direct genome size estimate for a baleen whale, and is the lowest value reported for any cetacean. It is near the low end of values reported for cetartiodactyls and is relatively low for mammals. The relatively small size of the genome of bowhead whales could be associated with metabolic rate, oxygen exchange, or simply a plesiomorphic trait shared in common with other basal cetartiodactyls.

The Committee noted that the two suggested explanations are not mutually exclusive, i.e. it can be at the same time plesiomorphic and adaptive. It was also noted that differences between directly estimated (from flow cytometry) and indirectly estimated (from sequence) genome size are considered primarily due to removal of highly repetitive sequences not included in sequence-based estimates. Details of this paper and the discussion are found in Annex N.

SC/65b/BRG09 reported progress on the transcriptome sequence of the bowhead whale. This study compared two methods of RNA sequence to characterise the bowhead whale transcriptome including polyA RNA isolation and RiboZero which does not involve the capture of a RNA molecule by the end of its 3' tail. The study sequenced the transcriptome from pituitary gland, adolescent testis, vibrissa follicle, mesenteric lymph node, and spleen using the RiboZero protocol and the heart, cerebellum, liver, adolescent testis, and retina from 2011 using the polyA protocol for a total of 51,637,573,518 bp of sequence. The data are being explored for the discovery of SNP loci for population genetic studies.

The Committee **commends** the large amount of work undertaken and notes the valuable data being produced in this study. It was noted that SNP discovery using genome and transcriptome sequence has some advantages over the use of anonymous loci, but that there are also some difficulties with this approach. Details of this paper and the discussion are found in Annex N.

SC/65b/BRG13 summarised results from a bowhead whale genetics project. The project had two parts, development of an mtDNA database and identification of SNP loci including the development of a SNP database. Regarding mtDNA loci a total of 570 whales have been sequenced for HVR1, 480 for ND1, and 389 for cyt-b. A total of 155 SNP loci were identified for bowhead whale, including 99 new SNPs reported in SC/65b/BRG13, 14 sex-specific SNPs reported in SC/65a/BRG22 and 42 from the literature (Morin *et al.*, 2010b). It was reported that the data in these databases will continue to be used for monitoring stock structure, population size estimates, and estimates of historical demography. Work is ongoing to fill the gaps in the database.

The Committee again **commends** the amount of work undertaken in this study. The authors clarified that the transcriptome upon which the SNP loci were identified was based on multiple individuals (all from the BCB stock), multiple sexes, and multiple tissues.

In discussion, the Committee was informed that most but not all of the mtDNA sequences are from bowhead whale tissues obtained from the aboriginal harvest in Alaska and the sequences are linked to the tissue sample by a unique identifier code. Tissues are archived at the Department of Wildlife Management, North Slope Borough, Barrow, AK, with duplicate samples archived at the Southwest Fisheries Science Center (National Marine Fisheries Service, NOAA) in La Jolla, CA. Published sequences are deposited on *GenBank* and publicly available.

16.2 Review results of the amendments of sequences deposited in *GenBank*

Last year, the Committee agreed that the list of accession numbers involving inconsistencies due to a lag in the taxonomy recognised by *GenBank* or uncertainty in taxonomic distinctions currently under investigation (IWC, 2014j) should be sent to *GenBank* with a letter explaining the background and the main reasons for the inconsistencies (IWC, 2014c, p.56).

Cipriano informed the Committee that he had sent the list and letter to *GenBank* during the intersessional period. A positive response was received informing that *GenBank* is willing to work with the IWC on this particular problem, and requested further explanations on the list received on accession numbers associated with problematic taxonomic designations. The Committee **agrees** that Cipriano should continue to work with *GenBank* during the next intersessional period to facilitate the work by *GenBank* staff on the correction of the inconsistencies based on the list sent.

In discussion the Committee was further informed that the NCBI staff is already making changes to taxonomy fields of sequences in *GenBank* on the advice of the Scientific Committee and that additional changes needed in *GenBank* annotations include a mechanism for providing clear and consistent geographic source information. Situations where taxonomy is in flux (such as the revision of cetacean species and subspecies names currently underway) would also benefit from continued dialogue between the Scientific Committee and NCBI.

The Committee also suggested further discussion by the Committee on issues regarding new species descriptions and taxonomy of baleen whales.

16.3 Collection and archiving of tissue samples from catches and bycatches

The Committee previously endorsed a new standard format for the updates of national DNA registers to assist with the review of such updates (IWC, 2012a, p.53), and the new format worked well the last two years. This year the update of the DNA registers by Japan, Norway and Iceland were based again on this new format. Details are given in Appendices 2-4 of Annex N for each country, respectively, covering the period up to and including 2013. The Committee **thanks** the countries involved for providing this information.

16.4 Reference databases and standards for diagnostic DNA registries

Annex N, Appendices 2-4 summarise the status of mtDNA and microsatellite analyses of the stored samples for Japan, Norway and Iceland, respectively. In almost all cases, the great majority of samples have been analysed for at least one of either mtDNA or microsatellite and in most cases both. Work on unanalysed samples is continuing. Details of the exact number of samples collected and analysed are provided in Annex N.

The Committee **appreciates** the efforts of Japan, Norway and Iceland in compiling and providing this detailed information of their registries.

16.5 Workplan

The workplan is discussed in detail under Annex N.

Members of the Committee are encouraged to submit papers in response to requirements placed on the Committee by the IWC Resolution 1999-8 (IWC, 2000). Relevant information in documents submitted to other groups and sub-committees of the Committee will be reviewed next year. Results of the 'amendment' work on sequences deposited in *GenBank* will be reported next year.

17. SPECIAL PERMITS

17.1 Expert Panel Review of the results from JARPA II

This item was initially discussed by a working group (Annex O). Scientists from countries that made a statement at plenary that it was inappropriate for the SC to continue the review of the JARPA II programme under Annex P, did not participate in the discussion related to JARPA II agenda items (see Item 2). These scientists may not agree with any conclusions reached in this report under the relevant agenda items.

This agenda item is related to the Expert Panel Review of the results from JARPA II (SC/65b/Rep2).

The Expert Panel review took place in Tokyo from 24-28 February 2014 and followed the guidelines described in Annex P (IWC, 2013). The previous Chair of the Scientific Committee (Palka) chaired the review workshop. Typically, the chair of Special Permit reviews is the current Scientific Committee Chair. However, since the Chair of the Scientific Committee (Kitakado) is a member of the proponents, the Scientific Committee agreed last year that the previous Chair (Palka) would be an appropriate chair for this review workshop.

17.1.1 Expert Panel report

The Expert Panel was chaired by Palka and was comprised of the IWC Head of Science (in accord with the guidelines), 3 current members of the Committee, 2 scientists who rarely participate in the Committee and 3 scientists who have never participated. Expertise in all areas of the research programme was available. Thirty-eight papers were submitted by the proponents (SC/F14/J1-38), 8 papers submitted by other Scientific Committee members (SC/F14/O1-8), and 5 papers were submitted in response to the observer papers (SC/F14/R1-5).

The Panel report (SC/65b/Rep2) is divided into sections based on the stated objectives of the programme: monitor cetacean habitat; elucidate temporal and spatial changes in stock structure; monitor whale abundance trends; monitor krill abundance and feeding ecology of whale stocks; monitor effects of contaminants on cetaceans; model competition among whale species; and improve management procedure for Antarctic minke whales. Each of these sections contained the proponents' summary of their results followed by a review from the Panel that included specific technical recommendations. The final section presented the Panel's general overview and conclusions containing recommendations divided into short, medium and long-term.

The report is a long and detailed review. What follows here is a short Panel Chair's summary of only the broad conclusions. The Panel emphasised that its task was to provide an objective scientific review of the results of JARPA II; its task was not to provide either a general condemnation or approval of research under special permit.

Before considering individual objectives, general comments applicable to all aspects of the programme are identified. The Panel noted that the general and extremely broad nature of the objectives and its ongoing nature made it difficult to fully review how well the programme met its own objectives. It recommended refined objectives and sub-objectives with timelines for progress be developed to provide a basis to more easily assess if the objectives have been met.

Data collection disruption due to weather, ice conditions and increasing sabotage activities by protestors resulted in not achieving the designed sampling scheme for some years, and the Panel was concerned that this could severely compromise the ability of the programme's objectives to be met. The Panel recommended that an explicit protocol be developed to specify *a priori* how the design could be modified if disruption by protestors occurs; simulation studies based on existing data should assist in this.

The Panel recognised that this was the first period of the JARPA II programme but noted that the programme arose out of the long JARPA programme and that many of the papers analysed data from both programmes. The Panel welcomed the considerable work that was put into field and laboratory work and the development of papers, particularly those addressing recommendations made in previous JARPA reviews. However, the Panel recommended that considerably more effort and resources be put into the analytical side of the programme, both via more thorough analyses of individual datasets and through better integration amongst the datasets to integrate the information available from the various aspects of the programme.

The Panel recognised an important component of any programme is archiving data and samples. It agreed that a number of questions potentially could be addressed with material that may have been preserved from the historical commercial catch. While reports from JARPA and JARPA II detailed the availability of tissue samples, no similar information was available from the historical catch. The Panel recommended a detailed list of available historical samples be produced.

While the Panel agreed broadly with the conclusion that JARPA II catches will not adversely affect the stocks in the research area, it also noted that the most appropriate way to assess the impact of future Special Permit catches on stocks is within the framework of an RMP-type process; that approach explicitly accounts for uncertainty.

In regards to the monitoring the cetacean habitat objective, the Panel agreed that the monitoring of the whale habitat is

relevant to all of the objectives. Unfortunately this work has been limited. If the programme is to meet its own objectives, the Panel recommended the collection of the full suite of oceanographic data be resumed and the proponents should incorporate other oceanographic and related data that may exist within other international programmes to form a more comprehensive dataset. In addition, the proponents could develop a method to make their data available to other international programmes.

In regards to the temporal and spatial changes in the stock structure objective, the Panel agreed that considerable progress has been made in understanding stock structure within the research area. However, it drew attention to the fact that the programme incorporated little information from outside the research area. For Antarctic minke whales, the Panel welcomed the innovative integrative approach used which incorporated genetic and non-genetic data and it recommended consideration of other potential hypotheses. The Panel welcomed the examination of stock structure of several of the species by integrating data from biopsy samples collected during JARPA and JARPA II with other data collected within the Antarctic and lower latitudes. The Panel suggested increasing the sample sizes by using biopsy samples collected by other programmes (e.g. SOWER) and from earlier commercial whaling, if available.

In regards to the monitoring abundance trends objective, sightings data analyses and statistical catch-at-age analyses (SCAA) were used. The Panel agreed that survey results from the JARPA and JARPA II programmes contribute significantly to the objectives of the programme. The survey work represents a considerable expenditure of research time and a large dataset for long-term monitoring. The Panel agreed that the papers on Antarctic minke whales (SC/F14/J3) and humpback whales (SC/F14/J4) had adequately addressed most of the concerns raised in the JARPA review meeting. In terms of future field work, the Panel recommended consideration of the use of Independent Observer mode in future surveys to address the issue of g(0) and the collection of killer whale ecotype data.

The Panel noted that the SCAA analyses, whilst using data from JARPA and JARPA II, has been directed by the Scientific Committee and was undertaken by non-proponent scientists. The Panel agreed that the SCAA model is both the best currently available model for examining stock dynamics for the minke whales in the JARPA II area, and that the model performed well in this regard. The Panel noted that certain results from the SCAA model may not be consistent with inferences developed from other components of JARPA II or may suggest potential revisions to the design of JARPA II itself. These points concerned inter alia MSYR, stock structure and growth rate changes.

Examining and understanding the distribution of whale species and the reasons for any changes in distribution is central to the objectives. The Panel recommended that more robust and comprehensive analyses of the existing data be undertaken that incorporate many more potential explanatory variables. In addition, a more rigorous area occupancy analysis should be undertaken that incorporates recent advances in spatial modelling. The distributional information was used to formulate their 'competition' hypotheses. The Panel agreed that a conceptual model for such competition should be developed. Additional field efforts will be needed to develop plausible hypotheses, such as focused studies of prey density and swarming behaviour in relation with local whale distribution and abundance or comparison of stomach contents in areas where both species overlap, and in areas where they segregate.

In regards to the monitoring krill abundance objective, the Panel recommended that future krill surveys should be frequent because the density of krill in any given stratum may vary significantly from year to year, and the objectives of JARPA II require an area-based time-series view of how the prey field changes over time. The JARPA II study area is very large, and it is probably not possible to survey the entire study area every year with a single survey vessel. Thus, the Panel recommended either using multiple survey vessels to synoptically cover the JARPA II study area every 1-3 years or using one vessel to survey alternating halves of the study area every year.

In regards to the monitoring feeding ecology of whale stocks objective, the Panel agreed that this work was central to achieving several of the objectives. The Panel agreed that the approach to the feeding ecology study developed by the proponents during the Workshop to address some shortcomings was a useful way forward. The Panel also recommended the work be extended by computing a time series of Monte Carlo results for the total potential consumption of krill using abundance estimates of minke whales and the uncertainties around these estimates. These Monte Carlo results can also be used to re-evaluate the future research and sampling in JARPA II.

In regards to monitoring whale biological parameters, the Panel noted that these analyses assumed that the sampling scheme was broadly representative of the population and was related to the stock structure hypotheses agreed at the JARPA review rather than those that were subsequently presented to this meeting. In regards to the age at sexual maturity and pregnancy rates, the Panel recommended additional analytical work before conclusions can be drawn. The Panel welcomed the work presented on the evaluation of the use of aspartic acid racemisation as an alternative approach to estimating age and made a number of recommendations for an updated paper and future work.

In regards to the studies on nutritive condition, the Panel recognised that the factors considered in the models arose primarily from discussions within the Scientific Committee and were not derived from biological hypotheses. The Panel recommended a conceptual model of the system be developed and then used to identify a set of covariates to consider in the model. The Panel also noted that it is inappropriate to automatically select the 'best model' because such a model can lead to covariates being selected for which there is no reason that they are related to response variable. Despite the complexity of the analyses and the protracted discussion of appropriate statistical techniques, the Panel expressed the opinion that the 'weight of evidence' (i.e. the different measures consistently indicated that there was an overall decline in body condition of minke whales through the JARPA period), as well as the implications of such a result, warrant careful consideration in terms of cause.

Following the discussion at the JARPA review meeting and the advantages of considering lipid content of the blubber as

well as thickness, the Panel strongly recommended that any further studies should incorporate blubber lipid content analyses for all samples, and that the collection of current measurements also continue to ensure comparability with past and future data. The Panel also recommended that faecal samples (from the colon) be compared with stomach samples for species composition.

In regards to the monitoring effects of contaminants objective, the Panel noted the low levels observed, and therefore recommended lower priority for pollutant studies in the future and agreed that it would be sufficient to undertake pollutant analyses on a suitably chosen subsample at periodic intervals (say 3-5 years).

In regards to the model competition among whale species objective, the Panel recognised that this work is at a preliminary stage. The Panel stressed the fundamental importance of this work to most of the objectives of JARPA II. The Panel therefore recommended that considerably more effort be allocated to this aspect. The Panel recommended that simulations be used to determine the data needed to reliably distinguish among competing hypotheses to explain the available data, including the proponents' preferred option, competition among species. These simulations may also be used to identify (1) whether models are able to respond in predictable ways to known signals in the data and (2) the required level of precision in the data to parameterise them. The Panel emphasised that producing ecosystem models is a long-term exercise, which requires the integration of a large amount of data as well as ecological and biological knowledge of the system. The work conducted to date represented a useful start. To this end, the Panel recommended increased collaboration with other researchers from outside the JARPA II area to improve the modelling exercise.

In regards to the improve the management procedure for Antarctic minke whales objective, the Panel agreed that the information from JARPA and JARPA II, particularly with respect to stock structure and abundance will greatly improve any future *Implementation Simulation Trials*, should these ever be requested by the Commission. Similarly, SCAA and related analyses could be used to develop hypotheses related to carrying capacity, natural mortality and variation in birth rates. In principle, the work on ecosystem modelling could be used to develop a set of operating models that allow for competition. However, the ecosystem models need to be developed with sufficient resolution (e.g. age- and sex-structure for minke whales).

The Panel agreed that a number of aspects of the JARPA II programme are relevant to the several IWC resolutions and discussions.

Although a comparison of the utility of lethal and non-lethal sampling is not an objective of the JARPA II programme, the samples and data already collected to achieve the objectives can be analysed to investigate this general research question. The Panel recommended that the proponents examine the approaches for comparison used in the Icelandic programme and develop an approach to formally and objectively compare the results from different approaches in the light of the programme's objectives.

In conclusion, the Panel's Chair thanked the Panel, the proponent scientists and the observers for their constructive and patient approach to the workshop and the Fisheries Agency of Japan for providing excellent facilities and logistic support.

17.1.2 Response to Expert Panel report

Pastene presented an overview of SC/65b/SP01. This paper summarises the general response of the JARPA II proponents to the JARPA II Panel Review report (SC/65b/Rep2). The International Whaling Commission's Scientific Committee (IWC SC) convened a workshop to review the progress made in the research conducted under the Japanese Whale Research Program under Special Permit in the Antarctic–Phase II (JARPA II) in its first six years (2005/06-2010/11). The review followed the guidelines specified in the Annex P. An international Panel of experts (Review Panel) carried out the review on the basis of 38 scientific papers prepared by the proponents, eight prepared by IWC SC members and five prepared by the proponents in response to some of the documents from the IWC SC members. Scientists involved in the JARPA II research participated in the workshop only to present papers on particular agenda items and to respond to questions of clarification and substance regarding the work that had been undertaken or further work expected to be undertaken. The report of the Review Panel is presented in document SC/65b/Rep2. The present paper summarises the views of scientists involved in the JARPA II research on the evaluation and scientific suggestions from the Review Panel. Short-term recommendations offered by the Review Panel were responded to in different papers presented to sub-committees: SC/65b/EM1,2,3; SC/65b/IA1,2; SC/65b/SD1,2,3 and SC/65b/DNA1. The proponents agreed with most of the medium and long-term recommendations, and this paper shows the proponent's view and plan regarding those recommendations. This paper also offers some general comments on the JARPA II review process which could be considered to improve future reviews. The proponents consider that, in general, the Review Panel report represents a fair and balanced evaluation of the work conducted by the JARPA II in its first six years. The Review Panel welcomed the scientific contribution of JARPA/JARPA II. At the same time it identified those areas where further work is required and provided suggestions and recommendations that if correctly implemented, will contribute to improve analyses from the first six years of research as well as future research.

Some members of the Committee expressed concern about the JARPA II Expert Panel review, especially with respect to the Panel's ability to evaluate: (1) the utility of lethal research methods during the JARPA II programme; and (2) results based on combined data from both JARPA and JARPA II that formed the basis for a number of the documents reviewed by the Expert Panel, making a review of just the JARPA II programme somewhat difficult. These concerns are summarised in Annex O1.

In response to Annex O1, other members of the Committee stated that JARPA/JARPA II has provided substantial new knowledge related to the management of minke whales in the Antarctic and on the functioning of the Antarctic ecosystem and that much of this information could not have been obtained from non-lethal methods alone (see Annex O2).

In discussion of Annex O2, Wade noted that in response to the Expert Panel review, the proponents of JARPA/JARPA II authored papers that often concluded that they 'did not agree' with the advice provided. Wade stated that he did not find many of the revised analyses to be convincing and found the proponents had often not modified their analyses in response to recommendations from the Expert Panel but had instead agreed to disagree.

Pastene responded that several papers responding to the JARPA II review workshop had been prepared by Japanese scientists and presented in different sub-committees this year, mainly in the IA (biological parameters), EM (body conditions and stomach content trends) and SD (stock structure) sub-committees. Some of those analyses have been accepted while that for others further work has been required but this is normal in the scientific world. It is clear that many research topics from JARPA/JARPA II, for example body condition, biological parameters and stock structure, have promoted interesting and detailed scientific discussion in the Scientific Committee.

Wade provided several examples of how biopsy sampling could be effectively conducted in the Antarctic. These include the successful biopsy sampling of Antarctic minke whales in nearshore waters (A. Friedlaender pers. comm.; SC/65a/IA12) as well as the previous biopsy experiments during SOWER cruises that showed the practicality of biopsy sampling minke whales in offshore waters, as noted by Gales in his testimony to the International Court of Justice. Experiments in 2000 and 2008 on Japanese IDCR/SOWER cruises showed that Antarctic minke whales could be biopsied, that they could be biopsied at distances similar to the distance used to harpoon minke whales, and that the average time it took to biopsy a minke was approximately the same as the time it took to harpoon a minke whale, and much less considering the handling time of a harpooned whale (information taken from Ensor *et al*. cruise reports, 2001-2008). Moreover, the average time to biopsy an Antarctic minke whale was less than any other baleen whale (blue, fin, humpback, and right whales), and this was accomplished under difficult open ocean conditions. Given the success that JARPA II has had biopsy sampling other baleen whales, Wade thought there was no reason that Antarctic minke whales could not be biopsied in large numbers, if the effort was made to do so.

Pastene reiterated that the Scientific Committee has on several occasions recommended the use of multiple techniques, genetics and non-genetic, to resolve questions on stock structure (IWC, 2013a, p.10). Non-genetic approaches include morphometric analysis, which require lethal sampling. Biopsy sampling of Antarctic minke whales has proven to be difficult, particularly in offshore areas and for small schools (see details in Ensor *et al.*, 2004, p.17; Ensor *et al.*, 2001, p.14) for experiments based on IDCR/SOWER and Nishiwaki (2000) for experiments based on JARPA and JARPN). Even if biopsy sampling became possible under the more challenging conditions, he believes that it would still be difficult to collect the number of samples required for statistical analyses of stock structure.

Wade also debated the statement made in Annex O2 regarding the inadequacy of conducting organic pollutant (lipophilic) and trace elements pollutant analyses from biopsy samples, stating that he has published three studies that used biopsy samples to examine organochlorine concentration in cetacean blubber.

Pastene clarified that his opinion was based on a comprehensive and detailed comparison between lethal and non-lethal techniques made by the Review Panel on the Icelandic Special Scientific Permit Review that concluded that the lethal sampling is more practical than the non-lethal sampling to investigate some pollutants in the common minke whale (IWC, 2014a, p.480).

Víkingsson highlighted the improvement in the working methods of the Committee concerning review of results from Special Permit programmes with the introduction of independent Expert Panels. He commended the high professional quality of the review of the Expert Panel of the JARPA II programme. While generally recognising the scientific value in the great amount of work conducted as a part of the program, the Panel criticised some parts of the analyses and made constructive suggestions for improvements. Víkingsson commended the wide-ranging combination of lethal and non-lethal research techniques used in JARPA II that had helped explain recent changes in the Antarctic ecosystem. Concerning the use of lethal and non-lethal methods, Víkingsson concurred with the suggestion of the Panel regarding further evaluation of the usefulness of biopsy sampling by direct comparisons of different research techniques applied on the same animals as done in the Icelandic research programme reviewed in 2013. Those studies had, for example, indicated variable utility of biopsies (skin and outermost blubber) in studies on diet composition and pollutant levels.

17.2 Review results from ongoing permits

The Committee has decided not to discuss annual cruise reports between the periodic reviews. Therefore, the cruise reports are briefly summarised below.

17.2.1 JARPN II

SC/65b/SP02 outlined the twelfth cruise of the full-scale JARPN II offshore component conducted in the western North Pacific. There were three main research components in the 2013 survey: whale sampling survey, dedicated sighting survey and whale prey survey. The whale sampling survey was carried out from 25 July to 7 October 2013. A total of 1,846n.miles was surveyed in a period of 65 days by the two SSVs. A total of three common minke, 100 sei, 28 Bryde's and one sperm whale was sampled by the SSVs. In August, common minke whales fed mainly on Japanese anchovy, mackerels and Pacific saury in sub-area 9. Sei whales fed mainly on mackerels followed by copepods from August to September in sub-areas 8 and 9. Bryde's whales fed mainly on krill followed by Japanese anchovy and mackerels in sub-areas 8 and 9 from late July to early October. Dominant prey species in the stomach of the sperm whale was various kinds of squids, which inhabit in mid- and deep-waters. Three dedicated sighting surveys were carried out from 18 May to 26 June in sub-areas 7 and 8, from 20 July to 23 August in sub-area 9 and from 12 September to 7 October in sub-areas 8 and 9. A total of 3,470, 987 and 539n.miles was surveyed during those surveys by the SVs, respectively. The whale prey survey was carried out from 24 July to 22 August. The survey was conducted concurrently with SSVs and NM in a part of sub-areas 8 and 9. The main purpose of the prey survey

in this year was recording of underwater behaviour of Bryde's and sei whales by using acoustic transmitters. Data obtained in this research will be used in the elucidation of the role of whales in the marine ecosystem through the study of whale feeding ecology in the western North Pacific.

There were two questions of clarification regarding this document on (1) whether the survey tracklines (depicted within the red block of fig 3.) were designed for abundance estimation and (2) how the survey tracklines were randomly started. In response, the authors stated that the survey tracklines in question were not designed for abundance estimation and that the starting points of the track lines were randomised following methods described in Matsuoka *et al.* (SC/65b/IA06).

SC/65b/SP03 outlined results of the ninth survey of the JARPN II coastal component conducted off Sanriku. The survey was carried out from 18 April to 3 June, using four small-type whaling catcher boats and one echo sounder trawl survey vessel. Sampling of common minke whales was conducted in coastal waters within 50 n. miles from Ayukawa port in the Sanriku district, and all animals collected were landed at the JARPN II research station established for biological examination in Ayukawa. A total of 7,188.3 n.miles (709.3 hours) was surveyed and 59 schools (59 individuals) of common minke whales were sighted. A total of 34 animals were sampled. Average body length of the animals was 5.02 m (SD: 1.12, *n*=17) for males and 5.21 m (SD: 0.60, *n*=17) for females. Dominant prey species found in the fore stomach of common minke whales collected in the Sendai Bay were juvenile Japanese sand lances, and those collected outside the Sendai Bay were Japanese anchovies. This suggests that common minke whales in the Sendai Bay and in the outside slope feed on different preys. Furthermore, common minke whales significantly fed on juvenile sand lances in 2012 and 2013, with the proportion of adult sand lance decreased in recent years. This result indicates that feeding habit of common minke whales in coastal waters off Sanriku changes year by year.

SC/65b/SP04 outlined the results of the JARPN II coastal component off Kushiro, northeast Japan (the sub-area 7CN) in 2013. The survey was conducted from 6 September to 25 October 2013, using four small-type whaling catcher boats as sampling vessels. During the survey, a total of 4,629.7 n. miles (451.8 hours) was searched, 126 schools/ 142 individuals of common minke whales were sighted and 58 whales were sampled. Average body length of sampled whales was 6.77m (SD=0.88, *n*=41) for males and 6.55m (SD=1.39, *n*=17) for females, respectively; 27 of the 41 males (65.9%) and seven of the 17 females (41.2%) were sexually mature. The dominant prey species found in the stomach was Japanese sardine *Sardinops melanostictus* (63.8%), followed by walleye pollock *Theragra chalcogramma* (22.4%), mackerel *Scomber japonicas* (6.9%), krill *Euphausia pacifica* (5.2%) and Japanese common squid *Todarodes pacificus* (1.7%). In the 2013 survey, Japanese anchovy *Engraulis japonicus* and Pacific saury *Cololabis saira* could not be found in the stomach. From late 1960s to 1987, Japanese sardine and mackerel were recorded as the major prey species of common minke whales taken by the commercial whaling. But, when the coastal component off Kushiro started in 2002, Japanese anchovy was the major prey species found in the stomach, and dominance of the Japanese anchovy was continued until 2011 survey. In 2012, Japanese sardine and mackerels were detected again from the stomach by the survey, and in the present survey, Japanese sardine became the most dominant prey species. Conversely, Japanese anchovy was not present. Apparent change in the dominant prey species from Japanese anchovy to Japanese sardine observed here suggested that the distribution and amount of those prey species in the coastal waters off Kushiro were changed, and the stomach contents of the whales could reflect those environmental changes. Such information is valuable in considering the habit of the whales and environmental change in the region, and will contribute to the objectives of the JARPN II feeding ecology and ecosystem studies.

In discussion, the high number of humpback whale sightings in fig. 4 of the paper was noted and it was asked if this represented an increase over what had been observed in past surveys. The authors stated that at the start of the programme in 2002 there was a lower number of humpback whales sighting but beginning about 3-4 years ago the number of humpback whale sightings increased. In discussion, it was postulated that the increased number of humpback whale sightings may be related to changes in oceanographic conditions and available prey species. It was then asked if fluke photographs for photo-identification purposes are being collected. The authors confirmed that fluke photographs are being collected but that humpbacks in this area do not regularly fluke-up dive.

Finally, it was asked if the changes in the diet composition of minke whales as depicted in fig. 6 of the paper were correlated with changes in body condition. The authors stated that an analysis of this type was pending.

17.2.2 JARPA II

SC/65b/SP05 report the results of the 2013/14 survey of the Second Phase of the Japanese Whale Research Program under the Special Permit in the Antarctic (JARPA II). Two dedicated sighting vessels (SV), one sighting and sampling vessels (SSV) and one research base vessel engaged in the research for 70 days, from 3 January to 13 March 2014 in Areas V (130°E - 170°W) and VI West (VIW: 170°W - 145°W). Unfortunately the research activities were interrupted several times by an anti-whaling group which directed violent sabotage activities against Japanese research vessels in previous seasons. As a result the planned dedicated sighting survey was cancelled in the whole research area because the two SVs had to be dedicated to security tasks. The total searching distance was 3,182.0 n.miles by the SSV, which was approximately one-third of the searching distance in 'normal' years. Seven species including five baleen (blue, fin, sei, Antarctic minke and humpback) and two toothed (sperm and southern bottlenose) whales were sighted during the research period. A total of 313 schools (531 individuals) of Antarctic minke whales were sighted. It was the dominant species in the research area followed by the humpback whales (82 schools/133 individuals) and fin whales (45/99). The number of sightings of the Antarctic minke whales was about 4.0 times higher than that of humpback whales. A total of 251 Antarctic minke whales was sampled which were examined on board the research base vessel except one whale was lost during the transfer to the research base. Of 250 Antarctic minke whales, 125 were male (50.0%) and 125 were female (50.0%). Photo-id experiments were conducted and a total of two blue whales were photographed. Oceanographic surveys

to investigate vertical sea temperature profiles were also implemented using XCTD system. The research activity of the SSV was also interrupted several times. This situation was continued over three seasons from the 2011/12 surveys. The authors concluded that this represents a great loss for the Antarctic whale research and management under the IWC SC objectives.

17.3 Review of new or continuing proposals

17.3.1 JARPA II

In light of the announcement by Japan to cancel the JARPA II programme in the 2014/2015 season in accordance with the 31 March 2014 Judgment of the International Court of Justice (ICJ), there was no discussion of JARPA II under this agenda item.

In the 2014/2015 season, Japan will undertake a sighting survey in the Antarctic areas previously covered by the JARPA II activities.

17.3.2 JARPN II

The Committee was advised that following the 31 March 2014 Judgment of the ICJ regarding activities related to JARPA II, the Government of Japan voluntarily reviewed JARPN II. This voluntary review resulted in the reprioritisation of the research focus as well as recalculation of sample sizes to be pursued during the 2014 JARPN II survey.

Some members of the Committee recognised that substantial effort went into the design and planning of JARPN II. Changes in the allotment of lethal versus non-lethal approaches as well as recalculation of sample sizes may impact achieving the stated objectives of the JARPN II programme and that such changes must be accompanied by a scientific justification. Further, some members of the Committee expressed uncertainty about whether the stated changes represent a modification of the existing JARPN II programme or if this needs to be viewed as a 'new' programme.

In response, the proponents of JARPN II stated the overall objectives of the programme remain the same, focusing on the study of interactions between whales and fisheries in the coastal area and interactions among whale species in the offshore area as well as a contribution to the management of whales. The recalculation of sample sizes for target species was conducted to assess the appropriateness of the current target sample sizes (see below) and the non-lethal components of the programme were strengthened in order to address concerns raised by the ICJ in its consideration of JARPA II.

With respect to the 2014 JARPN II Offshore Component, keeping in mind the desire of the Government of Japan to balance scientific objectives with advice stemming from the ICJ decision, the following rationale was provided:

(1) Allocation of some samples to non-lethal means was decided by the Government of Japan based on advice/suggestions from the ICJ.
(2) Sampling of sperm and common minke whales was suspended because their role in the study of interactions between whales and fisheries in the coastal waters (a prime objective of the 2014 survey) seems to be limited.
(3) Sei whale sample size of 100 (as in the original plan, see below) of which 10 will be studied using only non-lethal methods.
(4) Bryde's whale sample size of 50 (as in the original plan, see below) of which 25 will be studied using only non-lethal methods. A larger number of Bryde's whales were allocated to non-lethal methods because they are better studied than sei whales through *the Comprehensive Assessment and the Implementation Review*.
(5) A study for verifying the feasibility of using non-lethal method will be carried out and results of the study could be reflected in the future research programs.

With respect to the 2014 JARPN II Coastal Component, and keeping in mind the desire of the Government of Japan to balance scientific objectives with advice stemming from the ICJ decision, the following rationale was provided:

(1) Allocation of some samples to non-lethal means was decided by the Government of Japan based on advice/suggestions from the ICJ.
(2) Minke whale sample size of 114 (57 in each of the spring and autumn season as recalculated with the latest information, see below) of which 12 (6 in each of the periods) will be studied using only non-lethal methods.
(3) A study for verifying the feasibility of using non-lethal method will be carried out and results of the study could be reflected in the future research programs.

When developing the JARPN II research programme, sample sizes of target species necessary for the estimation of food consumption by cetaceans were calculated with the method employed under the Norwegian research (Government of Norway, 1992, SC/44/NAB18) taking into account the following information derived from its past research:

(1) Composition of prey species (%)
(2) Average weight of each prey species in the stomach contents (kg)
(3) SD and CV of the compositions and weights

Sample sizes were calculated with a condition that the stomach contents of a target prey species be calculated, with CV =0.2, for each year.

Re-calculation of the sample sizes for the 2014 JARPN II survey was made in the same manner as above while also incorporating the latest information derived from the ongoing JARPN II research. The results of these recalculations are as follows:

COASTAL COMPONENT

Ayukawa (Spring) - Re-calculation of the sample size for Minke whale was made for the main prey species (juvenile sand lance) with CV=0.2 for each year using the results of the latest JARPN II research (Coastal Component conducted in Ayukawa) in 2003-2010. The result of the re-calculation was 57 (the average during the research period).

Kushiro (Autumn) - Re-calculation of the sample size for Minke whale was made for the main prey species (Japanese anchovy and walleye pollock) with CV=0.2 for each year using the results of the latest JARPN II research (Coastal Component conducted in Kushiro) in 2002-2010. The results of the re-calculation was 50 for Japanese anchovy (2002-2007) and 57 for walleye pollock (2008-2010). Taking account the recent possible change of the distribution of prey

species, the sample size has been set 57 for walleye pollock (the average during the research period).

OFFSHORE COMPONENT

Bryde's whale - Re-calculation of the sample size was made for the main prey species (Japanese anchovy and krill) with CV=0.2 for each year using the results of the latest JARPN II research (offshore) in 2000-2012. The results of the re-calculation was 75 (the average during the research period).

Sei whale - Re-calculation of the sample size was made for the main prey species (copepods, Japanese anchovy and krill) with CV=0.2 for each year using the results of the latest JARPN II research (Offshore Component) in 2002-2012. The results of the re-calculation was 135 (the average during the research period).

With respect to Bryde's and sei whales, the Government of Japan decided to maintain the sample sizes as originally calculated since recalculation for those species showed the need for substantial increases of sample sizes. The Government of Japan considered that such increases could be regarded as revisions of the programme and therefore should be examined after the due process including review of results that is planned in 2016 for the 2nd period of JARPN II (2008-2013).

In discussion, the Committee **recommends** that the proponents of JARPN II develop a more comprehensive document for review at the 2015 Annual Meeting that details how the above recalculations of sample size and changes in allotments of lethal versus non-lethal methods fit with achieving the overarching programmatic objectives. This recommendation is made because the written information available to the Committee was not sufficient to evaluate whether the numbers of animals to be taken had been adequately justified in relation to the specific objectives of the research.

Further, the Committee recalled that the last JARPN II expert review in 2009 (IWC, 2010a) called for certain analyses to be performed to determine appropriate sample sizes for the JARPN II programme. The Panel concluded that it could not complete its review until this information (among other items) was supplied. The Committee (IWC, 2010b) subsequently expressed concern that the Panel was not provided with the information and guidance necessary to review programme progress and to draw conclusions regarding the appropriateness of programme sample sizes. The requested analyses were not performed and the review could not be completed.

Finally, some members of the Committee expressed concern that the effectiveness of non-lethal methods was directly related to effort. That is, non-lethal methods are likely to be more effective given a high level of effort and more likely to ineffective given a low level of effort. Given this concern, evaluating the utility of lethal versus non-lethal methods is not possible.

17.4 Workplan (and see Table 19)

17.4.1 Planning for a periodic review of JARPN II

According to the procedure outlined in 'Annex P', the JARPN II programme is due to a periodic review in 2016.

The next step of this review process (revised in accord with discussions under Item 27.2) is that the proponents make the data description document available two months before the next annual meeting. Requests for use of the data will be made one month in advance of the 2015 annual meeting. The data will be available in electronic form one month after the end of the Annual Meeting. Then the proponents will send a document to the Secretariat describing the analytical methods to be discussed at the Workshop. This will happen nine months prior to the next Annual Meeting; i.e. the beginning of September. Based on the description of analytical methods, the Steering Group (Chair, Vice Chair, Head of Science and the last four Scientific Committee Chairs) will begin the process of identifying experts to participate in the Workshop. Given his involvement in the programme, the Scientific Committee Chair, Kitakado, will not take part in the Steering Group. Palka (as immediate past Chair) will act on his behalf.

Table 19

Overview of the tentative workplan as it relates to special permits.

Species / area	Intersessional 2014-15	SC66a 2015	Intersessional 2015-16	SC66b 2016
New Japanese Antarctic proposal	Follow 'Annex P' with expert workshop early 2015,	Review of expert workshop; Committee comments.	Depends on discussions at SC66a,	Depends on discussions at SC66a,
Regular review of JARPN II	Submission of data description document 2 months before annual meeting; data requests data 1 month before meeting,	Discussion of any data requests.	Follow 'Annex P' with expert workshop early 2016,	Review of expert workshop; Committee comments

Japan announced that the Government of Japan will meet the necessary costs for organising the Workshop to be held in Tokyo in January/February 2016, which includes the cost for the meeting venue and other miscellaneous costs other than the travel/stay costs for the participants. Travel/stay costs for the participants at the Workshop (8-10 invited experts and a representative from the IWC Secretariat) are expected to be met by IWC.

The Committee **agrees** to submit a budget request for the 2015/16 intersessional period to cover the travel and stay of the expert panel (see Item 26).

17.4.2 Planning for review of future Japanese Special Permit research in Antarctic

Japan announced that the Government of Japan plans to issue a Special Permit for a new research programme in the Antarctic starting in the season 2015/16. Japan wishes this programme to be reviewed at the 2015 Annual Meeting, in accordance with 'Annex P'.

The new proposal will be reviewed under the process stipulated in the Annex P. Japan will submit a new proposal to the chair of the Scientific Committee no later than six months before the next Annual Meeting of the Scientific Committee in 2015 (October/November 2014). The proposal should then be reviewed by a small specialist workshop with a limited but adequate number of invited experts. The Workshop should be organised at least 100 days before the Annual Meeting in 2015 (January/February 2015). Results of

the Workshop should be duly submitted to the next Annual Meeting of the Committee in 2015 for its final review.

The Government of Japan will meet the necessary costs for organising the Workshop to be held in Tokyo in January/February 2015, which includes the cost for the meeting venue and other miscellaneous costs other than the travel/stay costs for the participants. Travel/stay costs for the participants at the Workshop are expected to be met by IWC.

The Committee **agrees** to submit a budget request for the 2014/15 intersessional period to cover the travel and stay of the expert panel (see Item 26).

18. WHALE SANCTUARIES[26]

The issues to discuss under this Item were to facilitate the decadal review of the existing Southern Ocean Sanctuary (SOS) and the review of the proposed South Atlantic Whale Sanctuary (SAWS). Kitakado read out instructions from the Chair of the Commission that the decadal review of the SOS and review of the proposal for SAWS should follow the existing instructions and guidance from the Commission for the review of Sanctuaries. The terms of reference for discussions this year are given in Annex R.

18.1 Preparation for the regular review of the Southern Ocean Sanctuary

The Chair of the Commission had noted in a letter to the Chair of the Committee that the Commission has not yet agreed scientific objectives for the Southern Ocean Sanctuary as requested through the 2004 review, but that these were expected to be discussed at the Commission meeting in September 2014. She suggested that the Committee may wish to commence its review process by assembling information necessary to establish scientific objectives. The Commission would then provide further advice regarding review of the Southern Ocean Sanctuary.

Some suggestions for the review process were presented in SC/65b/O1. This summarised the previous review of the SOS in 2004 and in particular noted the difficulties of conducting a review without fully specified objectives. In 2004 the Scientific Committee had developed a series of recommendations that, once the overall objectives of the SOS have been refined, would allow these objectives to be evaluated, and would facilitate evaluation in future reviews. These recommendations were endorsed by the Commission in 2004.

Based on the direction from the Chair of the Commission, the Committee **agrees** to establish an intersessional email group (comprising Zerbini (chair), Bjørge, Donovan, Double, Fortuna, Hall, Jackson, Kitakado, Palka and Robbins) to assemble scientific information that might assist the Commission to establish scientific objectives for SOS. The review from 2004 will provide a useful background document for starting this work. Other relevant information on whales in the Southern Ocean had been compiled for the IWC-CCAMLR workshop in 2008. The group should focus on existing information from the Committee's reports, assessments and National Progress Reports rather than seeking the latest updates from the many active national research programmes in the SOS area, which would be a major task. The report from the group should provide a summary of information on distribution, migration, current abundance, status and trends, threats, and catches by species/stock in the Southern Ocean Sanctuary. In addition, the report should **reiterate** the Committee's recommendations from the 2004 review to facilitate reviews of Sanctuaries and Sanctuary proposals (item B, numbers (1)-(7) in Appendix 1) and outline how the information provided relates to these recommendations. The report of this email group will be circulated for information of the members of the Committee and submitted to the Commission three weeks before IWC65.

The Committee **agrees** that there was a need for more discussion of the review process. There were differing views on the merits of the proposals in SC/65b/O1 and the success of the process in 2004. The Committee **agrees** these discussions can better take place at the 2015 Annual Meeting following elaboration of objectives and guidance from the Commission.

18.2 South Atlantic Sanctuary proposal

The head of delegation for Brazil (Secretary of Biodiversity and Forests, Roberto Cavalcanti) summarised the proposal for a South Atlantic Whale Sanctuary (IWC/65/8 Rev1). He stressed that the IWC is not dealing with a new proposal and that the Commission had been considering this matter for more than a decade. During this period the amount of scientific research in the South Atlantic has increased and the new proposal reflects this. The new version of the proposal is intended to address the guidelines for reviews in Annex R. The SAWS proposal is consistent with modern and emerging management practices including protected areas, and provides an opportunity for countries with different management regimes to co-ordinate activities to address emerging issues. To give just one example, there are relatively few ports and generally low levels of ship traffic in the South Atlantic but this is set to expand considerably. The co-ordinated approach provided within SAWS will thus help to address existing and emerging environmental and anthropogenic threats such as shipping while finding a balance with the needs of conservation and industrial development. The primary goal of the SAWS is to promote the biodiversity conservation, non-extractive and non-lethal utilisation of whale resources in the South Atlantic Ocean. To achieve this goal, specific objectives are described in IWC/65/8 Rev1. The proposed SAWS is intended to promote cooperation well beyond the strict interpretation of preventing commercial direct takes from impacting cetacean populations, including support for the coordination between MPAs established at national levels or under other relevant international initiatives, such as the World Heritage Convention and UNESCO Man and the Biosphere programme.

Iñiguez noted that Argentina had been a proponent of SAWS with Brazil when it was presented for the first time 13 years ago. Later on South Africa and Uruguay also sponsored this proposal. The last review of the SAWS was in Ulsan, Korea

[26] The Committee had established an *ad hoc* working group chaired by Zerbini and Hall to discuss this item at times when there were no other sessions taking place to allow full participation of those who wished to attend. It was agreed to incorporate the report of that group in full into the Committee's report here.

in 2005 (IWC, 2006) and subsequently the proponents incorporated the changes requested by the Commission. He added that large whale species were exploited by commercial whaling in the South Atlantic until the mid-1980s. Hunting occurred along migratory routes in addition to feeding and breeding grounds, reducing some populations to very small numbers (e.g. Antarctic blue whales, southern right whales, and humpback whales). Even though whale populations are currently protected, they face other threats including ship strikes, emerging disease, pollution, hydrocarbon exploitation and exploration, entanglement and climate change. The Chairman's report of the Thirty-Fourth Annual Meeting identifies the prime objective of a sanctuary as a place where individual or groups of whale populations are protected from whaling for a specified period with additional objectives related to information and research interests. He noted that the objectives of the SAWS had already been outlined by Cavalcanti and that the SAWS will provide the framework to coordinate and cooperate on cetacean research, conservation and management in the South Atlantic. The proposal was being submitted to SC65b in the hope that, consistent with its mandate and competences, the Scientific Committee will provide its contribution to improve the proposal as requested by Commission.

In discussion, some members noted that the measures contained in the proposed Schedule amendment that would establish the SAWS would only prohibit whaling. The amendment text does not include any of the other scientific objectives such as the coordination of research. The review of the Southern Ocean Sanctuary had been difficult because the objectives were not clearly specified. The lack of objectives within the proposed Schedule amendment text would make the SAWS difficult to assess following the terms of reference for the review process.

In response, it was noted that the Schedule amendment was just one of the points that needed to be addressed to establish the Sanctuary and that the Schedule contains those regulations applicable to whaling which are mandatory. Previous IWC reviews of sanctuaries had emphasised the need for clear objectives and the SAWS proposal had learnt from this by specifying detailed objectives.

In discussion of one of the primary objective of SAWS (maximise the rate of recovery of depleted whale populations towards their natural carrying capacity levels, and to monitor and maintain these populations at these levels), it was noted that further details of the monitoring plan were needed in order to evaluate whether the monitoring was likely to be successful in assessing whether the objectives had been achieved. In addition, changes to the environment, and particularly the impact of commercial fisheries, are likely to prevent whale populations recovering to natural carrying capacity, since this will have changed. The proposal should give more details of the proposed monitoring programme, including how carrying capacity will be assessed to take into account multi-species effects of mid-latitude fisheries.

In response, it was noted that the proposal mentions that carrying capacity will have been affected by human activities and therefore the objective is not necessarily to return to pre-whaling population levels. The way in which human impacts may have affected carrying capacity is complex and would need the kind of coordinated research outlined in the proposal to address these questions. For MPAs, this level of detail is generally developed once the MPA is established. The SAWS contains some of the best monitored whale populations in the world. The Committee could assist in helping to define objectives in relation to environmental change, and refine monitoring programmes, once the SAWS was in place and a monitoring framework had been established.

The proposal describes general features of critical habitat but it was suggested that insufficient detail was provided in order to provide advice on whether the sanctuary addresses the issue of critical habitat and non-critical whale habitat. The Committee **advises** that a revised proposal, with more detail on the issue of monitoring and objectives with respect to carrying capacity and on critical habitat, would assist with the review. The Committee would also **welcome** further details on how potential threats might be addressed in collaboration with other international bodies.

In 2004, the Committee agreed that the involvement of independent external reviewers in the review of the SOS had been largely positive and that involvement of external reviewers should continue, both for future reviews and reviews of future Sanctuary proposals. It was agreed that external experts should be involved in the SAWS review process but there were different views on the success of the process used to review the SOS in 2004. Some members noted that they did not support the method used in 2004 if the external reviewers operated independently from the Scientific Committee. Therefore, these members only support the use of external reviewers in the upcoming review of the SAWS if they work in conjunction with the Committee. It was suggested that the review process should be initiated with a workshop or pre-meeting including selected invited experts and members of the Scientific Committee, followed by the review by the full Committee. The Committee **requests** further clarification from the Commission at IWC65 on recommendations for the SAWS review process. Based on any advice from the Commission, the Committee could then finalise the details of the review process at the 2015 Annual Meeting such that the review can be completed at the 2016 Annual Meeting.

18.3 Workplan

The Committee developed a draft workplan, **recognising** that the workplan may be modified under new guidance from the Commission at IWC65. The overview of future work on sanctuaries is given as Table 20.

Table 20

Overview of the tentative workplan as it relates to sanctuaries

Task	SC66a (2015 Annual Meeting)	SC66b (2016 Annual Meeting)
Review of methods for reviewing sanctuary proposals and periodic reviews of existing sanctuaries	Receive and act in line with advice provided by the Commission at IWC 65	Perhaps review how new process (if given) performs.
Periodic review of Southern Ocean Sanctuary	Receive advice from Commission on objectives. Finalise details of review process	Finalise review
Review South Atlantic Sanctuary proposal	Perhaps receive revised proposal. Finalise details of review process	Finalise review

19. SOUTHERN OCEAN RESEARCH PARTNERSHIP

The Scientific Committee received 22 documents detailing progress on the five major projects of the Southern Ocean Research Partnership (IWC-SORP). These included: (1) the Antarctic Blue Whale Project; (2) Distribution, relative abundance, migration patterns and foraging ecology of three ecotypes of killer whales in the Southern Ocean; (3) The foraging ecology and predator-prey interactions between baleen whales and krill: a multi-scale comparative study across Antarctic regions; (4) The distribution and extent of mixing of Southern Hemisphere humpback whale populations around Antarctica? Phase 1: East Australia and Oceania; and (5) Acoustic trends in abundance, distribution, and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean**.** All of these projects are still on-going and contributing to the work of five sub-committees and working groups. The Scientific Committee **welcomes** the scientific information contributed by on-going IWC-SORP research projects and **recommends** their continuation.

The Committee **expresses concern** that there are few funds remaining in the IWC-SORP budget, including the funds necessary to maintain centralised project coordination. It therefore **recommends** the continuation of a funded coordinator within IWC-SORP in order to sustain the momentum of this large collaborative research effort, to ensure the communication of high-calibre scientific research to the Committee, and to leverage future funding to the project (see Item 26). It also **urges** the Commission to review the funding status of IWC-SORP and to facilitate sustainable support for these long-term research initiatives.

20. IWC LIST OF RECOGNISED SPECIES

Mendez *et al*. (2013) described multiple lines of evidence to re-evaluate the genus *Sousa* and four species, one still un-named, were recognised. *Sousa* exhibit some of the greatest degrees of genetic differentiation yet observed in small cetaceans, indicating that migration events are either very infrequent or may no longer occur. The Mendez *et al.* re-evaluation was accepted by the Society of Marine Mammalogy (SMM)Taxonomy Committee and the Committee **agrees** that the IWC list of recognised species should be amended accordingly:

> *Sousa teuszii* (Kükenthal, 1892) Atlantic humpback dolphin
>
> *Sousa chinensis* (Osbeck, 1765) Pacific humpback dolphin
>
> *Sousa plumbea* (G. Cuvier, 1829) Indian Ocean humpback dolphin
>
> *Sousa* un-named species. From Australia[27]

The Committee **appreciates** the work of the SMM Taxonomy Committee and **agrees** that this should be reviewed annually in the context of the IWC list to keep them synchronised.

21. CONSERVATION MANAGEMENT PLANS

The Committee had discussed CMPs in the context of large whales last year (IWC, 2014). This year, there was discussion of the concept of threat-based CMPs that they can apply to a single threat requiring international coordination and affecting multiple species or large habitats. The Committee **reiterates** its recommendation of last year for a review of the template and criteria to enable better consideration of the options for a threat based approach. The Committee **agrees** that the issue of marine debris is appropriate for consideration as a first threat-based CMP.

With respect to small cetaceans, the Committee **agrees** that CMPs for some threatened species and populations would be highly beneficial and would allow coordination of efforts. Their implementation is more problematic when species ranges are limited to a single country, as with the vaquita, Maui's dolphin and Yangtze finless porpoise. The situations of the boto and the franciscana might make them appropriate candidates to be suggested for CMP development.

22. UPDATED LIST OF ACCEPTED ABUNDANCE ESTIMATES

The Committee received an update on the work being undertaken by Allison to complete the list of accepted abundance estimates. A number of issues that require clarification had arisen during the year and it was agreed to establish an intersessional group to assist in this work (Allison, Brownell, Butterworth, Donovan, Gunnlaugsson, Kitakado, Palka, Wade, and Witting).

23. RESEARCH AND WORKSHOP PROPOSALS AND RESULTS

23.1 Review results from previously funded research proposals

Progress on Research Proposals and Workshops funded last year (for details see IWC, 2014, pp. 66-70 and carryovers from the previous year were primarily discussed in the appropriate sub-groups. Table 21 summarises the results of the items allocated funds under the 2013 Scientific Committee budget (see IWC, 2014, pp. 66-70) plus one project that was originally funded in 2012. All projects were completed successfully and made a major contribution to the Committee's work (see the relevant sub-group Annexes for details) apart from two workshop that will be held after the close of this meeting (BRG-2 and E-5) and one project that is ongoing (E-3).

23.2 Review workshop proposals for 2014/15

The Workshop proposals for the 2014/15 period are discussed under Item 26 and summarised in Table 22. The Committee **notes** that these Workshops are essential to it being able to meet its proposed two-year workplan discusses under Item 24.

[27] The new species from Australia will soon be named and published. Therefore, both the scientific names and common names should be examined again at the next SC meeting.

Table 21

Progress on workshop and research proposal agreed last year

Number	Title	Status
(16) from 2012 (IWC, 2013)	Review and guidelines for model-based and design-based line transect abundance estimates	Completed (SC/65b/RMP11)
AWMP-1	AWMP Workshop on developing *SLA*s for the Greenlandic hunts	Completed (SC/65b/Rep06)
AWMP-2	AWMP developers fund	Completed (SC/65b/AWMP03 and 04)
BRG/AWMP/1	Gray whale rangewide Workshop	Completed (SC/65b/Rep08)
BRG-1	Southern right whale kelp gull Workshop	Workshop in August 2014
E-1	State of the Cetacean Environment Report (SOCER)	Completed (SC/65b/E01rev)
E-2	POLLUTION 2020	Completed (SC/65b/Rep05)
E-3	Complete implementation of the CERD website	Ongoing
E-4	Joint IWC/IQOE Workshop predicting soundfields-global soundscape modelling	Completed (SC/65b/Rep03rev)
E-5	2nd phase Workshop on marine debris	Workshop in August 2014
HIM-1	Ship strike data coordinator	Completed (SC/65b/HIM04, 05, 09)
IA-2	Statistical catch-at-age issues for further investigation	Completed (SC/65b/IA03)
IA-3	2014 IWC-POWER North Pacific survey	Completed (SC/65b/Reps 01, 09, SC/65b/IA05, 011)
RMP-1	Intersessional Workshop on North Atlantic fin whales	Completed (SC/65b/Rep07)
RMP-2	Pre-meeting on North Atlantic minke *Implementation Review*	Completed (Annex D, Appendix 5)
RMP/AWMP/SD	Simulations to evaluate power and precision of genetic clustering at critical [demographic] dispersal rates	Completed (SC/A14/AWMP-RMP01, 05)
RMP/AWMP-1	Joint AWMP-RMP Workshop on stock structure hypotheses for North Atlantic common minke whales	Completed (SC/65b/Rep04)
RMP/AWMP-2	Computing support for RMP and AWMP	Completed (Annexes D and E)
SH-1	Minimum abundance estimates of Breeding Stock D humpback whales	Ongoing
SH-2	Modelling work to complete assessments of Breeding Stocks D, E and F	Completed (SC/65b/SH04rev)
SH-3	Antarctic Humpback Whale Catalogue	Completed (SC/65b/SH03)
SH-4	Comparison of JARPA II photographs to Antarctic Blue Whale Catalogue	Completed (SC/65b/SH20)
SH-5	Southern Hemisphere Blue Whale Catalogue 2012/13	Completed
SH-6	Pre-meeting to complete the assessment of Breeding Stocks D/E/F	Completed (Annex H)
SP-1	Expert Workshop to review JARPA II	Completed (SC/65b/Rep02)

Table 22

Workshop proposals agreed during this meeting

			Up to SC66a		Up to SC66b	
RP nos*	Title	Relevance	Date	Venue	Date	Venue
AWMP1	AWMP Workshop to Develop *SLA*s for the Greenland Hunts	AWMP	?6-10 January 2015	Copenhagen	Early 2016	Copenhagen
BRG3	Workshop to forward the modelling process to understand the status of gray whales across the North Pacific	BRG, AWMP, E	24-26 March 2015	La Jolla		
E7	CERD pre-meeting	E	Prior to SC66a	TBD		
E8	Investigations of large mortality events and mass strandings	All (incl. SM)			Late 2015	San Francisco
EM2	CCAMLR-IWC Workshop on the development and application of multi-species models to the Antarctic marine ecosystem: pre-meeting	EM			Prior to SC66b	TBD
HIM2	Preventing the Entanglement of Whales in Fishing Gear	HIM, COMM			April 2016	TBD
IA1	IWC-POWER planning and Technical Advisory Group meetings	IA, BRG, RMP	October 8-12 2014	Tokyo	October 2016	Tokyo
RMP2	Evaluating abundance estimates: diagnostics and testing	All (incl SM)				
RMP3	Workshops to further progress on the *Implementation Reviews* for the North Atlantic minke and fin whales	RMP, AWMP	?16-20 February 2015	Copenhagen	?Spring 2016	Copenhagen
SP1	WS for periodic review of JARPN II	SP			Early 2016	Tokyo
SP2	WS on Review of New Special Permit Proposals	SP	Early 2015	Tokyo		
E6	Climate Change meeting	E	19-20 August 2014	Glasgow		

* The full proposals are available as numbered documents: SC/65b/AWMP-RP1 etc.

24. COMMITTEE PRIORITIES AND INITIAL AGENDA FOR THE 2015 AND 2016 MEETINGS

Table 23 provides an overview of the main items for consideration based upon the workplans developed by the sub-groups and discussed in detail in their reports and in the relevant Items in this report. The Committee emphasises that much of its work is iterative and thus depends on progress made intersessionally and at Annual Meetings. The progress made is also integrally related to budget requests (see Item 26).

Table 23

Priorities for Committee work in 2015 and 2016

Topic	SC66a 2015	SC66b 2015
RMP-related matters		
Evaluate energetics based model	Review progress	Review results
Evaluate *CLA* performance	Review results when density-dependence acts upon natural mortality; Evaluate Norwegian *CLA* proposal	Complete if not done at SC66a
Other *CLA* related tasks	Review progress	As above
Abundance estimates	Hold pre-meeting on Diagnostic software to assist in evaluating design-based estimates	As above
	Review results	As above
Common minke whales (WNP)	Review hybrid RMP variants & research proposals if submitted; agree abundance estimates for use in actual applications of the RMP	Complete if not done at SC66a
Common minke whales (NA)	Assign plausibility to trials; review trial results; complete *Implementation Review?*	Complete *Implementation Review* (if needed)
Fin whales (NA)	Review trial results; Assign plausibility; finish *Implementation Review?*	Complete *Implementation Review* (if needed)
Sei whales (NA)	Decide to initiate or not pre-implementation assessment	Pre-implementation assessment (if agreed at SC66a)
Bryde's whales (WNP)	Review new information	Review new information
HIM-related matters		
Reviews of mitigation measures for ship strikes and entanglement	Produce simple summary information and advice table	Finalise if not completed at SC66a
Entanglement	Continue to examine new information on rates, risks and mortality and provide advice	Continue to examine new information
Entanglement (support Commission initiatives)	Communication of key issues; advice for specific CMPs; review recommendations from workshop; work with other organisations	Continue to support
Ship strikes	Continue to examine new information on rates, risks and mortality and provide advice	Continue to examine new information
Ship strikes (database)	Update and improve database, including review process and criteria	Continue
Ship strikes (support Commission initiatives)	Communication of key issues; advice for specific CMPs; review recommendations from workshop; work with other organisations	Continue to support
AWMP-related matters		
Validate *Humpback SLA*	Receive report formally	No
SLA for bowhead whales	Expect to finalise *SLA* recommendation	Finalise *SLA* recommendation if needed
SLA for common minke whales	Review progress; Developers' work	Hope to finalise *SLA*
SLA for fin whales	Review progress	Review progress; Developers' work
Annual review of catch limits	Complete	Complete
Implementation Reviews	None scheduled	Prepare for gray whale *Implementation Review*
Whale stocks-related matters		
Antarctic minke whales	Try to finalise the in-depth assessment with a focus on the Indo-Pacific region	Finalise if not completed at SC66a and [consider how to] address the remainder of the Antarctic
Southern Hemisphere humpback whales	Undertake review and synthesis of the completed 8-year circumpolar assessment. Begin to evaluate data requirements and process for future assessments.	Complete evaluation and determine future workplan
Southern Hemisphere blue whales (including pygmy blue whales)	Review available existing and new information on stock structure abundance etc. and determine feasibility of conducting area-based assessments with an associated workplan	Depends on workplan developed in 2015
North Pacific sei whales	Begin in-depth assessment	Complete in-depth assessment
North Pacific gray whales	See detailed workplan provided in Annex F	Continue and possibly complete
Southern right whales	Focus on reviewing new information, e.g. with respect to matters related to CMPs	Continue to review new information and develop workplan with respect to future updated assessments
North Atlantic right whales	Review new information. Determine when to undertake a new assessment and develop workplan.	Depends on outcome of discussions in 2015.
North Pacific right whales	New information expected from the Sea of Japan/Kamchatka region. Determine when to undertake an assessment and develop workplan.	Depends on outcome of discussions in 2015.
North Atlantic bowhead whales	Continue to review new information.	Continue to review new information and develop a workplan towards eventual assessment.
Okhotsk Sea bowhead whales	Review new information.	Continue to review new information and develop a workplan towards and eventual assessment.
Arabian Sea humpback whales	Review new information expected from several research initiatives. Continue to assist in efforts to develop a CMP.	Depends on outcome of discussions in 2015.
Sperm whales	Review information and develop a workplan	Depends on outcome of discussions in 2015.
Stock definition-related matters		
Terminology review and unit-to-conserve	Continue with a focus on examining terms used for small cetaceans. Try to finalise an initial list for use by the Committee.	Finalise if not completed at SC66a.

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Topic	SC66a 2015	SC66b 2015
Updates to genetic data analysis and DNA data quality guidelines	This is part of maintaining an online and evolving set of guidelines.	Review to see if updates are required
Statistical and genetic issues concerning stock definition	Continue to review technical issues regarding papers submitted to all sub-groups of the Committee.	Continue.
Testing of Spatial Structure Models (TOSSM)	Examine the future application of TOSSM datasets; advance the use of TOSSM to provide guidelines for setting subarea boundaries for assessment.	Continue based on discussions at 2015
Environmental concerns-related matters		
POLLUTION 2020	Refine population modelling approach; finalise priority contaminants list for future studies.	Continue to refine modelling approach; in utero transfer analyses and modelling
Oil spills	Review new information	Plan for an oil spill workshop
Contaminant threat information	Focus sessions on regional trends and POPs in cetaceans	Data integration and mapping
CERD	Pre-meeting. Data input and website management.	Improved communications on disease issues
Strandings and mortality events	Plan intersessional workshop; review new information	Receive report of intersessional workshop; review new information
Anthropogenic sound	Continue work on soundscape mapping; plan for 'masking' focus at SC65b. Review new information	Continue work on soundscape mapping; focussed sessions on 'masking'; plan for 'stress and sound' workshop; focus session on effectiveness of marine mammal observers in mitigation
Ecosystem modelling-related matters		
Co-operation on ecosystem model development	Discuss how best to further the long-term scientific exchange between IWC SC/EM and SC-CCAMLR WG-EMM	Receive results of Joint CCAMLR-IWC Workshop and continue
Processes in ecosystem model development	Receive results of IWC funded project to use tagging data to incorporate into models	Review progress and continue
Ecological change in the Southern Ocean	Review new analyses of the minke whale body condition and stomach content data to further examine temporal trends	Continue if necessary
Effects of long-term environmental change	Review work of intersessional group to determine suitable long time datasets and determine workplan	Depends on discussions at SC66a
Small cetacean-related matters		
Main topic to be decided by December 2014	*Tursiops* systematic or regional assessment of the status of small cetaceans	Depends on what happens in 2015 and the venue for 2016
Voluntary fund for small cetaceans conservation research fund	Continue	Continue
Review previous recommendations	Continue (priority will be given to vaquita, Hector's and Maui's dolphins, franciscana, beluga, river dolphins)	Continue
Review on takes of small cetaceans.	Continue	Continue
Whalewatching-related matters		
Assess the impacts of whalewatching on cetaceans	This is the ongoing and primary topic.	Continue
Review progress on the Commission's five-year strategic plan including the Handbook	As the Handbook is an online 'living' document then it is anticipated that this will be ongoing work although the initial work will be the most intense.	Continue
Review work of intersessional steering groups	These are listed in Annex M, table 2	Continue
Review whalewatching in the region of the meeting	The next meeting venue is unknown but this is an ongoing item	Continue
Consider information from platforms of opportunity	Finalise standard elements and guidelines including data collection items to be hosted on the IWC website	Review progress and modify if required
Review whalewatching guidelines and regulations	Ongoing work –the most recent compilation is submitted to the IWC Secretariat and included on the IWC website	Continue
Emerging whalewatching industries of concern	Ongoing work	Continue
Progress on previous recommendations	Ongoing work	Continue
DNA-related matters		
Progress on genetic methods	Ongoing work	Continue
Amendments to *GenBank*	Ongoing work	Continue
Progress on archiving of samples from catches and bycatches	Ongoing work	Continue
Reference databases and standards for diagnostic registers	Ongoing work	Continue
Special Permit-related matters		
New Japanese Antarctic proposal	Follow 'Annex P' with expert workshop early 2015	Review of expert workshop and comments by Committee.
Regular review of JARPN II	Consider requests for access to data	Discussion of any data requests.
Sanctuary-related matters		
Consider review methods	Receive and act in line with advice provided by the Commission at IWC 65	Perhaps review how new process (if given) performs.
Periodic review of Southern Ocean Sanctuary	Receive advice from Commission on objectives. Finalise details of review process	Finalise review
Review South Atlantic Sanctuary proposal	Perhaps receive revised proposal. Finalise details of review process	Finalise review

25. DATA PROCESSING AND COMPUTING NEEDS FOR 2014/15

Allison reported on the computing needs and requirements identified for the forthcoming year. These are summarised in Table 24.

Table 24

Computing tasks for 2014/15

REVISED MANAGEMENT PROCEDURE (RMP) – GENERAL ISSUES
(1) Evaluate the performance of the *CLA* for trials when natural mortality rather than fecundity is density-dependent (Annex D, Items 2.3 and 2.4);
(2) Address the remaining tasks related to testing the *CLA* (Annex D, Item 2.5);

RMP – IMPLEMENTATION-RELATED MATTERS

North Atlantic fin whales
(1) assemble data for the combined sub-area EG+WI (stock structure hypothesis VII) (Annex D, Item 3.2.1)
(2) update the catch series to include incidental catches off Eastern Canada (Annex D, Item 3.2.1)
(3) finalise the initial validation of the code (Annex D, Item 3.2.1)
(4) continue to work towards conditioned *Implementation Simulation Trials* (Annex D, Item 3.2.2)

North Atlantic minke whales
(1) Finalise the catch series (commercial and aboriginal) catch series (Annex D, Item 3.3)
(2) Code finalisation and conditioning (Annex D, Item 3.3)
(3) Conduct projections and circulate results (Annex D, Item 3.3)

North Atlantic sei whales
(1) Summarise information on the distribution of sei whales from catch records (Annex D, Item 3.4.2)

Western North Pacific minke whales
(2) Run 'hybrid' versions of RMP variants if requested by Japan, to allow evaluation of candidate 'variants with research' (Annex D, Item 3.1);

AWMP
(1) Validate and confirm results for the *Humpback SLA*
(2) Provide operating model to developers for common minke whales and possibly fin whales (See also related tasks under RMP).

IN-DEPTH ASSESSMENT
(1) Validation of the 2012 and 2013 POWER cruise data
(2) Further validation and correction of IDCR/SOWER data if the problems are elucidated (item 10.13.8)
(3) Complete validation of the 1995-97 blue whale cruise data and incorporate into the DESS database (carried over).

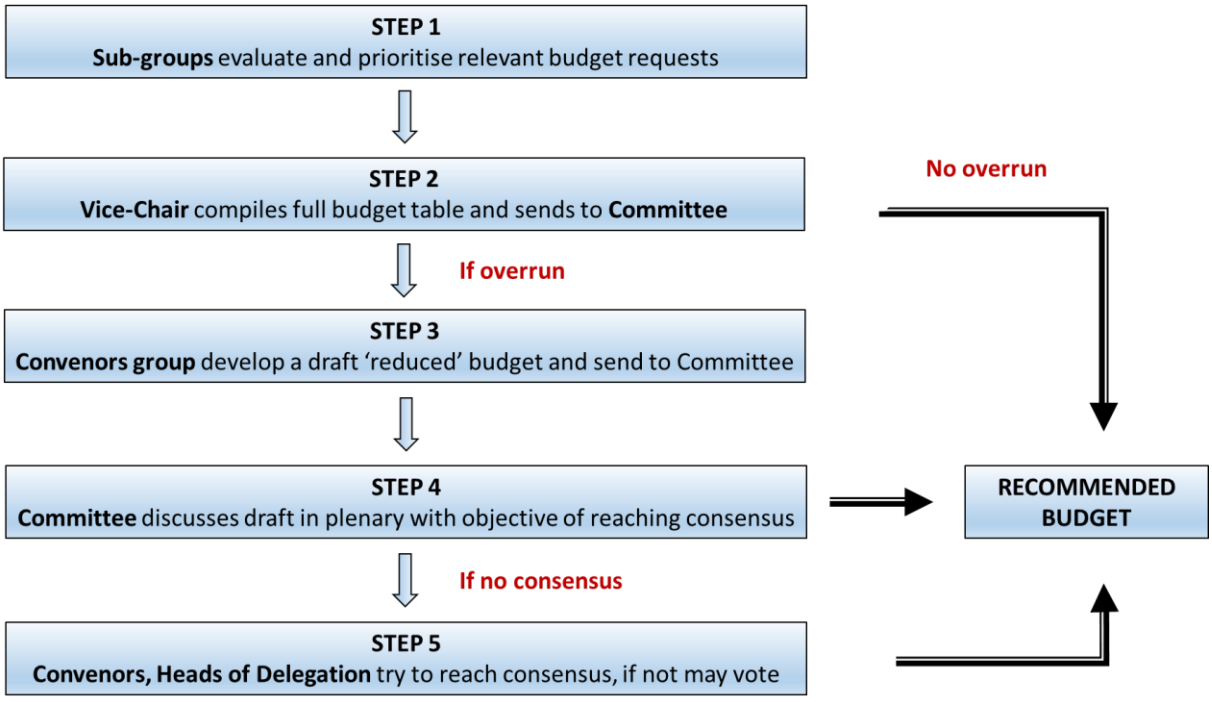

Fig. 4. Summary schematic of the budget process

26. FUNDING REQUIREMENTS FOR 2014/15 AND 2015/16

The Committee noted that this year it was expected to put forward a budget for a two-year period. In doing so it **draws the Commission's attention** to the unavoidable mismatch between the Scientific Committee year (May-June year 1 to May-June year 2), the Commission's biennial period (September year 1 - September year 3) and the Commission's financial year (1 January - 31 December). This makes planning rather more difficult, and is particularly difficult when the tasks undertaken are iterative i.e. the work needed in year 2 is heavily dependent on the results of year 1. This timing difference can be problematic if funded work is expected to be carried out in the period between the close of the Scientific Committee meeting and the adoption of the budget by the Commission which comes into force on the following 1 January (i.e. 6 months after the Committee meeting).

In response to discussions last year, the Committee discussed the process of developing a budget early in the plenary. As part of that discussion it received a report from the Secretary on the background to the IWC process and comparative information from other organisations (SC/65b/SCP02) as well as other discussion papers (SC/65b/SCP03 and 04).

After some discussion, the Committee **agrees** to the process given in Annex S and summarised in Fig.4. The approach agreed for the intersessional period and next year, based upon the experience gained this year, is given under Item 27.3.

Using the approach in Annex S, and following up to step 4, the Committee **recommends to the Commission** the budget request shown in Table 25, following discussion within sub-groups and a suggestion from the Convenors that was adopted by consensus.

The Committee notes that *pro formas* for all of the funding requests received are available on the Scientific Committee website. The Committee **thanks** the Convenors (and especially the Vice-Chair) for their hard work in developing the proposed draft and for the explanatory text. As the expected budget of £315,800 was exceeded in 2014/15, the explanation for the proposed reduced budget is given below (by project order in relation to the table).

26.1 Rationale for the reduced budget items

RMP-RP4. EVALUATION OF DENSITY DEPENDENCE PARAMETERS FOR INCLUSION IN RMP TESTING BASED ON ENERGETICS MODELLING.

The Committee **agrees** that this project can be spread over two years with no impact on its outcomes. The results can thus be considered at the 2016 meeting.

RMP-RP5. GENETIC ANALYSIS TO AID THE FORMULATION OF STOCK HYPOTHESES FOR PRE-IMPLEMENTATION ASSESSMENT OF N. ATLANTIC SEI WHALES.

The Committee **agrees** that this has scientific merit. However, there had not been time for it to be fully discussed during the sub-committee meeting. The Committee **agrees** that a revised proposal be resubmitted for consideration next year with the possibility that funding may be allocated then, following the process agreed under Item 24.3.

BRG-RP2-SOUTHERN RIGHT WHALE MORTALITIES AT PENINSULA VALDES: REQUESTED BUDGET FOR POPULATION AND HEALTH MONITORING RESEARCH.

In discussing this project the Committee made two general observations.

(a) The Committee has always strongly encouraged long-term monitoring programmes and recommended their continuation. However, given the nature of the Scientific Committee budget, its policy has been only to support such programmes financially if there was an emergency funding situation in a single year (as was the case for southern right whales off South Africa).
(b) This project is of importance for the Conservation Management Plan for South Atlantic right whales approved by the Commission through the Conservation Committee, which receives some partial funding through the CMP fund.

The Scientific Committee is of course recognises the importance of CMPs and is pleased to provide scientific and technical advice on the relevant components of them. However, it notes that (a) CMPs may have many scientific actions within them and (b) that the number of CMPs is expected to increase. It **requests** that the Commission considers whether funding requests for scientific actions of CMPs, especially with respect to long-term programmes such as monitoring, are expected to be considered under the Scientific Committee's regular budget allocation. It notes that, if this is the case, then this may cause difficulties for the Committee to achieve its workplan in the future unless the regular budget allocation is increased.

The Committee recognises that the current worldwide economic situation can cause serious problems for long-term studies and monitoring programmes. It also recognises the present die-off situation in Peninsula Valdes. Recognising that the three components of the project (i.e. aerial survey, photo-identification and post-mortem inspections on stranded animals) also have a strong scientific importance and that their interruption could jeopardise the scientific objectives of the project, it is **agrees** to allocate the related amount for those components (£13,000) for 2015.

The Committee had considered the option to split the funding over two years but **agrees** that this was inappropriate as it would affect the aerial survey component and therefore the achievement of the scientific objectives of the project.

BRG-RP4 - IDENTIFICATION OF SNP LOCI IN GRAY WHALES USING NGS SEQUENCING APPROACHES AND GRAY WHALE SAMPLES FROM ACROSS THE NORTH PACIFIC

The Committee **agrees** that this proposal has scientific merit. However, there had not been time for it to be fully discussed during the sub-committee meeting. The Committee **agrees** that a revised proposal be resubmitted for consideration next year with the possibility that funding may be allocated then, following the process agreed under Item 24.3.

Table 25

Summary of budget requests for the 2014-16 period. For explanation and details of each project see text.

RP nos*	Title	Relevance	2015	2015 reduced	2016	2016 reduced
AWMP1	AWMP Workshop to Develop *SLAs* for the Greenland Hunts	AWMP	7,000	7,000	7,000	7,000
AWMP2	AWMP developers fund	AWMP	7,000	7,000	7,000	7,000
BRG1	Development of an sex- and age-structured population dynamics model for North Pacific gray whales	BRG, AWMP, E	15,000	15,000	0	0
BRG2	Southern right whale mortalities at Península Valdés: population and health monitoring research	BRG	20,000	13,000	0	0
BRG3	Workshop to forward the modelling process to understand the status of gray whales across the North Pacific	BRG, AWMP, E	8,000	8,000	0	0
BRG4	Identification of SNP loci in gray whales using NGS sequencing approaches and gray whale samples from across the North Pacific	BRG	0	0	[11,000]	[11,000]
E1	State of the Cetacean Environment Report (SOCER)	E	3,000	3,000	3,000	3,000
E2	POLLUTION 2020	E, SM	4,000	4,000	2,000	2,000
E2b	Contaminant Status, Trends and Risk Assessments in Cetaceans	E	0	0	5,000	5,000
E7	CERD pre-meeting	E	5,000	5,000	0	0
E8	Investigations of large mortality events and mass strandings	All (incl SM)	5,000	5,000	0	0
EM1	Using baleen whale tag data to inform ecosystem models	EM	12,500	11,000	4,100	5,600
EM2	CCAMLR-IWC Workshop on the development and application of multi-species models to the Antarctic marine ecosystem	EM	1,200	1,200	4,000	4,000
HIM1	Ship strike database coordinator	HIM	10,000	10,000	10,000	10,000
HIM2	Preventing the Entanglement of Whales in Fishing Gear	HIM, COMM	0	0	10,000	10,000
IA1	IWC-POWER cruises 2015 and 2016	IA, BRG, RMP	36,000	36,000	36,000	36,000
IA2	Assessment modelling for in-depth assessments of Antarctic minke and North Pacific sei whales.	IA	0	0	5,000	5,000
RMP1	Testing proposed new guidelines for evaluating spatial model-based and design-based abundance estimates	All (incl SM)	2,200	2,200	0	0
RMP2	Evaluating abundance estimates: diagnostics and testing	All (incl SM)	14,300	14,300	0	0
RMP3	Workshops to further progress on the *Implementation Reviews* for the North Atlantic minke and fin whales	RMP, AWMP	7,000	7,000	7,000	7,000
RMP4	Evaluation of density dependence parameters for inclusion in RMP testing based on energetics modeling	RMP/EM	12,000	6,000	0	6,000
RMP5	Genetic analysis to aid the formulation of plausible stock hypotheses for North Atlantic sei whales	RMP	4,100	0	0	0
RMP6	Essential computing support to the Secretariat for RMP	RMP	10,000	10,000	10,000	10,000
SC	Following up from WS recommendations	ALL	0	0	20,926	31,160
SH1	Synthesis of the results of the comprehensive assessment of Southern Hemisphere humpback whales	SH	1,000	1,000	1,000	1,000
SH2	Modelling support/ Southern Hemisphere humpback whales	SH	2,000	2,000	2,000	2,000
SH3	Research contract 16, Antarctic humpback whale catalogue	SH	15,000	15,000	15,000	15,000
SH4	Southern Hemisphere blue whale catalogue 2014/16	SH	15,000	15,000	18,300	18,300
SH6	Priority tasks to support the regional conservation effort of Arabian Sea humpback whales	SH	14,573	14,573	17,290	17,290
SH7	Southern ocean research partnership (IWC-SORP) coordination	SH, IA, SM	17,596	13,000	17,734	0
SP1	WS for periodic review of JARPN II	SP	0	0	23,000	23,000
SP2	WS on Review of New Special Permit Proposals	SP	13,000	13,000	0	0
WW1	Emerging whalewatching industry in Oman	WW	3,850	3,850	3,450	3,450
	TOTAL REQUEST 2014-16		341,319	318,123	315,800	315,800
	Project to be considered for 2014					
E6	Climate Change meeting	E	6,000	4,000		
	Projects to be considered in the 2016-18 period					
E3	Sound field mapping in data-poor and data-rich priority regions	E/HIM				
E4	Masking and ship noise	E/HIM				
E5	Anthropogenic noise and stress	E, SM, BRG, SH				
	Unsolicited Project that would need to be resubmitted correctly					
SH5	Photo-identification analysis of blue whales from the newly discovered foraging ground in the South Taranaki Bight (NZ)	SH	1,300	0	0	

* The full proposals are available as numbered documents: SC/65b/AWMP-RP1 etc.

SH-RP7-SOUTHERN OCEAN RESEARCH PARTNERSHIP (IWC-SORP) COORDINATION.

In discussing this proposal, the Committee made the following general observations.

(1) The nature of this proposal is somewhat different to proposals usually received by the Committee. The initial proposal appeared to be primarily an administrative role with a fund-raising component. After seeking clarification, it was found that some 90% of the proposed activities were more science-related. The Committee **seeks guidance** from the Commission as to whether this type of administrative request is appropriate for consideration under the regular Scientific Committee budget in the future.

(2) The Committee is also aware that the Commission has a voluntary SORP fund generously initiated by the Australian Government that may also be appropriate for this kind of request. The Committee **urges** other SORP member countries to consider additional voluntary contributions to that fund. It was noted that since its

inception after a similar generous major contribution from Australia, the Small Cetaceans Voluntary Conservation Research fund has received some £170,000.

Having said that, the Committee **recognises** the valuable scientific work being undertaken as SORP projects (see Item 19) and the urgency of the situation (the coordinator contract will expire soon and there is little money in the SORP fund). It **agrees** to fund the 90% activities that are more science-related for the 2015 period on the expectation that further SORP funds will be generated during the 2015 period to pay for future years. The Committee notes that the Commission does not pay 'salary-on costs' so that these have been removed from the budget.

EM-RP1. USING BALEEN WHALE TAG DATA TO INFORM ECOSYSTEM MODELS.

This is a voluntary rearrangement of the project budget over the two years. The total budget of the project remains unchanged.

E-RP6. CLIMATE CHANGE MEETING (AUGUST 2014).

This activity does not fall under the 2015-2016 Scientific Committee budget. It is proposed that this is partially funded from a small projected underspend of the 2014 budget.

SH-RP5. PHOTO-IDENTIFICATION ANALYSIS OF BLUE WHALES FROM THE NEWLY DISCOVERED FORAGING GROUND IN THE SOUTH TARANAKI BIGHT (NZ).

This Committee **agrees** that this project falls under the category of an 'unsolicited' research proposal and had not therefore complied with the correct process (IWC, 1996b). It **agrees** that it should be resubmitted following the appropriate mechanism and timetable (see Item 24.3).

26.2 Summary information on all of the proposals received

(1) AWMP-RP1 WORKSHOP ON DEVELOPING *SLA*S FOR THE GREENLAND HUNTS FOR BOWHEAD, MINKE AND FIN WHALES

The Commission has requested that the Committee provide it with aboriginal subsistence *Strike Limit Algorithms* (*SLA*s) for use by 2018, i.e. the Committee must target being able to recommend *SLA*s to the Commission by no later than the 2017 Annual Meeting. The Committee has identified completion of the development of long-term *SLA*s for these hunts as high priority work. In order to meet the proposed timeframe, an intersessional Workshop is required. The focus of the proposed Workshop is to: (1) Review the performance statistics and plots for revised candidate *Strike Limit Algorithms* for bowhead whales off West Greenland; (2) Identify a work plan to which will allow the Committee to recommend a *Strike Limit Algorithm* for this hunt; (3) Review the performance of initial candidate *Strike Limit Algorithms* for minke whales off West Greenland and advice on how these *SLA*s can be adjusted to perform better; (4) Review a draft trials structure for fin whales off West Greenland which can be used to evaluate SLAs for this hunt.

The Workshop will be held in early 2015 in Copenhagen, Denmark. It is intended to hold this back-to-back with the RMP workshop on fin whales to save travel costs given some common participants.

(2) AWMP-RP2 AWMP DEVELOPERS' FUND

The developers fund has been invaluable in the work of *SLA* development and related essential tasks of the SWG. It has been agreed as a standing fund by the Commission. It has been proved to be of great value in ensuring progress throughout the *SLA* development period for the Alaskan and Chukotkan hunts as well as recent work on the PCFG and Greenlandic hunts, including the completion of the *Humpback SLA* at the present meeting. The primary development tasks now facing the Committee are for the remaining Greenlandic fisheries.

(3) BRG-RP1 DEVELOPMENT OF AN SEX- AND AGE-STRUCTURED POPULATION DYNAMICS MODEL FOR NORTH PACIFIC GRAY WHALES

This proposal is essential to the workplan agreed by the sub-committee on BRG for gray whales and it is connected to the workshop proposal BRG-3. SC/65b/BRG1 presented to this meeting provides an outline of simple modelling framework based on the discussions at the workshop and explains how it could be implemented for hypothesis 3a. The aims of this project are to implement the model of SC/65b/BRG1, and to extend this model to include age- and sex-structure and apply it to the data available for the North Pacific gray whales. The results of the modelling will be presented to a planned intersessional workshop (scheduled for April 2015), the model specifications and data updated based on the outcomes from the workshop and results presented to the SC/66a.

(4) BRG-RP2 SOUTHERN RIGHT WHALE MORTALITIES AT PENÍNSULA VALDÉS: POPULATION AND HEALTH MONITORING RESEARCH (AND SEE ITEM 26.1)

The high mortality of right whales at Península Valdés prompted the IWC Scientific Committee to convene a workshop of specialists in Puerto Madryn, Argentina in March 2010 (IWC, 2010b for further details). In fact, the mortality reported for 2012 at Peninsula Valdés (116 dead whales including 113 newborns) is the highest mortality ever recorded for the species. Among the actions agreed in the Conservation Management Plan (CMP)for southern right whales, top priority was given to 'ensure long-term monitoring of abundance, trends and biological parameters' (objective MON-01) and to 'develop and implement a strategy to minimise kelp gull harassment' (objective MIT-02).

The objective of this proposal was to request funds for the continuation of the four research programmes and projects described below, in order to understand the effects of the increased mortality rates on the population dynamics and to make progress to address the kelp gull harassment issue in the context of the current southern right whale die-off at Península Valdés.

(5) BRG-RP3 WORKSHOP TO FORWARD THE MODELLING PROCESS TO UNDERSTAND THE STATUS OF GRAY WHALES ACROSS THE NORTH PACIFIC

This work is an integral part of the assessment process set in place by the Committee last year. It is of particular importance to: (1) the assessment of the status of gray whales in the North Pacific (BRG); (2) the management of subsistence whaling in the North Pacific in conjunction with the work of the AWMP SWG; (3) the evaluation of threats to gray whales in the North Pacific and the determination of future management advice (BRG); (4) the provision of advice in accord with the Commission's Arctic Workshop (E); (5) the western gray whale Conservation Management Plan endorsed by the Commission. This technical workshop will review the results of the work of Punt (BRG-1) and the Steering Group with respect to modelling the situation of gray

whales across the North Pacific. It will *inter alia* review trial structure, conditioning and initial model results from age-aggregated and age-structured models and work towards incorporating any new data obtained as part of the workplan. The results of this workshop will be presented to SC/66a.

(6) BRG-4 IDENTIFICATION OF SNP LOCI IN GRAY WHALES USING NGS SEQUENCING APPROACHES AND GRAY WHALE SAMPLES FROM ACROSS THE NORTH PACIFIC (AND SEE ITEM 26.1)

One of the recommendations made at the Rangewide Workshop on gray whales (SC/65b/Rep08) was to develop a panel of Single Nucleotide Polymorphism (SNP) markers for use with gray whales. This project proposal (2016 budget) aims to: (1) Utilise next generation sequencing approach to identify a panel of SNPs for use with gray whales; and (2) Conduct genotyping by sequencing for 200 samples from three. Expected outcomes are: (1) Assessment of population structure of gray whales utilising SNPs; (2) results can be compared to those generated using microsatellites to evaluate whether both approaches provide consistent results.

(7) E-RP1 SOCER REPORT

SOCER is a long-standing effort to provide information to Commissioners and Committee members on environmental matters that affect cetaceans in response to several Commission resolutions. Funds are for salaries, library services, and printing. The focus topic for 2015 will be the Pacific Ocean, and the Arctic Ocean in 2016, together with a section on issues of global concern.

(8) E-RP2 POLLUTION 2020

POLLUTION 2000+ has been a flagship programme of the Committee and the Commission has supported it and continued work on pollution in several Resolutions. POLLUTION 2020 is in effect Phase III of POLLUTION 2000+. POLLUTION 2020 will focus on the biennium 2015-2016 on three objectives. (1) To prioritise a list of 'contaminants of concern' for cetaceans (2015 activity) through a questionnaire to a range of acknowledged experts in the field to identify which contaminants are of highest priority and should thus be the focus of future modelling efforts. The output will be the collated results of the survey, with a prioritised tabulation of the listed contaminants. (2) To carry out a literature review and construct a database of appropriate dose-response relationships for the priority chemicals identified in (1) above (2015 activity). The output will be a database of dose-response relationships (in the form of a set of concentration-response functions with associated variability estimates) for the highest priority contaminants, where appropriate data are available. (3) To clarify the areas of uncertainty in the sPOCk population model already developed last year in terms of the amount of contaminants transferred from the female to the foetus *in utero* (2016 activity). The output will be an estimate, with uncertainty, of the proportion of contaminants transferred to the offspring *in utero*. This will replace the current single arbitrary point estimate of 0.6.

(9) E-RP2B CONTAMINANT STATUS, TRENDS AND RISK ASSESSMENTS IN CETACEANS

This item addresses the agenda item on Pollution and builds upon the work undertaken by POLLUTION 2000+ to provide an analysis of the trends and status of contaminants of concern in cetaceans globally. Its objectives are: (1) to collect status and trends contaminant data of cetaceans globally through country/region points of contact that were identified as part of POLLUTION 2000+ work (IWC, 2010b) - this will be accomplished through a focus meeting at the 2015 Annual Meeting and cetacean contaminant data available for use in trend and status analyses will be identified by 2016; and (2) to collate data and evaluate comparability of data sets among nations/regions/studies, including geospatial analyses to determine areas or species of concern and assess health and risks to cetaceans. This activity will occur intersessionally and be presented at the 2016 Annual Meeting.

(10) E-RP3 SOUND FIELD MAPPING IN DATA-POOR AND DATA-RICH PRIORITY REGIONS (AND SEE ITEM 26.1)

This project aims to assess the feasibility of sound field mapping in data-poor and data-rich areas. This project will follow two approaches: (1) in a high priority region where limited or no sound mapping products exist, preliminary regional to ocean basin scale mapping products should be produced - baseline status and trend analyses should be conducted in these regions, and where there is limited collection of acoustic data, efforts to obtain this data should be expanded; (2) in a region(s) with high quality data to support high resolution predictive sound mapping, case studies should be conducted quantifying uncertainty in predicted sound levels, model sensitivity to varying input parameters, and ideally, verification or comparison of model results with empirical data.

(11) E-RP4 MASKING AND SHIP NOISE (AND SEE ITEM 26.1)

'Masking' will be considered as either a one-day pre-meeting or a focus area at a future Scientific Committee meeting (biennium 2017-2018), with a particular emphasis on theoretical and field studies to assess how anthropogenic noise could mask biologically important signals used by cetaceans for vital life functions.

(12) E-RP5 WORKSHOP ON ANTHROPOGENIC NOISE AND STRESS (AND SEE ITEM 26.1)

In recent years, there has been a growing recognition that anthropogenic noise can cause physiological stress in marine mammals. This is an active research area, but much of the specialised research results have not yet been presented to the Scientific Committee. The proposal will be for an IWC-hosted intersessional workshop on noise and stress during the biennium 2017-2018.

(13) E-RP6 CLIMATE CHANGE MEETING (AND SEE ITEM 26.1)

The IWC Scientific Committee Steering Group meeting on Climate Change is intended to facilitate the ongoing work by the Scientific Committee on climate change. The meeting would review the topic, including the latest work from other IGOs (for example by the Convention for Migratory Species, IUCN and ACCOBAMS) and the latest pronouncements from the IPCC and produce a proposed process for the future engagement in this topic by the SC. The meeting will be held in conjunction to the International Marine Conference occurring in Glasgow in August 2014.

(14) E-RP7 CERD PRE-MEETING

Objectives of this 1-day pre-meeting of the Cetacean Emerging and Resurging Diseases (CERD) working group will be (1) to review website progress and (2) to develop plans for future work on cetacean emerging and resurging diseases including the possibility of health mapping and consistent reporting standards. This will be held prior to the 2015 Annual Meeting.

(15) E-RP8 INVESTIGATIONS OF LARGE MORTALITY EVENTS AND MASS STRANDINGS

The Workshop will bring together biologists, veterinarians, and stranding network investigators from various countries to facilitate the collaboration and coordination between national and regional programmes on responses to and investigations of unusual or large scale mortality events, mass strandings, and disease events. The goals of the workshop are: (1) to establish common terminology, (2) to facilitate consistency in investigation techniques, (3) to identify common issues and share information on potential solutions relative to causes, responses, and mitigation, and (4) to promote international data sharing and mutual aid particularly for mass strandings and large mortality events. The final agenda will finalised intersessionally and discussed at the 2015 Annual Meeting. This 3-day Workshop will be by invitation and will be held in conjunction to the 2015 Biennial Meeting of the Society for Marine Mammalogy (SMM) in San Francisco, CA. Its final report will be presented at the 2016 Annual Meeting.

(16) EM-RP1 USING BALEEN WHALE TAG DATA TO INFORM ECOSYSTEM MODELS

A central focus this year was discussing methods to model competition and competitive interactions between whales. Within this project preliminary analysis on fine-scale and satellite tag data will be conducted and this information will be used to develop individual-based models of cetacean foraging and generate specific hypotheses regarding competition between species from fine-scale foraging observations. The project objectives are: (1) estimates of feeding costs for a range of baleen whales species; (2) measures of how feeding costs change as a function of prey density; (3) analysis of movement patterns, habitat use and foraging bout duration from satellite-linked tags using state-space models. Objectives 1 and 2, including reports to the Committee will be completed by 1 June 2015. Objective 3, including reports to the Committee and manuscript submission will be completed by 1 June 2016.

(17) EM-2 CCAMLR-IWC WORKSHOP ON THE DEVELOPMENT AND APPLICATION OF MULTI-SPECIES MODELS TO THE ANTARCTIC MARINE ECOSYSTEM

The Joint CCAMLR-IWC Workshop on the development and application of multi-species models to the Antarctic marine ecosystem aims to foster collaboration between the two Committees in the development and application of multi-species models to the Antarctic marine ecosystem. The outcome from the workshop will be a set of specific and detailed proposals on the way forward in regard to both data collection and analysis, so as to move towards the development of tactical multi-species/ecosystem models of pertinence to the provision of scientific advice which addresses the objectives of both Commissions. It is proposed that this 2-day Workshop is convened in advance of the 2016 Annual Meeting.

(18) HIM-RP1 SHIP STRIKE DATABASE COORDINATOR

The ongoing development of the IWC ship strike database requires data gathering, communication with potential data providers and data management. Co-ordinators were appointed last year and the Committee agreed this should continue and a list of tasks was developed. It relates directly to the Commission's Conservation Committee working group on the topic.

(19) HIM-RP2 PREVENTING THE ENTANGLEMENT OF WHALES IN FISHING GEAR

This workshop responds directly to recommendations made in two previous Commission workshop reports and is of interest to the Commission's Working Group on Whale Killing Methods and Associated Animal Welfare Issues. Its overall objective is to identify methods and encourage further research into ways to prevent the entanglement of large whales; the funds here are for the scientific component of the topic. Detailed Terms of Reference will be finalised at the 2015 Annual Meeting of the Scientific Committee. The scientific output will inform a series of technical recommendations and policy advice to allow the Commission to develop a work programme to prevent entanglement.

(20) IA-RP1 2015-2016 IWC-POWER NORTH PACIFIC SURVEY

The Committee has strongly advocated the development of an international medium- to long-term research programme involving sighting surveys to provide information for assessment, conservation and management of cetaceans in the North Pacific, including areas that have not been surveyed for decades. The Committee has developed objectives for the overall plan and this money will fund the continuing work initial phase and progress on developing the medium-term phase. The amount of money is extremely small when seen in the context of Japan providing the vessel and associated costs for two years as it has in the past. The IWC contribution is for (1) IWC researchers and equipment, and (2) to allow the Committee's Technical Advisory Group to meet to review the multi-year results thus far and develop the plans for the next phase of POWER based on the results obtained from Phase I and (3) to enable analyses to be completed prior to the 2016 Annual Meeting.

(21) IA-RP2 ASSESSMENT MODELLING FOR IN-DEPTH ASSESSMENTS OF ANTARCTIC MINKE AND NORTH PACIFIC SEI WHALES

During 2015, the Committee will be starting an in-depth assessment of the North Pacific sei whales and will also be completing the in-depth assessment of the Indo-Pacific Antarctic minke whale. The project involves developing population dynamics models as required to progress the work on the In-depth Assessment sub-committee. The funds of this proposal will then be used between the 2015 and 2016 annual Scientific Committee meetings to implement the assessment model (including statistical catch at age assessment model for Antarctic minke whales) and conduct the runs. Results, including software and associated data files used to create the assessments, will then be submitted to the Committee during the 2016 annual meeting.

(22) RMP-RP1 TESTING PROPOSED NEW GUIDELINES FOR EVALUATING SPATIAL MODEL-BASED AND DESIGN-BASED ABUNDANCE ESTIMATES

This pre-meeting is relevant to all groups of the Scientific Committee. It is the point of delivery for intersessional work which comprises proposing updated guidelines (see RMP-2) for evaluating design- and (spatial-)model-based abundance estimates, and developing software for a diagnostic check on design-based estimates that have applied when the underlying criteria are not strictly met. The main objectives are: (1) to test the proposed new guidelines (see RMP-2) against several test cases of model-based abundance estimates made specifically for and during the workshop; (2) to demonstrate and discuss the proposed diagnostic software with a wider Committee audience involved in basic line-transect

abundance estimation. This will be a 2-day pre-meeting prior to the 2015 Annual Meeting by invitation only for objective (1) and the start of objective (2); and a half day on the first day of the 2015 Annual Meeting for delivery of objective (2) open to more general SC audience.

(23) RMP-RP2 EVALUATING ABUNDANCE ESTIMATES: DIAGNOSTICS AND TESTING

Abundance estimates are central to the Committee's work. Spatial modelling is a powerful tool for abundance estimation which, in principle, can: (a) be used in many cases where design-based estimates are inappropriate; (b) overcome some bias associated with uneven survey coverage; and (c) deliver more stable CVs than a standard design-based analysis even when the latter is appropriate. However, spatial modelling requires expertise both to use and to assess. Hence it is important to have clear guidelines both for assessing new abundance estimates made specifically with spatial models, and for handling the situation where a simple design-based estimate has been applied without its assumptions being met; in this latter case some diagnostic software is desirable. The general idea is that surveys with dense and evenly-distributed coverage should readily pass the diagnostic tests, whereas surveys with low or badly imbalanced coverage should raise a flag. Deliverables include software (R package of automated diagnostics based on results of automated trial fits of spatial models), workshop preparation and delivery (see RMP-1), and proposals for new guidelines in the form of a paper to the 2015 Annual Meeting.

(24) RMP-RP3 WORKSHOPS TO FURTHER PROGRESS ON THE IMPLEMENTATION REVIEWS FOR THE NORTH ATLANTIC MINKE AND FIN WHALES

Objectives of these back-to-back workshops are for fin whales: (1) review the conditioning of the initial trials; (2) update the specifications of the trials by defining a full set of sensitivity tests and (3) specify the management variants to consider intersessionally for fin whales. For common minke whales they are: (1) to review the conditioning of the trials; and (2) specify the management variants to consider intersessionally for common minke whales. The outcomes will be: (1) if all the trials for the minke whales can be conditioned successfully, the Committee should be in a position to complete the *Implementation Review* of the North Atlantic minke whales at the 2015 Annual Meeting; (2) if all the initial trials for the fin whales can be conditioned successfully, the Committee should be in a position to finalise the trial specifications for the North Atlantic fin whales at the 2015 Annual Meeting and complete the *Implementation Review* at the 2016 Annual Meeting. The proposal includes contingency funding for additional workshops in early 2016 in the event that it is not possible to complete the *Implementation Reviews* for North Atlantic minke and fin whales in 2015. This will be a five-day workshop held in March 2015 in Copenhagen.

(25) RMP-RP4 EVALUATION OF DENSITY DEPENDENCE PARAMETERS FOR INCLUSION IN RMP TESTING BASED ON ENERGETICS MODELLING (AND SEE ITEM 26.1)

The Committee has recognised the importance of the relationship between $MSYR_{1+}$ and $MSYR_{mat}$ in an RMP context and has agreed that it is desirable to explore the relationship arising out of the energetics-based model results further. This work is necessary before any conclusions or the need for additional RMP/*CLA*-related trials are considered. To this end the Committee developed a two-year workplan and this project addresses three elements of that workplan.

(26) RMP-5 GENETIC ANALYSIS TO AID THE FORMULATION OF PLAUSIBLE STOCK HYPOTHESES FOR NORTH ATLANTIC SEI WHALES (AND SEE ITEM 26.1)

A Steering Group (SG) has been given the task of investigating the feasibility of conducting a pre-*Implementation assessment* of North Atlantic sei whales. The further genetic analysis identified in this project will aid the formulation of plausible stock hypotheses for this species. A total of 172 samples from the Eastern, Central and Western North Atlantic have been identified, the analysis of which is likely to inform on potential stock structure. The project involves the generation of ddRAD-based SNP genotypes from the available tissue samples by the Marine Evolution and Conservation Group at University of Groningen in the Netherlands.

(27) RMP-RP6 ESSENTIAL COMPUTING FOR RMP

This is to provide essential assistance to the Secretariat with the large computing tasks it is facing in the coming year (see Item 25).

(28) SC FOLLOWING UP FROM WORKSHOP AND COMMITTEE RECOMMENDATIONS

This is a new budgetary line necessary in the second year (2016) of the Scientific Committee biennial budget to accommodate additional work that is generated by meetings, workshops and projects funded and concluded in the first year (2015). This budgetary line can also accommodate new project proposals generated during the 2016 Scientific Committee meeting.

(29) SH-RP1 REVIEW & SYNTHESIS OF THE RESULTS OF THE COMPREHENSIVE ASSESSMENT OF SOUTHERN HEMISPHERE HUMPBACK WHALES

This project will provide a summary overview of results arising from the Comprehensive Assessment of Southern Hemisphere humpback whales, in three parts: (1) assessment of findings by breeding sub/stock; (2) identification of data gaps during the assessment process (including recommendations for future work); (3) methodological developments in terms of analysis and other informative parameters over the period of the assessment (e.g. direct integration of mark recapture into models, N_{min} etc.).

(30) SH-RP2 MODELLING SUPPORT/ SOUTHERN HEMISPHERE HUMPBACK WHALES

This project will undertake modelling studies to assist the development of future syntheses of assessments of Southern Hemisphere humpback whales and optimised monitoring of these populations. It will contrast the relative information content of alternative data monitoring approaches to inform on the reliability of current predictions of population trends (and hence on the appropriateness or otherwise of the present population modelling framework).

(31) SH-RP3 RESEARCH CONTRACT 16, ANTARCTIC HUMPBACK WHALE CATALOGUE

The Antarctic Humpback Whale Catalogue (AHWC) collates photo-identification information from Southern Hemisphere humpback whales. Increasing awareness of the project among research organisations, tour operators and other potential contributors has widened the scope of the collection; research efforts in areas that had not previously been sampled have extended the geographic coverage. The AHWC has doubled in size in the past five years and grown by more than 10% in

the past year, substantially increasing the time required to analyse photographs. In addition to these requested IWC funds, additional funds from other sources will be sought.

(32) SH-RP4 SOUTHERN HEMISPHERE BLUE WHALE CATALOGUE 2012/2013

The Southern Hemisphere Blue Whale Catalogue (SHBWC) is an international collaborative effort to facilitate cross-regional comparison of blue whale photo-identifications catalogues. In 2006, the Committee agreed to initiate an in-depth assessment of Southern Hemisphere blue whales and in 2008, it endorsed a proposal to establish the SHBWC. Currently the SHBWC holds photo-identification catalogues of researchers from major areas off Antarctica, Australia, Eastern South Pacific and the Eastern Tropical Pacific. Results of comparisons among different regions in Southern Hemisphere will improve the understanding of population boundaries, migratory routes and model abundance estimates. In addition, assessment of blue whales and estimates abundance of populations will require improving software capabilities to access encounter histories of individuals.

(33) SH-RP5 - PHOTO-IDENTIFICATION ANALYSIS OF BLUE WHALES FROM THE NEWLY DISCOVERED FORAGING GROUND IN THE SOUTH TARANAKI BIGHT (NZ)

This project falls under the category of 'unsolicited project' and should be resubmitted according to the existing Scientific Committee rules of procedure.

(34) SH-RP6 PRIORITY TASKS TO SUPPORT THE REGIONAL CONSERVATION EFFORT OF ARABIAN SEA HUMPBACK WHALES

This project will help further two priority activities that were identified by the Committee for the improving conservation and research of Arabian Sea humpback whales for which the Committee has expressed serious concern in the past. These priorities are: (1) genetic analyses of archived samples; and (2) Kutch and Saurashtra coasts of Gujarat, India Exploratory Surveys. Reports will be submitted to the 2015 Annual Meeting and will be used to examine the funding requested for 2016.

(35) SH-RP7 SOUTHERN OCEAN RESEARCH PARTNERSHIP (IWC-SORP) (AND SEE ITEM 26.1)

The Southern Ocean Research Partnership (IWC-SORP) was endorsed by the IWC in 2009 and is now fully part of the IWC process. The Partnership includes 11 member States. SORP delivers Southern Ocean whale research, fully aligned with IWC priorities, and benefits from large scale collaboration. Approved funding is to employ an IWC-SORP coordinator for the period of one years (without ineligible local taxes and benefits) to (1) ensure, facilitate and implement continued delivery of high calibre science; (2) ensure the communication of high-calibre scientific research to Scientific Committee, IWC and the wider scientific community; and thus; (3) sustain the momentum of the collaborative research effort and (4) leverage future funding for IWC-SORP.

(36) SP-RP1 EXPERT WORKSHOP TO REVIEW JARPA II

The Committee has agreed a procedure for periodic and final reviews of results from Special Permit research (IWC, 2013g). This procedure outlines an intersessional review meeting by an expert panel in accordance with the 'Annex P' process agreed by the Commission. The report from the intersessional expert meeting will be reviewed and discussed at the 2015 Annual Meeting. The experts to the review workshop will be identified by September 2014 and the expert workshop will be convened during four days in February/March 2015. The requested funds are for travel for the invited experts.

(37) SP-RP2 WS ON REVIEW OF NEW SPECIAL PERMIT PROPOSALS

Japan announced that the Government of Japan will issue a Special Permit for a new research programme in the Antarctic starting in the season 2015/16. Japan wishes this programme to be reviewed at the 2015 Annual Meeting, in accordance with the 'Annex P' process agreed by the Commission. In accordance with the provisions for the review process stipulated in the Annex P, Japan will submit a new proposal to the chair of the Scientific Committee no later than six months before the next Annual Meeting of the Scientific Committee in 2015 (October/November 2014). The proposal should then be reviewed by a small specialist workshop with a limited but adequate number of invited experts. The workshop will be held in Tokyo in January-February 2015.

(38) WW-RP1 EMERGING WHALEWATCHING INDUSTRY IN OMAN

The goals of this three year project (2014-2016) are to improve, educate and stimulate the emerging cetacean watching industry in Oman, especially in areas where Arabian Sea humpback whales are sighted. The ultimate outcome is to raise the standards of cetacean watching tourism in Oman in order to actively support conservation of cetaceans and their habitat by: (a) maximising industry benefits; (b) enhancing industry standards; (c) minimising impacts to cetaceans; and (d) obtaining information on cetacean distribution and occurrence. The main task for Years 2 and 3 (2015 and 2016) is to promote a responsible and sustainable approach to dolphin/whale watching. This will be achieved by: (a) continuing hands-on training of operators by area and priority species; (b) identifying a liaison among operators who will represent the industry to continue to monitor guidelines and compliance; (c) continuing to support the data collection process during training exercises to increase knowledge of cetacean occurrence for science and management; and (d) discussing the development of a cooperative of operators with mutual benefit to all members.

26.3 Unspent and unallocated budget monies

Over the years, the money allocated to Scientific Committee work has inevitably been based on requests that involved a degree of 'informed guesswork' when putting together proposals. Previously, in the Commission's accounts this money had been held with the expectation that it might be spent in the future but these assumptions were unfortunately not reviewed annually. In the last 12 months, the Secretariat has been carefully reviewing and updating its financial procedures. This has now enabled detailed information on status of all IWC projects including those taking place through the Scientific Committee budget. This review has provided an accurate estimate of the extent of any monies remaining unspent from previous allocations.

Whilst the annual average may not seem so large, this has generated a large total amount of no longer allocated funds over the last ten years amounting to £135,000. This amount has arisen from a combination of underspends (some 'small' from overestimating IP costs at workshops, some 'large' from cruise participants being funded in kind therefore not requiring the grants that had originally been budgeted for) and

from projects where funding was originally allocated, postponed and ultimately did not take place (e.g. some Workshops). The £135,000 does not include money that is for ongoing projects earmarked for spending in the next two years but not yet completed.

Improved procedures are now in place so that in future each research budget item code will be reviewed biennially such that large amounts cannot accumulate. A document will be presented to the Scientific Committee showing the actual amounts allocated to a project, spent at the time the document is compiled and projected to be spent by the end of the financial year.

The Bureau of the Commission has indicated that there will be a discussion of how to deal with this unallocated amount at the Annual Meeting in September 2014. There are a number of possibilities. For example, it may be considered that the Commission funds particular items, not absolute amounts – it therefore follows that underspends should be returned directly to the Commission's general funds. Alternatively, there may be a view that these funds were allocated to the Scientific Committee and that they should be used primarily for scientific work. The unallocated monies relate to work similar to that now being carried out by the Committee. Clearly, how to deal with this is a Commission decision.

However, it seems appropriate for the Committee to provide some views on how the matter might be dealt with to assist the Commission in its discussions. One suggestion by the Committee and a variant on that is provided below.

The Committee's requirements can vary considerably from year to year depending on its workplan and priorities – in most years the desired budget has exceeded the amount of funds expected to be received but the extent of the difference vary considerably ranging from around £20,000 to as much as around £180,000 last year.

The Committee **fully recognises** the current economic situation and also **recognises** its responsibility to ensure that funded work is directly relevant to its agenda and workplan as agreed by the Commission. It therefore does not seem appropriate to suggest that all of the money should be allocated to the Scientific Committee to spend in a short time period. The principle that expenditure should be on value-for-money projects that directly support the Committee's ability to meet its agreed workplan and supply the best advice to the Commission remains.

The Committee therefore **respectfully suggests** that one option for a portion of the unallocated money could be for a special fund (say £50,000) to be established that would be available for the Committee[28] in addition to the money available through the Commission's regular budget (at present £315,800) to assist with the yearly variations in requirements. This money could only be used if the regular allocation was exceeded, and then only for essential work deemed necessary to meet the Committee's two-year workplan. The fund could be topped up in the future in the event of any future underspends.

A second option or variant upon the first option is relevant if the Commission agrees that it is appropriate for the Committee to receive the full £135,000 allocation. Under this option, the full allocation could be 'protected' within the overall Commission budget. The first option could be maintained but the special fund could be 'topped up' to the chosen level (say £50,000) as necessary. The money would then provide assistance to the Committee over a long time period.

27. WORKING METHODS OF THE COMMITTEE

27.1 Increasing the support of the Scientific Committee on conservation related issues

Of 3,259 statements within the Committee's reports, they classified 76% as *scientific statements*, 10% as *conservation statements*, while *management* and *administrative* statements represented 7% each (tables 2 and 3 in SC/65b/SCP1). In addition to this, they also examined qualitative aspects in the wording of the reports that could be improved in relation to the strength, clarity or absence of statements. With respect to funding requirements, they classified a large proportion (62%) of the funding as directed towards scientific research, 18% as related to management and 11% as related to administrative matters, mainly IPs. They assessed that only 9% has been allocated to scientific work with a conservation perspective (fig. 5 of SC/65b/SCP1). The work of the sub-committee on small cetaceans was not included in these analyses because funding for this sub-committee has come exclusively from the Small Cetacean Voluntary Fund. This funding source varies significantly from year to year and cannot be considered as a stable fund.

A number of recommendations were proposed including: (1) clearly and consistently highlight conservation concerns that can improve and support the IWC conservation work or as guidance for Range States; (2) including clear statements to point out the delicate conservation status or increasing risk for cetaceans; (3) reiterate previous statements where necessary; (4) include a summary of the status of the species/subspecies/population and the action needed; (5) whenever there is no agreement among SC members over an important discussion, properly highlight the issue in the report; (6) increase the funding allocated for conservation-oriented research, such as investigation on conservation or mitigation measures; (7) include the budgetary needs of the standing sub-committee on small cetaceans into the general Committee budget; (8) consolidate the mandate of the standing sub-committee on small cetaceans by agreeing the terms of reference; (9) consider making the results of IWC workshops more accessible; and (10) make an annual compilation of concerns and recommendations to be forwarded by the Secretariat to contracting and non-contracting governments, intergovernmental organisations and other entities to be considered in the development of national and regional cetacean action plans as appropriate.

[28] And the responsibility of its Chair in accordance with recommendations from the full Committee.

In addition, it was noted that the topics for the Scientific Committee in its Rules of Procedure have not been updated for many years and it was suggested that these should be updated, and based on this review the Commission may wish to consider amending the Terms of Reference of the Scientific Committee.

In conclusion the authors noted that implementing these recommendations would make an important contribution to the long-term survival of cetacean species, sub-species and populations, where it is most needed.

The Committee **thanks** the authors for the extensive review, recognising that the system for classifying statements, actions and funding was inevitably somewhat subjective. In discussion a number of points were raised. Some members broadly supported the document and its recommendations. Other members commented in particular that the Committee works hard to cover a broad range of topics, most of which are aimed at assessing and improving status, taking into account the many different kinds of potential threats to cetaceans. They did not believe that it was helpful to try to separate out concepts of 'conservation' and 'management' or suggest that they were conflicting within the work of the Scientific Committee. They referred to a number of international definitions that treated sustainable use and associated management as part of 'conservation'. They also noted the value of collaboration among scientists who might be described as working mainly on 'management' or mainly on 'conservation' under the terms as defined by the authors, to improve both conservation and management. In response, it was argued that while both terms looks to maintain viable cetacean populations, currently the Committee includes under agenda items 'management advice' and 'conservation advice' and that the differences between them is clear, being one aimed to direct takes of cetaceans while the other aimed to the rest of the threats.

With respect to small cetaceans, it was noted that although its budget was not included in the general budget request table of the Committee, the information was available within the reports. In particular, since the initial large donation from Australia, the fund had received some additional £170,000 in voluntary donations and had supported some excellent projects. The difficulties within the Commission over competency and small cetaceans are well known and resolving this is a matter for the Commission itself. In response it was noted that there is less stability when relying on a voluntary fund.

In conclusion, while different points of view had been expressed, the Committee broadly agreed with the need to:

(a) work carefully to ensure consistency and clarity over its recommendations especially those the expressed concerns over status and threats that required action by the Commission and others;
(b) improve communication with the Commission and others regarding the recommendations and concerns within its reports;
(c) keep track of recommendations and ensure that they are referred to and/or repeated as necessary;
(d) make workshop reports more accessible; and
(e) consider updating the 'specific topics of current concern' in its Rules of Procedure as had also been suggested in the review of other organisations produced by the Secretary (SC/65b/SCP02).

The Committee noted that the Secretariat was working to improve communications about all aspects of the Commission's work including that of the Scientific Committee, especially by improving the website. It had introduced the concept of news boxes on specific topics and that will include the work and report of the Scientific Committee. In addition, it had started to build up a series of webpages dedicated to workshops to make their conclusions and advice more accessible. It also annually developed a list of work actions for the Committee members, Secretariat and intersessional groups based on recommendations in the Committee's report and this could be expanded or a separate table be developed to refer to all recommendations.

The Committee **agrees** to keep this item on its agenda.

27.2 Data access under Annex P

In the run up to the JARPA II review, a request for access to the data was made as specified in Annex P through Data Access Protocol B. Unfortunately this process proved to be more time consuming and difficult than expected. This situation was caused by a number of different issues including: time zone differences; time for official response from data owners (according to Annex P allows up to 15 days which can become problematic if an exchange of views is required[29]); better guidance on the level of detail required in a proposal; availability of DAG members (e.g. holidays, fieldwork, etc.).

After a discussion amongst DAG members and representatives of data requesters and data owners on this specific case), a proposal for a following way forward in regard to improving the efficiency of the process was developed as outlined below. The Committee **agrees** that this is trialled from now, noting that further improvements may be made in the light of experience.

(1) Annex P specifies that a data description document is required at the Annual Scientific Committee Meeting prior to a review. This deadline should be advanced to **two months** before the Scientific Committee meeting. The preliminary data description document (which *inter alia* needs to broadly contain the types of data and the approximate sample size) will then be circulated to members of the Committee. The date for the final data description document remains as in Annex P (i.e. one month after the Scientific Committee meeting to allow for final checking of sample sizes etc.)
(2) Members who wish to develop analyses for the review should then develop those requests for data access for submission as a document to the Scientific Committee **four weeks** before the Scientific Committee meeting. This will allow other members of the Scientific Committee (including the data holders) to consider alternative analyses.

[29] E.g. if the proposal contains unclear aspects, the data owner will reply asking to the DAG to obtain clarifications from the proponents; this can add additional 15-30 days between the first request of clarification and the final response by data owners, via the DAG. If further clarifications are requested this multiplies.

(3) Requests will then be considered at the Scientific Committee Meeting. Initially, data requesters, data owners and the DAG can discuss the request early in the Meeting. This will provide opportunities for clarification and possible amendment of proposed studies. If there is disagreement over (e.g. whether analytical methods are appropriate and within the terms of reference of the workshop), this will be referred by the DAG to the appropriate sub-committee or an *ad hoc* group. In the hopefully rare event that disagreement remain after the sub-group discussion, then the DAG will be authorised to take the final decision on the request. Data forms and requests can then be signed/authorised at the meeting.
(4) In order to enable the DAG to function if one or more members are unavailable, the membership of the DAG (currently Chair, vice-Chair and Head of Science) will be expanded to include the Chair of the Scientific Permit working group and the Chair(s) of the most relevant sub-group(s). Any decisions (which should be few in view of the approach outlined above) can be taken with a quorum of three.
(5) While Committee members can still submit requests after the meeting in accordance with the existing timeframe in Annex P, they should be aware that the process may take a longer time and the request may not be accepted.

This process requires only minor amendments to the existing process. The revised Annex P is given as Annex P.

27.3 Improving the Scientific Committee budget review process

Following the development of the budget as described under Item 26, the initial feedback on the experiences from various sub-groups showed how complex (and time-consuming) agreeing and prioritising items for the Scientific Committee budget can be.

The primary function of the Scientific Committee budget is to allow the essential work to take place that the Committee needs to fulfil its workplan as agreed by the Committee. It is not intended to be seen as a 'research fund' in the usual sense of the term. Should the Commission wish to establish a traditional research fund then it would be appropriate for this to dealt with outside the Scientific Committee's regular budget and handled in a similar way to the Small Cetaceans Voluntary Fund.

In order to facilitate discussions next year on the budget process and build upon this year's experience, the Committee **agrees** to establish an intersessional working group (Members: Kitakado, Fortuna (Convenor), Donovan, Double, Holm, Jackson, Rendell, Roel, Rojas-Bracho, Ritter, Víkingsson, Walløe).

That group will:

(1) receive comments from members on any aspect of the process received by 1 September 2014;
(2) review and as appropriate modify revised proformas taking into account the discussions and experience this year by 1 November 2014 which will be placed on the IWC website and circulated to the Committee by 7 November 2014;
(3) develop a discussion document to be available at least one month prior to the 2015 Annual Meeting that includes suggestions/proposals on:
    (1) advice for the Committee and sub-groups on broad 'principles' with respect to examining proposals including: further clarifying what falls into category (c) type requests (see below); the factors to be taken into account when accepting and prioritising proposals of different types (workshops, research, databases etc.); the linkage between agenda, workplan, and budget requests; how to handle 'conflicts of interest'; where flexibility or discretion is appropriate; how to present the results in the report etc.
    (2) proposals or options on the overall process including prioritisation across sub-groups and presentation of the budget to the Commission;
    (3) other related issues that might arise out of discussions within the group and suggestions received under Item 1.

In addition, the Committee notes that the types of requests received by the Committee can considered to be of three broad types:

(a) proposals developed directly from discussions within sub-groups that are focused to allow fulfilment of the two-year workplan – examples include targeted workshops and any associated analyses/programming;
(b) ongoing issues that support the work of the Committee and for which data are freely available – this could include items such as databases, catalogues, IWC-designed multi-national long-term programmes;
(c) research proposals, often for field work, that relate to broad Committee recommendations but do not arise directly out of a specific request from the sub-group during the annual meeting at which they are proposed, based upon its workplan.

Recognising that the borderline between the categories can be somewhat grey, the Committee notes that it has been receiving an increasing number that seem to fall into the last category. This is not to say that they are not a valuable contribution to the Committee's work but there has often been be insufficient time (or detail presented in the request) to review them properly in the way that they deserve either from a scientific perspective (can they deliver and are they value for money?) or a priority perspective (how essential are they to an agreed workplan?).

The Committee recalled that the Committee in the past developed an approach for what at the time were called 'unsolicited' research proposals (IWC, 1996b, p.227) i.e. proposals not directly requested by the Committee but of relevance to its work. However, no requests under this system have been received for some time as scientists are aware that there is rarely money left in the Committee's budget. The process requires early submission such that the proposals get reviewed by a smaller group who then report to the Committee – the Committee has the final say as usual.

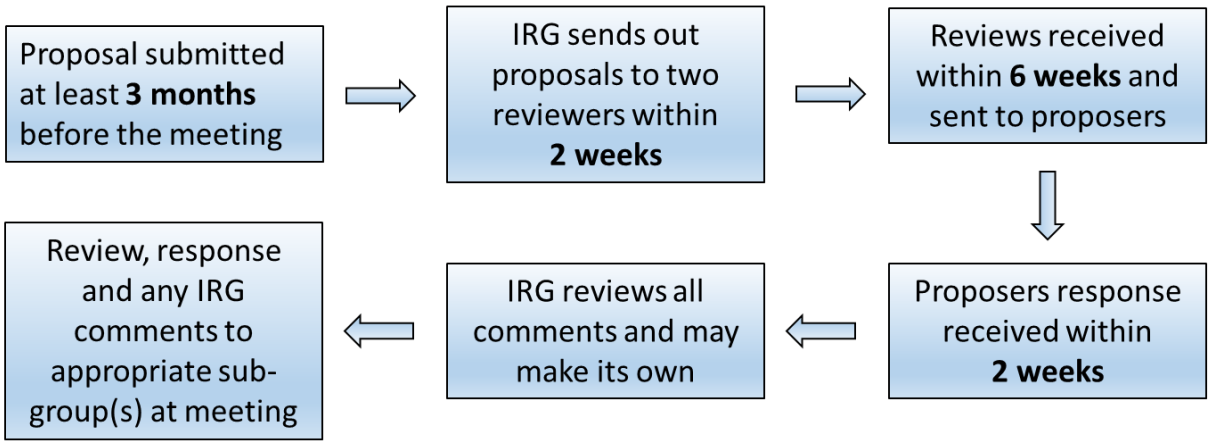

Fig. 5. Summary of the trial process

In parallel with the intersessional working group proposed above, the Committee also **agrees**, on a trial basis for the next intersessional period, the following process (and see Fig. 5) for proposals fitting within category (3) above, including proposals identified under Item 26 this year.

(1) Proposals are submitted **3 months** in advance of the Committee meeting following a standard *pro forma* (see above);
(2) Within **two weeks** of receipt of the proposal, an intersessional review group (IRG) comprising the Chair, Vice-Chair, Head of Science and the most relevant convenor(s) to a proposal will agree two anonymous reviewers (with some experience of the IWC) for each proposal with instructions to comment **within six weeks** on the following aspects (taken from IWC, 1996b):
   (a) relevance to the work of the Committee;
   (b) scientific quality of the project;
   (c) scientific competence of the proposer(s);
   (d) likelihood of meeting its objectives;
   (e) feasibility of the proposed work schedule;
   (f) reasonableness of the budget;
   (g) multinational context.
(3) The reviewers' comments will be sent to the proposers for comment when both are available and the proposer(s) will be given **three weeks** to respond;
(4) The reviewers' comments, the views of the proposers and any views of the IRG will be provided to each sub-group at the annual meeting whose views on the proposal are given to the relevant sub-group when discussing proposals and prioritised budget requests.

28. ELECTION OF OFFICERS

The Committee **welcomes** the fact that Kitakado and Fortuna have agreed to continue in their roles. It notes that their three-year terms of office conclude at next year's meeting.

29. PUBLICATIONS

Donovan was pleased to report that the *Journal* was now set up to be completely online and free access. This covers all stages of the review process from submission of manuscripts to publication. This allows papers to be made available immediately they have been accepted and pages finalised which will make the publication process much more efficient. He also noted that although the *Journal* will no longer be available in hard copy, members of the Committee attending Annual Meetings will continue to receive a hard copy of the supplement as agreed last year. All of the published *Journal of Cetacean Research and Management* (i.e. since 1999) and all of the *Reports of the International Whaling Commission* (i.e. the 48 volumes pre-1999) are now available on the IWC website.

The Committee **welcomes** this news and **thanks** Donovan and his team for their efforts. They **reaffirm** the importance of the *Journal* to the work of the Committee and **encourages** continued submission of papers to the *Journal*.

Donovan also reported on progress with digitising the entire set of papers submitted to the Committee since 1950 with a view to making them available online. This work has been progressing starting with the most recent years and he was now pleased to report that the complete set (over 8,600 papers) has now been digitised. The Secretariat are now focussing on how best to make these available online – this work is ongoing and should be completed before the next annual meeting of the Committee. A similar exercise is ongoing for papers submitted to the Commission.

In discussion, it was noted that as part of making the papers online, it was important that the agreed statement[30] on unpublished papers be highlighted when people downloaded papers, i.e.

'Papers submitted to the IWC Scientific Committee are produced to advance discussions within that Committee; they may be preliminary or exploratory. It is important that if you wish to cite this/a paper outside the context of an IWC meeting, you notify the author at least six weeks before it is cited to ensure that it has not been superseded or found to contain errors.'

30. OTHER BUSINESS

There was no other business.

31. ADOPTION OF REPORT

The Committee adopted the report at 1700hrs on 24 May 2014, apart from the final items discussed during the last session. As is customary, those items were agreed by the Chair, rapporteur and Convenors. The Chair thanked the participants for their positive and co-operative attitude,

[30] http://iwc.int/scientific-committee-handbook#five

particularly given the sensitivity of some agenda items. He especially thanked the rapporteurs, Secretariat and Vice-Chair for their excellent assistance. Finally, he reiterated his thanks to the host government and the hotel for the excellent facilities which contributed greatly to the success of the meeting. The meeting thanked the Chair for his expert and fair handling of the meeting.

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Report of the Workshop on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales

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The Workshop was held at the Southwest Fisheries Science Center, La Jolla California from 8-11 April 2014. The list of participants is given as Annex A.

1. INTRODUCTORY ITEMS

1.1 Convenor's opening remarks

Donovan and Punt (co-convenors) welcomed the participants. In particular they thanked the Southwest Fisheries Science Center for hosting the Workshop at its excellent facilities and in particular Dave Weller for co-ordinating the logistics. The objectives of the Workshop were to:

(1) review available information (especially new telemetry, genetics and photo-ID data) and reappraise the population structure and movements of North Pacific gray whales with a focus on examining status;

(2) develop a modelling framework to better assess the status of gray whales and the potential impact of human activities and possible changes in regime or climate – if possible such that some initial runs may be available for the 2014 Annual Meeting of the Scientific Committee.

(3) provide information for updating the IUCN/IWC Conservation Management Plan for western gray whales and develop a mechanism for updating the plan.

1.2 Election of Chair

Donovan was elected chair.

1.3 Appointment of rapporteurs

Reeves co-ordinated production of the report assisted by Donovan, Cooke, Moore, Lang, Weller, Punt and Bradford.

1.4 Adoption of Agenda

The adopted Agenda is provided as Annex B.

1.5 Documents and data available

The list of documents is available as Annex C.

2. SUMMARY OF POPULATION MODELLING APPROACHES THAT HAVE BEEN OR MAY BE RELEVANT FOR NORTH PACIFIC GRAY WHALES

2.1 AWMP (including Pacific Coast Feeding Group or PCFG)

The AWMP trial approach has since 2011 included consideration of the Chukotkan hunt and the potential hunt by the Makah tribe off Washington State (IWC, 2012). The trials considered two plausible 'stocks': 'PCFG' and 'north'. PCFG whales are defined as gray whales observed (i.e. photographed) in multiple years between 1 June and 30 November in the PCFG area (IWC, 2011, p.22). Not all whales seen within the PCFG area (the precise boundaries are somewhat arbitrary as discussed in IWC (2011) at this time will be PCFG whales and some PCFG whales will be found outside of the PCFG area at various times during the year. The geographic regions considered were:

(1) the 'north' area (north of 52°N, i.e. roughly northern Vancouver Island);

(2) the 'PCFG' area (between 41°N and 52°N with the exception of Puget Sound); and

(3) the 'south' area (south of 41°N).

The trials used to evaluate candidate *Strike Limit Algorithms* (*SLA*s) for the PCFG are based on operating models that include the 'north' and PCFG 'stocks', each of which is represented using age- and sex-structured population dynamics models (IWC, 2013). Allowance is made for immigration and emigration between the 'north' group and the PCFG group. The operating model allows for catastrophic mortality in 1999 and 2000 from the 'north' group given the large numbers of gray whales observed stranded along the coasts of Oregon and Washington in those years (Gulland *et al.*, 2005; Brownell *et al.*, 2007). A variety of levels for the annual rate of immigration from the 'north' to the PCFG was considered, along with the possibility of an immigration pulse into the PCFG in 1999 and 2000.

The catches accounted for in the operating model include aboriginal subsistence catches as well as incidental removals. The operating model allocated the catches to four types: (a) catches north of the PCFG area, (b) catches in the PCFG area during December to May, (c) catches in the PCFG area during June – November, and (d) catches south of the PCFG area. All of the catches north of the PCFG area were assumed to be 'north' group whales, the

catches from the PCFG area during June – November were all assumed to the PCFG group whales, and the other two types of catches were assumed to be from both stocks.

The values for the parameters of the operating model were estimated using Bayesian methods. Uniform priors were placed on the parameters on the model based on data for the eastern North Pacific stock of gray whales. The data used when fitting the model were the shore-based counts at Granite Point and Yankee Point (Laake *et al.*, 2012) and estimates of abundance based on mark-recapture data (Calambokidis *et al*., 2012; IWC, 2013). It is well-known that it is impossible to develop a model of the eastern North Pacific gray whales which assumes that carrying capacity has been unchanged since the start of commercial whaling, and nevertheless fits the available abundance estimates (Butterworth *et al.*, 2002). Consequently, in terms of providing management advice for present whaling operations, the model projections are initiated in 1930 with the age-structure of a depleted population (IWC, 2013).

The process adopted for developing operating models for commercial whaling (IWC, 2005) and aboriginal subsistence whaling aims to identify a range of uncertainties, including those associated with stock structure, such that future information should reduce rather than increase the range. Consequently, the range of uncertainties considered during trials development should be inclusive. This process has been applied to the western North Pacific minke whales (IWC, in press), the western North Pacific Bryde's whales (IWC, 2008) and the North Atlantic fin whales (IWC, 2009), as well as for eastern gray whales and bowhead whales under the AWMP. Under the RMP, the trials based on the hypotheses developed to encompass the uncertainties are assigned plausibility ranks, and only trials which are not considered 'low plausibility' are used when selecting 'variants' (IWC, 2005). In addition to stock structure hypotheses, the trials include hypotheses related to productivity, to changes over time in carrying capacity and natural mortality, to time-trends in survey bias, and to the quality and quantity of data on which future management advice might be based.

2.2 Western North Pacific (Cooke model)

Cooke summarised the population modelling approach used for assessment of western North Pacific gray whales since 2004. The model has been applied to the group of whales studied on a summer feeding ground off Sakhalin Island. Photo-id data, supplemented with sex determinations from biopsies, collected under the Russia-US programme since 1994 were used to inform the model. The latest assessment was presented in SC/65a/BRG27 (using data through the 2011 season), where details of the model are to be found (see Item 5.1.1.1 for a summary of results).

The population model is stage-structured. The stages include: calves; each of the immature age classes by sex; mature males; and three stages of mature females: pregnant, lactating and resting. The minimum observed time between calvings is two years: the model allows zero or more additional resting years so that calving intervals of three or more years are also possible. The model is individual-based, so that it can be fitted to individual photo-id capture histories. A "capture" in this case means that a whale was photo-identified in a given year as either: (i) a mother with a calf; (ii) a calf with its mother; (iii) a calf on its own; or (iv) any other whale. These were the only categories of animal that were considered to be distinguishable with close to 100% reliability in the field.

The transition probabilities between stages are assumed to depend on various combinations of parameters to be estimated. The transition probabilities can vary between years and between individuals. Availability (sighting probability) can vary between years, stages and individuals. Variations between individuals are modelled by allowing individuals to have additional attributes, and stages in the model are replaced by stage-attribute combinations. Model selection using the AIC criterion is used to determine which parameters are allowed to vary over time.

The results of greatest potential ecological interest are the annual variations in population parameters. The analyses presented in SC/65a/BRG27 found strong indication of inter-annual variability in both calf (post-weaning) survival rates and calving intervals. The variations in these two parameters were significantly correlated with each other subject to a 2-year time lag.

The variations in parameters and the time lags between them potentially provide insights into the impact of external factors on the life cycle. For example, correlations have been identified using a similar model for South Atlantic right whales (Leaper *et al.*, 2006): between right whale calving intervals and environmental variables such as the ENSO (El Niño Southern Oscillation), water temperatures in the South Georgia feeding ground, and reproductive success of other species (fur seals, gentoo penguins) feeding in the same area.

Work is in progress to identify the ecological and climatic variables most strongly correlated with the demographic changes observed in Sakhalin gray whales. Understanding the ecological factors affecting the demography can also provide important background information when interpreting data on the possible impacts of anthropogenic factors such as acoustic disturbance on the feeding ground.

The main reason for using an individual-based model is not that the individual processes are necessarily the focus of interest, but that the longitudinal individual data from photo-id have been found to be extremely informative with respect to population parameters and their variations. In order to make maximal use of these data to draw inferences on population parameters, an individual-based model is required.

An application of the model that also uses data collected from eastern Kamchatka is contained in the latest report of the Western Gray Whale Advisory Panel[1] (iucn.org/wgwap/wgwap/meetings/wgwap_13). Those results were obtained by simply merging the available data sets as if they were from a single study. It is recognised that this is probably not a valid approach, and that it would be desirable, when using data from more than one location, for the model to take account of differences between locations. In the case of Kamchatka and Sakhalin, for example, there may be differences in the relative availability of the different population stages (for example, adults versus subadults). Furthermore, the observations off Kamchatka may include whales that do not "belong" to the group of whales summering off Sakhalin Island.

Work is in progress to extend the model to allow location-specific differences in the relative availability of the different population stages, and to allow data from locations where not all animals necessarily belong to the population of interest.

The Workshop **welcomes** this information and **strongly encourages** the continued development of the approach. It **reiterates** the importance of careful incorporation of all relevant data from Sakhalin and Kamchatka into the model (e.g. IWC, 2013).

3. STOCK STRUCTURE AND MOVEMENTS

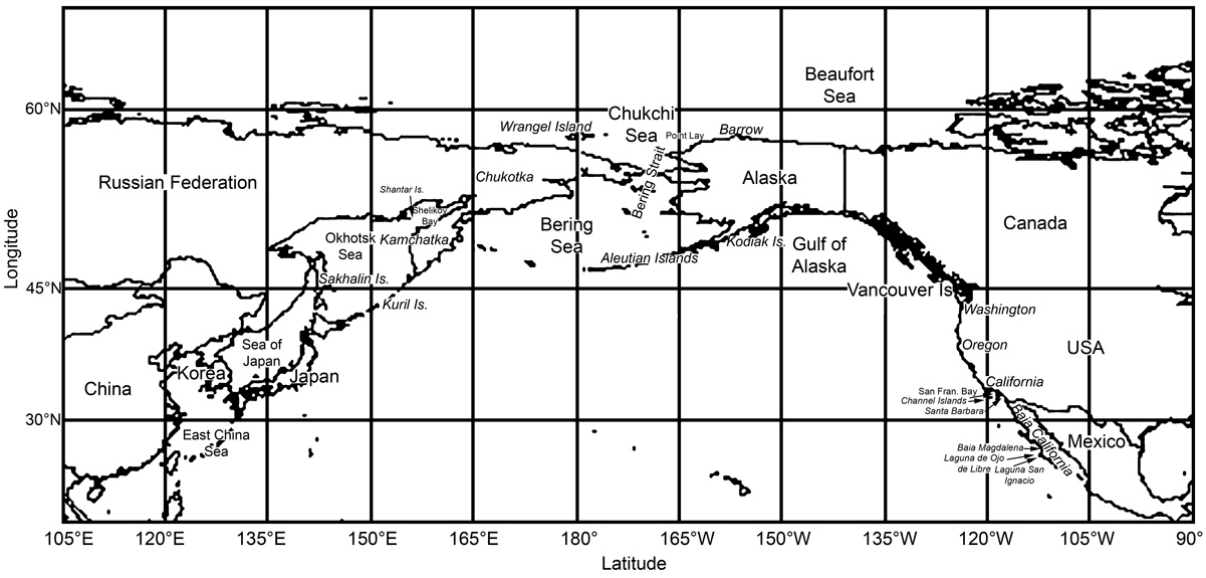

Fig. 1. Map of the North Pacific showing place names in the text.

3.1 Summary of existing hypotheses

Until recently, it was generally believed that there were two separate gray whale stocks in the North Pacific. According to that paradigm, the 'eastern' stock winters in Mexican waters, migrates along the North American coast and feeds during the summer and autumn in Arctic waters of Russia (primarily Chukotka) and the USA. This stock is considered to have recovered to around its pre-exploitation level (~20,000 individuals). The greatly depleted 'western' stock is considered to feed mainly in waters off Sakhalin Island, migrate along the coasts of Japan and possibly Korea and winter somewhere in the South China Sea (see Fig. 2 for a simple schematic). The AWMP *Implementation* for gray whales which evaluated and agreed the *Gray Whale SLA* (strike limit algorithm) agreed to a single eastern stock (IWC, 2001)

However, during the AWMP *Implementation Review* of eastern North Pacific gray whales in 2010 (IWC, 2011), which examined the subsistence hunts of gray whales off Chukotka and potentially Washington State, the

[1] www.iucn.org/wgwap/wgwap/meetings/wgwap_13

Scientific Committee agreed that there was sufficient evidence to consider the Pacific Coast Feeding Group (PCFG) of gray whales separately for management purposes related to the proposed Makah hunt and this evaluation was completed in 2012 (IWC, 2013), as defined above under Item 2.1.

In an effort to obtain more information about the southern migration route(s) and wintering area(s) of gray whales in the western North Pacific (WNP), a satellite telemetry project was undertaken in 2010 and 2011 by a team of Russian and American scientists (Mate *et al.* 2011). While the objective of the study was to document gray whale movements within the WNP, the three whales tracked for more than a few weeks travelled from the Sakhalin feeding area to the eastern North Pacific (ENP) (see Item 3.2.4).

Lang summarized the stock structure hypotheses put forward at the last IWC Scientific Committee meeting (IWC/65A/Rep 1 Annex I). These hypotheses are focused on the stock identity of the whales that feed off Sakhalin, and they did not address possible stock structure among whales considered part of the eastern North Pacific (ENP) stock. It was suggested that these existing hypotheses should be modified to include Kamchatka, as some data are available from this area. The addition of a model that incorporates multiple migratory routes in the western North Pacific was also proposed.



Fig.2. Schematic of the suspected distribution of what were thought to be two distinct populations of gray whales with little overlap (see text)

3.2 Review of available data and analyses

3.2.1 Genetic data on population structure

A small working group, consisting of Lang, Bickham and Urbán, was formed to summarize the available genetic data and analyses by region. A short summary is included as Table 1 and a full summary in Annex D.

Lang reviewed the results of previous genetic studies of gray whales that were relevant to stock structure. Recent studies investigating whether structure exists among feeding grounds used by ENP gray whales have found significant differences in mtDNA haplotype frequencies when PCFG whales were compared with whales sampled in other regions of the ENP stock's range (PCFG v. Bering and Chukchi Seas, Lang *et al.*, 2014; PCFG v. ENP migratory route, Frasier *et al.* 2011). No significant differences were detected when comparing microsatellite allele frequencies between the PCFG and whales sampled in the Mexican wintering lagoons (D'Intino et al. 2012) or between the PCFG and whales sampled in the Bering and Chukchi Seas (Lang et al. 2014). Structure on the ENP wintering grounds has also been investigated, with small but significant differences in mtDNA haplotype frequencies identified between cows (females with calves) sampled in two of the primary calving lagoons in Mexico and females sampled in other areas (Goerlitz *et al.,* 2003). A subsequent study by Alter *et al.* (2009), however, did not detect significant levels of mtDNA differentiation when comparing whales sampled in the three primary calving lagoons, although a small but significant departure from panmixia was detected between whales in two of the lagoons using microsatellites.

Comparison of whales feeding off of Sakhalin Island, Russia, with whales sampled on ENP feeding grounds and migratory routes have identified significant differences in both mtDNA haplotype and microsatellite allele frequencies (LeDuc *et al.,* 2002, Lang *et al.,* 2011). Between 1995 and 2007, 56 mother-calf pairs were sampled off Sakhalin; males sampled off Sakhalin were assigned as putative fathers for 46 to 50% of these calves (Lang *et al.*, 2010). Meschersky *et al.* (2012) analysed additional mtDNA sequence data, totalling ~2800 bps of sequence and including two protein-coding genes, generated from biopsy samples collected from whales encountered off Sakhalin Island, the eastern coast of Kamchatka, and the Russian Koryak coast as well as from samples collected as part of the aboriginal hunt in the coastal waters of the Chukotka Peninsula. Two sequence variants were found in relatively high frequencies among whales sampled off Sakhalin but only in low frequencies among the Chukotka whales.

Urbán reported that samples have been collected from gray whales in the Mexican lagoons over the last three seasons. Approximately 450 samples have been collected and 300 are being processed for mtDNA. Once produced, these data may provide additional insight into whether structure among lagoons exists.

Ilyashenko noted that approximately 150 samples collected from whales harvested in the Chukotka hunt had been sent to Japan for analysis; data are not currently available. Bickham noted that in addition to the samples analysed in Bickham *et al.* (2013), additional samples collected from whales off Sakhalin in 2012 (n = 20) and 2013 (n = 9) exist.

Lang reported that an analysis of relatedness among whales sampled off Sakhalin is ongoing; the primary objective of this work is to evaluate what proportion of the whales sampled off Sakhalin share a putative mother-offspring relationship with Sakhalin whales known to migrate to the eastern North Pacific. Similar studies to examine relatedness among sampled PCFG whales are also underway and will focus on examining internal recruitment into the group by identifying putative mother-offspring pairs among sampled whales.

Table 1

Summary of available samples of gray whales (not all have been analysed and there may be some overlap between studies included here). For details and further explanation see text and Annex D).

Region	Reference	N*	Years	Months
MEX				
Baja, all three lagoons	Urbán in process	450[1]	2012-2014	Feb-Mar
Baja, Bahia Balenas	Goerlitz *et al.* 2003	2	1996	Mar
Baja, Bahia Magdalena lagoon	Alter *et al.* 2009	32	2001-02, 2005-2006	Feb-Mar
Baja, Offshore, San Jose del Cabo	Goerlitz *et al.* 2009	1	1996	Mar
Baja, Ojo de Liebre lagoon	Alter *et al.* 2009	24	2001-02, 2005-2006	Feb-Mar
Baja, Ojo de Liebre lagoon	Goerlitz *et al.* 2009	14	1997	Feb-Mar
Baja, San Ignacio lagoon	Alter *et al.* 2009	56	2001-02, 2005-2006	Feb-Mar
Baja, San Ignacio lagoon	Goerlitz *et al.* 2009	66	1996, 1997	Feb-Mar
ENP (not specified)	Alter *et al.* 2007	42		
Migration				
CA/OR/WA (89), AK (9), Chukotka (5)	LeDuc *et al.* 2002	104	1979-2000	All
PCFG/South				
Pacific Northwest, (not id'd as PCFG)	Lang *et al.* 2011, pers. comm.	33	1996-2012	May-Nov
Pacific Northwest	Alter *et al.* 2012	16	150-2690 ybp)	?
PCFG				
Pacific Northwest,	Ramakrishnan *et al.* 2001	45		?
Pacific Northwest, PCFG	Lang *et al.* 2014, Lang pers. comm.	134	1996-2012	All but Mar?
Pacific Northwest, PCFG	D'Intino *et al.* 2012	82		Jul-Nov
Pacific Northwest, PCFG	Frasier *et al.* 2011	40	1995-2006	Jul-Nov
Pacific Northwest, PCFG	Steeves *et al.* 2001	16	1995-1996	Jun-Nov
SE AK				
Alaska, Kodiak	Lang pers. com	6	2001, 2005	Jul-Aug
NE CHUKCHI				
Alaska, Barrow	Lang *et al.* 2014, Lang pers. comm.	23	1997-8, 2000, 2002, 2010-1	Jul-Sep
NBS/SCH				
Russia, Chukotka	Kanda *et al.* 2010	7	2008	Jun-Oct
Russia, Chukotka	Meschersky *et al.* 2012	84		
Russia, Chukotka	Ilyashenko pers. comm.	~150		
Russia, Chukotka	Lang *et al.* 2014	75	1994, 2001, 2003-2005	Aug-Nov
Russia, Koryak coast	Meschersky *et al.* 2012	16	2010-2011	
Russia, Koryak coast	Lang *et al.* 2014	17	2010	Jun
SAK				
Russia, Sakhalin Island	Meschersky *et al.* 2012	14	2010-2011	
Russia, Sakhalin Island	Lang reported	155	1995-2007, 2010-2011	Jul-Sep
Russia, Sakhalin Island	LeDuc *et al.* 2002	45	1995-1999	Jun-Oct
Russia, Sakhalin Island	Bickham *et al.* 2013	6	2011	Jun-Oct
Russia, Sakhalin Island	Bickham pers comm.	29	2012-13	Jun-Oct
KAM-E				
Russia, SE Kamchatka	Meschersky *et al.* 2012	17	2010-2011	
Russia, SE Kamchatka	Lang pers. comm.	16	2004, 2010-2011	Jun-Aug
PAC-J				
Japan, Pacific coast	Kanda *et al.* 2010	5	1995-2007	Jan, Apr-May, Jul-Aug
S OF J				
Japan, Sea of Japan coast	Kanda *et al.* 2010	1	1996	May
AS				
China	Lang Pers. Comm.	2*	1996, 2011	Nov-Dec

[1] MtDNA analysis of 300 is underway. *to be added

3.2.2 Osteological data comparing populations

Kato and Nakamura (doc for this meeting) reported initial results of osteological comparisons among five gray whales from Japan (1 mature, 4 immature), one from Korea (Andrews, 1914), one from California (Andrews, 1914) and five additional California specimens (body lengths 9.3–11.7m). They concluded that the specimens from Japan (all from the Pacific coast) were more similar to the California specimens than to the Korea specimen and thus inferred that the feeding range of 'eastern' gray whales has expanded to the coast of Japan (an idea also suggested by Nishiwaki and Kasuya, 1970).

The Workshop welcomed this initial analysis but cautioned against over-interpretation of the results given that (1) the sample size is small and there are the long temporal gaps in timing of collections and (2) the sample includes immature specimens and some skeletal and skull features are known to vary by age or stage. The Workshop **encourages** continuation of this work provided sufficient additional specimens can be identified.

In discussion, it was noted that bone material can also be used for stable isotope and DNA studies (see below).

3.2.3 Individual identification data (photo and genetic)

Research on gray whales in the western North Pacific has been ongoing since 1995, predominantly on the feeding grounds off north-eastern Sakhalin Island and more recently also off south-eastern Kamchatka. These studies monitor gray whales using photo-identification methods. Data have been collected primarily between July and September off Sakhalin, and July and August off Kamchatka. The Sakhalin catalogue contains about 230 whales. The Kamchatka catalogue contains about 155 whales, of which approximately 55% have also been sighted off Sakhalin. In addition to the Sakhalin and Kamchatka catalogues, opportunistic photographs exist for a number of other regions in the Okhotsk Sea, the northern Kuril Islands, Japan and China.

Research on gray whales in the eastern North Pacific has been ongoing since the late 1960s. Photo-identification data useful for analyses of stock structure have been collected in a number of areas including: (1) Baja California, Mexico (Urbán *et al.*, 2013), (2) the north-western USA and southern British Columbia, Canada (~ 41°-52°) (Darling *et al.*, 1984; SC/A14/NPGW03) and (3) around Kodiak Island, Alaska, USA (Gosho *et al.*, 2011).

The photo-catalogue from Mexico includes images obtained primarily between January and April from all of the major wintering lagoons including: (1) Laguna Ojo de Liebre (2001-2003, 2013), (2) Laguna San Ignacio (2005-2013) and (3) Bahia Magdalena (1998-2010, 2012-2013). Altogether, 6,900 individual gray whales have been photo-identified in these three study areas.

The photo-catalogue from the Pacific Northwest (PNW) contains ~1,500 'Pacific Northwest' gray whales identified by a large number of researchers working in US and Canadian waters from California to Alaska, primarily between 1998 and 2013. The PNW catalogue focuses on gray whales that feed during the summer and fall in coastal waters between northern California and the Gulf of Alaska, the PCFG, but also includes some migrating whales identified in the spring (March to May) during their northward passage to high-latitude feeding grounds; there are some but fewer southbound sightings from December to February.

Gray whale photo-identification images have also been collected opportunistically during the past decade off southern California and off Alaska including Southeast Alaska, Kodiak Island and Barrow and vicinity. In addition some photographs are available from St. Lawrence Island and the SE Chukchi Sea (also see Item 3.2.6).

Table 2 provides a summary of the photo-id efforts across the North Pacific.

Ilyashenko reported that he has asked biologists working in Chukotka to try to obtain photographs of harvested gray whales for photo-id work even though this is difficult because carcasses on shore are generally not oriented in a convenient position and their flukes have been trimmed to facilitate towing to shore. This recommendation has also been made by the IWC Scientific Committee (e.g. IWC, 2009).

Results from photo-identification (Urbán *et al.* 2013, Weller *et al*. 2012), genetic (Lang, 2010; Baker *et al.,* 2002), and telemetry studies (Mate *et al*. 2011) have documented spatial and temporal overlap between western and eastern gray whales. Observations include: (1) six whales photo-matched from Sakhalin Island to southern Vancouver Island, (2) two whales genetically matched from Sakhalin to Santa Barbara, California, (3) 13 whales photo-matched from Sakhalin Island to San Ignacio Lagoon, Mexico, and (4) two satellite-tagged whales that migrated from Sakhalin Island to the west coast of North America. Despite this overlap, significant mtDNA and nDNA differences are found between whales in the western North Pacific and those summering in the eastern North Pacific (Lang *et al*., 2011). Although it is clear that some whales feeding in the western North Pacific during the summer/fall migrate to the west coast of North America during the winter/spring, past and present observations of gray whales in the western North Pacific off Japan, Korea and China during the winter/spring suggest that not all gray whales in the WNP share a common wintering ground (Weller *et al*., 2013). The possibility that not all whales migrate to the same grounds each winter was also raised.

Table 2.

Photo-identification data for North Pacific gray whales

Location	Photos	Catalogue Size	Years	Season(s)
Mexico Lagoons	Yes	< 7000 IDs	2006-present*;	Primarily January-April
Mexico Offshore	Yes	No catalogue; < 100 IDs	2007-2013	Primarily January-April
California (31-41°N)	Yes	No catalogue; Opportunistic/whale watchers		South and northbound migration
PCFG (41°-52°N)	Yes	> 1500 IDs	Primarily 1980s-2000s*	Primarily June-November Opportunistic year round
Aleutians (52°N)	?	NA	NA	NA
Kodiak	Yes	< 130 IDs	2002-2012 some annual gaps	Primarily August-September
US Bering Sea	Yes	< 10 IDs; Opportunistic (St. Lawrence Island)	2012	August
Chuckchi-Beaufort Sea	Yes	< 40 IDs	2013	August-September
Chukotka	No	NA	NA	NA
East Kamchatka	Yes	< 160 IDs	2004-2012	Primarily July-August
Okhotsk Sea, West of Kamchatka	Yes	No catalogue; Opportunistic	1990s-2000s	NA
Sakhalin	Yes	< 230 IDs	1994-present (no data in 1996)	Primarily July-October
Korea	No	NA	NA	NA
Japan: Pacific	Yes	No catalogue; < 10 IDs	1990s-2000s	NA
Japan: Sea Of Japan	Yes	No catalogue; 1 ID	2014	March-April
China	Yes	No catalogue; 1 ID	2011	November

* Some historic data to 1970s

In view of the evidence that at least some of the whales that summer off Sakhalin migrate to the eastern North Pacific in winter, the Workshop considered that a combined analysis of all available data to place bounds on the proportion of whales that move from Sakhalin to the eastern North Pacific and vice-versa would be useful. The Workshop **recommends** that such an analysis be performed, preferably before SC65b. It **requests** that curators of the different catalogues provide summary data as outlined under Item 10.4, if they have not already done so.

3.2.4 Telemetry data

ENP: MIGRATION AND FORAGING AREAS

The eastern gray whale population numbers around 21,000 whales and the population is censused from shore during its annual south-bound migration past Granite Canyon, central California (Laake *et al.,* 2012; Durban *et al.*, 2013). Mother whales (N=17) tagged by Oregon State University (Mate) in Baja California in April 2005 showed staggered departure times over a period of ~6 weeks. Additional tagging by John Durban *et al.* of whales in San Ignacio Lagoon (N=18) resulted in localized movements in Baja California and southern California. Travel speeds of adult females accompanied by calves were slower going north than single whales traveling south. Mothers with calves also travelled closer to shore than earlier (Phase A) north-bound single whales. Most tagged whales provided very few locations from British Columbia to Unimak Pass (Alaska), probably because wind-generated waves and swells compromised the antenna and saltwater switch. One whale 're-appeared' after a period of more than a week without positions. By that time it was moving northeast along the Russian coast of the Bering Sea and subsequently continued through Bering Straits. The feeding destinations of 7 tagged whales were primarily in the Chukchi Sea between Barrow (Alaska) and Wrangel Island (Alaska), with arrivals to that region starting in mid-June. One tagged whale was killed by hunters in Chukotka. Five additional whales tagged by John Ford *et al.* (2013) in British Columbia remained in coastal waters while migrating north. Six whales tagged by NMML in the Alaskan Chukchi Sea and whales tagged by M.P. Heide-Jørgensen off Chukotka showed localized foraging. Six whales tagged by researchers from Alaska Department of Fish and Game (one off Tuktoyuktuk in Canada and five off Barrow) foraged in the Beaufort Sea, while one tagged off St Lawrence Island moved to the Russian coast during a 65-day track.

The Workshop **welcomes** a report from Ilyashenko that Litovka is planning to tag gray whales off Chukotka this year in collaboration with researchers from Europe.

PCFG: S & N MIGRATIONS, WINTERING AREAS, FORAGING AREAS

Mate *et al.* tagged 35 PCFG whales (see definition under Item 2.1) feeding during late autumn in coastal waters off Oregon and northern California, where whales seem to stage before the south-bound migration. Nineteen whales left the PCFG area with staggered departure dates over a period from late November to early February. Some tagged whales had returned to California waters from Mexico before other PCFG whales arrived in Baja California. There were several such 'waves' of Baja arrivals for each of the three years of tagging.

Table 3

Summary of telemetry information (see text)

Area	Months	Age/sex class	Activity	Time in area	Travel speed	*n*
Animals tagged on eastern side (Mexico) N = 18						
Mexican lagoons	Apr-May	Mothers	suckling	0.5-1.5mo[1]	nominal	17(ENP)
Mexican offshore	May-July	Mothers	Migrate N	weeks	Moderate-fast	
32-41°N		Adults	Migrate N	Days[2]	Moderate-fast	5 (ENP)
41-52°N						
52° - Aleutians						
Kodiak	No info	No info	No info	No info	No info	
US side Bering Sea	Jun-July	Adults	Migrate & forage[3]	3-8days	Moderate-fast	
Chukchi-Beaufort	June-Nov	Adults	Forage[4]	3-4 mo[5]	Slow	Home range
Chukotka	June-Sept	Adults	Forage	0.5-2.0mo[6]	Slow-moderate	Home range
Animals tagged off Sakhalin N = 7						
Sakhalin	Aug-Dec	Adults	Forage	2-2.5mo	slow	
E. Kamchatka	Nov-Jan	Adults	Migrate E	Few days	fast	3
US Bering Sea	Dec-Jan	Adults	Migrate E	Week	fast	3
52° - Aleutians	Dec-Jan	Adults	Migrate S	Two weeks	fast	3
41-52°N	Jan-Feb	Adults	Migrate S	Week	fast	2
Mexican offshore	Jan-Feb	Adults	Migration, 'Reproduction?'	Month	Directed/ moved between	1
Mexican lagoons						
32-41°N	Mar	Adult	Migrate N	Week	fast	1
41-52°N	Mar	Adult	Migrate N	Week	fast	1
52° - Aleutians	Mar	Adult	Migrate N	Two weeks	fast	1
US Bering Sea	Apr	Adult	Migrate W	Few days	fast	1
Sakhalin	May-Oct	Adult	Forage	5 mo		
Animals tagged on eastern side (PCFG) N= 35						
41-52°N	Nov-Feb	Adults	Migrate S	2 weeks	fast	35
32-41°N						
Mexican offshore	Dec-Mar	Adults	'Reproduction'	3-10 weeks	Directed/ moved between	17
Mexican lagoons						
32-41°N	Mar-Apr	Adult	Migrate N	Week	Mod. fast	
41-52°N	Mar-Apr	Adult	Migrate N & forage[8]	Week	Mod. fast	
52° - Aleutians	Mar-Apr	Adult	Migrate N &forage	Two weeks	Mod. fast	

[1] added data from Durban; [2] added data from Ford (2013); [3] added data from 1 whale Quakenbush *et al.* (2013); [4] added data from 6 whales Quakenbush *et al.* (2013); [5] added data from NMML; [6] added data from Heide-Jørgensen *et al.* (2011); [7] transmitter stopped so may have been longer (as in previous year); [8] added data from CRC limpet tags, Ford *et al.,* 2013.

Seventeen tagged whales were tracked to the breeding and calving areas of Baja California, where most of them stayed in nearshore waters. Most of the whales began their southward migration near Pt. St. George, CA. However, in 2012 two of them travelled north to the Washington coast before migrating south. Another individual began its southerly migration from Pt. St George but reversed course near San Francisco Bay, CA, and travelled north to the northern Washington coast before again turning south and migrating to Mexico. One healthy-appearing male did not migrate south at all, instead remaining off northern California and Oregon for the duration of the winter, with two extended periods off Pt. St. George in October-February and February-May during its 382 day tracking period.

In Baja California, most whales spent extended time in the area offshore of Ojo de Liebre (ODL) lagoon and two whales passed farther south offshore of San Ignacio Lagoon en route to Magdalena Bay. Locations inside ODL lagoon accounted for 23% of all high-quality locations. No tagged whales had more than 69% of their high-quality locations within the lagoon. Eight of 17 whales did not have any high-quality locations within the lagoon.

Tagged whales arrived at the breeding grounds from late December to early March. Most of them spent an average of 21 days in reproductive areas before heading north on migration. One female and another whale of unknown sex remained in the breeding area for 2.5-3 times as long as other whales. These were likely both females that gave birth and then departed the lagoon area in late February or early March. The observed variability in arrival and departure times indicates that the entire population is never in the lagoon region at the same time. Thus, population estimates based on surveys in the breeding areas will severely underestimate the population if typical 'closed population' assumptions are made.

Twelve whales were tracked back to the 'Pacific Northwest' following their northbound migration from wintering areas off Baja California. Migratory routes were typically close to shore and followed the coastline. However, some whales in each year travelled directly across the California Bight, through the outer Channel Islands (Santa Rosa and Santa Cruz), rather than following the coastline. Most whales travelled continuously after starting their migration until they reached their destination. However, one whale stopped for 9 days near San Miguel Island in the California Channel Islands (where it was first photographed before the telemetry study) before continuing its

journey south. Ford *et al.* (2013) tagged three PCFG whales as they passed Vancouver Island migrating north. These three whales continued north exhibiting similar migratory speed and path as whales not thought to be PCFG whales until their tags stopped working in southeast Alaska.

Rather than migrating to the Bering, Chukchi and Beaufort Seas like the rest of the ENP population, tagged PCFG whales returned on their north-bound migration to traditional PCFG areas, although two went farther north to Icy Bay (60N) for variable periods before working their way farther south. Some of the emphasis in the data on foraging locations in the area of Pt. St. George reflects the large number of tag deployments there (23 out of 35 whales). Six whales recorded locations either inside (or adjacent to) the Makah Tribal U&A Fishing grounds during five months (Feb, Apr, May, Sep, Dec).

It has often been noted that the number of calves found at any one time in the three main Mexican lagoons is smaller than the total estimated calf production. The large proportion of tagged whale locations outside ODL lagoon during the breeding season suggests not only a greater amount of time spent outside the lagoon, but also that most of the population (and probably calves as well) can be outside lagoons at any point in time. In the case of eight whales, none of their good-quality locations were inside the lagoon. If some whales rarely if ever enter the lagoon, and others spend a large percentage of time outside the lagoon, it would be necessary to include offshore surveys to properly characterize the population's distribution during the breeding season. As relatively small areas, lagoons could serve to help drive genetic isolation of the PCFG whales (and possibly also Sakhalin whales) from other eastern gray whales. However, ODL is the largest of the three major lagoons and has peak populations of nearly ten times the estimated number of PCFG whales.

Gray whale calls have been recorded throughout the winter in the Beaufort Sea (Stafford *et al.* 2007), suggesting either that (a) some whales do not migrate or (b) there is considerable variation in the timing of migration into and out of the region, with the turnover ensuring that the area is never 'unused' by gray whales. Moreover, results from tagged PCFG whales provide unequivocal evidence that not all gray whales migrate to Mexico every year.

Re-sight photographs showed that tagged whales, whales that had shed their tags and untagged whales were often together in the Pt. St. George area (especially very late in the season). This mingling suggests that the movements of tagged whales represent, at least to some extent, the movements of some other, untagged whales.

WESTERN GRAY WHALES: N & S MIGRATIONS AND FORAGING AREA

Three of seven gray whales tagged at Sakhalin Island migrated to the ENP after staying at Sakhalin for several months after tagging (the tags on the others stopped transmitting prior to movement away from Sakhalin). They crossed the Bering Sea, using varying routes, timings and entry points through the Aleutian Islands into the Gulf of Alaska. Two of the whales entered the traditional coastal south bound migration route for 'traditional' ENP gray whales from late December to late January. These whales migrated at faster speeds than ENP whales. One male's transmitter was last heard along the Oregon coast in February while migrating south while a female migrated to Baja California where it spent 42 days and passed all three major calving areas before a return northbound. The latter involved a different route across the Bering Sea than the winter migration eastward and southward. The first arrival point on the Russian coast was the western? side of Kamchatka peninsula. The whale continued on to the NE coast of Sakhalin Island in mid-May, passing through what was characterized as heavy ice.

The Workshop **reiterates** the great importance of further telemetry studies, particularly off Sakhalin, Kamchatka and in the northern areas such as Chukotka and **recommends** that such work be undertaken.

3.2.5 Removals data (catch and incidental catch; strandings)

Uni (2008) analysed records of Japanese whaling along with recent sightings, bycatch and strandings data and concluded that although most gray whale catches over the past 400-500 years were in the Sea of Japan (including the Korean peninsula), recent sightings, entrapments and strandings have been mainly along the Pacific coast (although see Nambu, 2008). These data, together with the Korean whaling records (Mizue, 1951), have been interpreted as suggesting two or three 'substocks' of gray whales using different migration routes along either side of the Japanese archipelago and along the Korean Peninsula. There is also some evidence to suggest a wintering area in the Inland Sea of Japan, in addition to the presumed wintering area in southern China (around Hainan Island).

Reeves *et al.* (2008) plotted the approximate positions and dates (i.e. months) of 160 kills and sightings of gray whales by American whalers in the Sea of Okhotsk in the latter half of the 20th century. Gray whales were observed consistently in Shelikhov Bay (Zaliv Shelikhova) and Penzhinskaya Gulf (Penzhinskaya Guba) from early May to the end of August. They were also seen in Gizhiginskaya Bay (North-east Gulf) between mid-May and late August and near Magadan along the north central coast of the Sea of Okhotsk from at least early June to early July and from mid-August to mid or late September. The American whalers apparently did not visit the

coastal waters off north-eastern Sakhalin Island where gray whales now congregate to feed throughout the summer.

Brownell reported that the large catches (>1,750 gray whales) by Japanese modern whalers in the East Sea of Korea from 1890-1966, but mainly in the first third of the 20th century (Kato and Kasuya 2002), came at a time when the population of gray whales in the eastern Pacific was seriously depleted as a result of 19th century whaling. This mismatch in the timing of peak catches in the eastern and western North Pacific is consistent with the hypothesis of separate populations. The observation that not all eastern gray whales visit Mexico each year was also noted in this regard.

Whaling data from the eastern North Pacific are generally consistent with the well-known concept of a north-south coastal migration between summering grounds off Chukotka or Alaska and the Mexican wintering grounds. Some shore whaling stations in California operated seasonally in accord with the arrival of southbound migrating gray whales (relatively fat) in December or January and the departure of northbound migrants (relatively thin) from March to early May (Rice and Wolman, 1971; Reeves and Smith, 2010). At some stations, winter/early spring catches comprised mainly gray whales whereas at other seasons humpback whales were the main targets (Reeves and Smith, 2010).

3.2.6 Sightings data

NORTHERN BERING-SOUTHERN CHUKCHI SEAS (NBS/SCH), NORTHERN CHUKCHI SEA (NCH) AND CALIFORNIA (CA) REGIONS

Sue Moore summarised sightings data from aerial surveys in the northern Bering, north-eastern Chukchi and Alaskan Beaufort seas from 1982 to the present; noting a hiatus in broad-scale surveys in the region from 1992-2007 (Clarke *et al.,* 2013). Since 2008, surveys have been conducted from July-October by researchers at the National Marine Mammal Laboratory (NMML) as part of the Aerial Surveys of Arctic Marine Mammals (ASAMM) program[2]. Gray whales are distributed predominantly along the Alaska coast in the north-eastern Chukchi Sea from roughly Point Lay to Barrow, and in the south-central Chukchi Sea southeast of Point Hope (Fig. 4). Many of the whales seen are associated with mud plumes and as a result are designated 'feeding whales'.

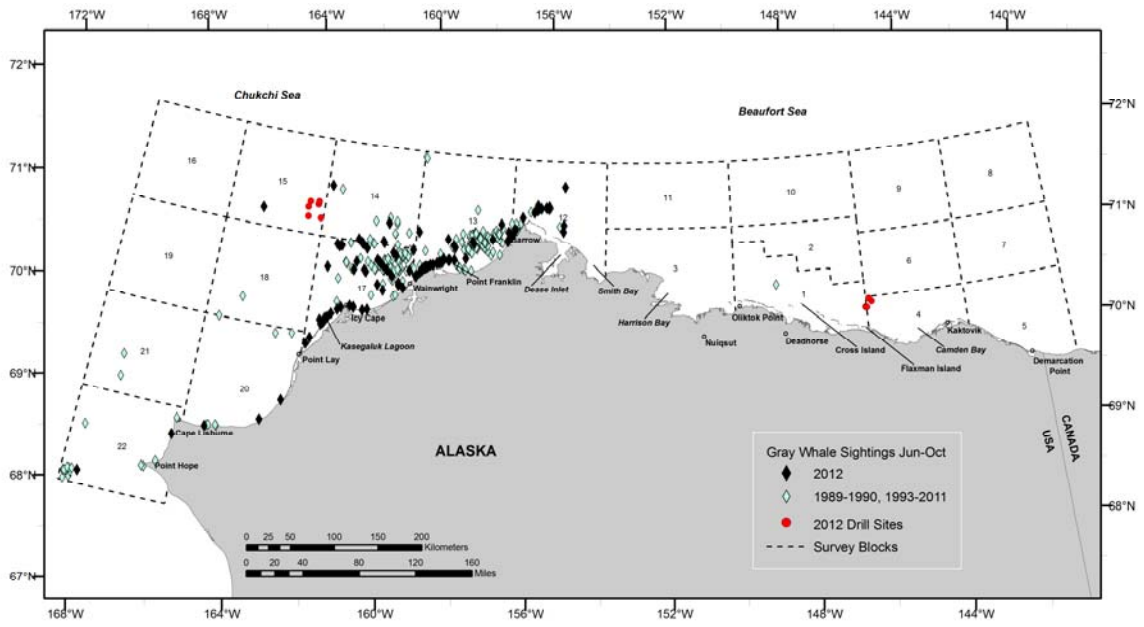

Fig. 4. Gray whale on-transect sightings in 2012, compared to years with light sea ice cover: 1989-1990, 1993-2011. Includes all on-transect sightings from primary and secondary observers. Reproduced with permission from Clarke *et al.,* 2013: fig. 24.

Recent surveys resulted in fewer observations of gray whales feeding near Hanna Shoal than was the case during the 1982-1991period. Female-calf pairs are commonly observed along the Alaska coast with no noticeable change from the 1980s through 2013. In addition to ASAMM sightings, gray whales were routinely observed during

[2] http://www.afsc.noaa.gov/nmml/cetacean/research/caepresearch.php?url=nmmlcaep1405

summer oceanographic cruises that extended into Russian waters between 2009-2013, including two sightings of eleven whales in 2009, north of Wrangel Island (Moore *et al.,* 2014). Together, these sightings confirm the broad distribution of gray whales in the Chukchi Sea, as summarised by Berzin (1984).

In discussion it was noted that with so many calves seen along the Alaska coast, there might be opportunities for photo-identification and/or biopsy sampling there. In 2013, 36 gray whale photo ID's were obtained and 5 gray whales were tagged with satellite transmitters under the NMML-led ArcWEST program[3]; unfortunately, biopsy samples were not obtained. The ArcWEST program will continue for the next 2-3 years, and there may be opportunities to include biopsy sampling in future cruise plans. The Workshop **encourages** the ArcWEST program to collect biopsy samples if at all possible.

Female-calf sightings extend into September, beyond the time when females are generally thought to have weaned their calves. Moore noted that NMML staff had analysed calf sightings specifically, with results presented at the annual Alaska Marine Science Symposium each January. Moore noted that there might be sufficient sighting data from the 1980s to calculate relative abundance indices for comparison to sighting rates from recent (and ongoing) surveys in the 2000s, although the record is not continuous for gray whales in the Chukchi Sea. The Workshop **recommends** that such an analysis is undertaken if the data are found to be sufficient.

Shore-based sighting surveys of northbound gray whale cows with calves have been conducted annually from the Piedras Blancas Light Station, located near San Simeon, CA, since 1994 (Perryman et al. 2012). Weller reported that starting in 2012, photographs for identification of northbound mother-calf pairs passing the site have been collected and images forming this catalogue will be shared with other researchers for comparison to their catalogues. The primary goal of this effort is to identify migrating mother-calf pairs for comparison with gray whales known to be part of the PCFG. Annual additions of calves to the PCFG are thought to be underestimated because some calves are weaned before being photo-identified. This photographic effort may be expanded in 2015 to include the use of a small UAS (unmanned aircraft system) for photo-identification purposes.

MEXICO

Scott noted that records are available of gray whale sightings off Mexico (1970s to present) by tuna purse seine vessel observers of the US NMFS, Inter-American Tropical Tuna Commission and the Agreement for the International Dolphin Conservation Program. Additional sightings have likely been made during research cruises in the eastern tropical Pacific by the US NMFS.

RUSSIA

There have been local reports of distribution of gray whales around some of the whaling villages (e.g. Blokhin, 1986; 1987; 1989; 1990; 1998; Bogoslovskaya *et al.*, 1982; Melnikov, 2008; Melnikov and Bobkov, 1996; Melnikov *et al.*, 1997). Ilyashenko reported that V.V. Melnikov recently observed and filmed more than 20 gray whales near the Shantar Islands in the western Okhotsk Sea. Two gray whales were observed in September 2011 in the Laptev Sea in the central Russian Arctic (Shpak *et al.,* 2013). In addition, two gray whales were documented from a tourist ship near Frans Josef Land off north-western Russia in 2011.

3.2.7 Biological data (e.g. conception date)

Rice and Wolman (1971) provided the most detailed information available on gray whale life history, derived from 316 whales sampled off central California between 1959 and 1970. The authors reported that breeding and calving are seasonal and closely synchronized with timing of the migration. Non-pregnant mature females were found to ovulate regularly in late November and early December, which coincides with the initial phase of the southbound migration. Based on estimates of foetal growth rate, sampled females were determined to have conceived between late November and early January, with a mean conception date of 5 December. Rice and Wolman (1971) found that successive ovulations can occur, separated by a period of about 40 days, indicating that whales can enter oestrus while on the wintering ground. The gestation period is approximately 13 months, with calving occurring mainly from late December to early March on the wintering grounds, although some calves are born during the southbound migration (Shelden *et al*., 2004 – cited in Moore, 2008).

There are no comparable reproductive data for gray whales in the western North Pacific. Andrews (1914) examined 23 gray whales taken during the southbound migration off Ulsan, Korea, and summarised observations made by the whalers working there. Adult females taken off Ulsan in December and January were carrying near-term foetuses, and one of the whales Andrews examined was a foetus measuring 4.76m. Rice and Wolman (1971) reported an average near-term foetus size of 4.62m from the eastern gray whales sampled off central California.

The coincidence in observed foetus size, season, and latitude between Korea and central California (mothers were moving past Korea and central California at the same time of year carrying same-sized fetuses) provides support

[3] http://www.afsc.noaa.gov/nmml/cetacean/researc/caepresearch.php?url=nmmlcaep1407

for the hypothesis that at least historically there were separate populations in the eastern and western North Pacific (Weller *et al.*, 2002).

The Workshop reviewed biological parameter data more fully under Item 6. It was noted that in the past, data on conception dates had proved useful in formulating stock structure hypotheses (e.g. WNP common minke whales). However, the Workshop **agrees** that there are insufficient such data for gray whales to be used in a stock structure context.

3.2.8 Ecology and behaviour

Sue Moore provided a brief summary of information related to gray whale feeding ecology in the northern Bering and southern Chukchi seas (NBS/SCh). A decline in sighting rate of feeding gray whales between the 1980s and 2002 in the NBS (Chirikov Basin) was demonstrated to coincide with a decline in amphipod-prey biomass there over that period (Moore *et al.* 2003). Gray whales are commonly seen feeding in the SCh and five whales tagged there during the 2013 ArcWEST program co-occurred with areas of high benthic-prey biomass. Additional lines of evidence that gray whales alter their behavioral ecology in response to variability in biophysical forcing (e.g. Pacific Decadal Oscillation, sea ice cover) are reviewed in Moore (2008).

There is some evidence that gray whale feeding ecology may vary considerably amongst region; e.g. the PCFG whales feed primarily on a different and larger variety of species that those in more northern seas (Darling *et al.*, 1998).

3.2.9 Other

Scordino suggested that future consideration be given to examining stable isotopes from bone artefacts. Stable isotope analysis could contribute to evaluations of stock structure and movements. Alter *et al.* (2012) evaluated the stable isotopes of bones found in Makah and Quilleute tribal middens from whales hunted 500 to 1,500 years before present compared to the isotopes from migrating whales hunted in the 1970s off California. Those authors assumed that the whales hunted in California during the migratory season represent whales that feed in the Bering, Chukchi and Beaufort seas. They found significant differences in Carbon-13 which suggests that the whales historically hunted by the Makah and Quilleute tribes fed further south than the whales hunted off California, although it was acknowledged that other factors could have caused the observed differences in Carbon-13 values.

Ilyashenko reported that Chukotka whalers (and scientists) have reported seeing more and more dark-skinned gray whales with no or few white marks from skin parasites, which they interpret to mean that these animals do not migrate far south but stay in cold water year-round. The numbers of such animals are not large but are increasing.

Finally, a recent paper by Tsai *et al.* (2014) reported on two specimens of fossil juvenile gray whale from the sea bottom between Taiwan and the Penghu Islands. These fossil specimens are Quaternary in age and of potential value to further assessments of gray whales in the western North Pacific.

3.3 Discussion of possible population structure hypotheses

As noted under Item 3.1, seven possible stock structure hypotheses were put forward at SC/65a (IWC, 2014). The original seven hypotheses focused primarily on evaluating stock structure relative to the whales feeding off Sakhalin, and thus additional variants needed to be added to address stock structure across the entire North Pacific. A small working group was formed to identify additional hypotheses that should be included, and the schematic for each hypothesis was drawn (or re-drawn in the case of the original seven) to incorporate a number of spatial regions[4] (see Annex F) that were identified as areas where data were available that might be valuable in constructing and/or informing the hypotheses. The hypotheses identified at SC/65a retained their original numbering, and additional hypotheses were added as variants of the original seven hypotheses.

A number of key issues were identified during the initial discussion of hypothesis construction and these are considered below.

(1) Should each Mexican lagoon and the region offshore of Baja California be modelled as separate breeding sub-stocks?

Alter *et al.* (2009) compared mtDNA haplotype and microsatellite allele frequencies (n=9 loci) between the three major calving lagoons. Significant nuclear differences were found between Laguna San Ignacio and Bahia Magdalena, while the results of the remaining comparisons were not significant. While this finding provides an indication that structure among lagoons could exist, the evidence is equivocal given that most of the comparisons were not significant. Urbán noted that his group has collected approximately 450 samples from all three lagoons

[4] The North Central Pacific was originally included as a region to allow for visualisation of an area on the western migratory route used primarily by Sakhalin whales before they reached the 'common' eastern part of the migratory route along the North American coast (and where they may mate). This region is not included in Annex F as it will not be modelled; trials are informed only by demographic data (e.g. only the demographic data are compared to the model output to determine plausibility).

over the past three seasons, and they are in the process of generating data on mtDNA control region haplotypes for 300 of these samples. The results are expected to be available by the end of the year. As noted earlier, there is evidence from photo-identification and telemetry of animals moving among lagoons and the offshore area within a season.

The Workshop **agrees** that at present, the Mexican wintering grounds will be treated as a single breeding area. However, the possibility that structure between lagoons exists will be reconsidered if needed based on the results of the Urbán study, which incorporates a much larger set of samples than previous studies. No schematic depicting this possibility was constructed.

(2) Should a hypothesis be included that considers the PCFG and feeding regions in the Gulf of Alaska, Bering and Chukchi Seas to represent a single feeding sub-stock?
While not completely ruling out the possibility of a single feeding stock, the Workshop **agrees** to follow the example of the AWMP trials and to include the PCFG as a separate feeding sub-stock. From a management perspective this is the most conservative in that it is more challenging from a conservation standpoint wit respect to future hunting. Thus, although it may be plausible that the PCFG is part of the larger sub-stock that includes feeding areas north of the Aleutians, there is little value at this stage in running additional, less conservative variants. For this reason, no schematic depicting this possibility was constructed.

(3) Should a hypothesis that considers the PCFG to represent a breeding sub-stock be considered?
The results of previous analyses have not found significant nuclear differences when comparing samples collected from PCFG whales with samples collected on the feeding area(s) north of the Aleutians (Lang *et al*., 2014) or with samples collected from whales in the Mexican lagoons (D'Intino *et al*., 2012). These findings are consistent with interbreeding between PCFG whales and those from other feeding areas. However, as the Committee has noted many times in the past, the failure to detect significant differences does not necessarily mean that no differences exist.

There have been some observations of PCFG whales aggregating off northern California during late November to mid-December, which Rice and Wolman (1971) identified as the first breeding period. In principle, this could provide some limited support for a hypothesis that the PCFG may represent a separate breeding sub-stock. However, the Workshop **agrees** that this hypothesis should not be included at this time, recognising that in effect the existing hypothesis of PCFG as a separate feeding stock is sufficient. Analysis of relatedness patterns of PCFG whales by Lang and colleagues is underway, and the inclusion of this hypothesis will be reconsidered in the future if warranted by the results of this work. No schematic depicting this possibility was constructed.

(4) Should a hypothesis be included that considers the whales feeding in the northern Bering-southern Chukchi Seas to be a separate feeding sub-stock from those feeding in the northern Chukchi Sea?
Given that matrilineal fidelity of gray whales to feeding grounds on parts of their range is believed to occur (e.g., off Sakhalin and in the PCFG), it is possible that gray whales exhibit this behaviour throughout their range. However, little is known about whether this behaviour occurs in feeding areas north of the Aleutians. Six whales tagged in 2005 on the Mexican wintering grounds retained their tags through all or part of the subsequent feeding season in the Bering and Chukchi Seas. While some of these whales made wide-ranging movements (e.g., between Barrow and Wrangel Island, and between Barrow and the southern Chukchi Sea), others remained in smaller areas, particularly during the latter part (September and October) of the feeding season (Mate, 2006). Nine gray whales tagged off Chukotka and tracked for variable amounts of time between September and November remained in the western Bering Strait, largely staying within 5km of the Chukotka coast (Heide-Jorgensen *et al.*, 2012). Thus both wide-ranging and more localized movements have been documented in this area. Moore further noted that there are ecological differences between the two regions included in the existing models (NBS/SCH and NCH), which might result in the development of sub-structuring between these regions.

Given the limited data available, the Workshop **agrees** that while it is certainly possible that some sub-structure within the feeding area north of the Aleutians could exist, this hypothesis should not be evaluated as a priority at this time. However, that the Workshop also **recommends** that additional studies (photo-identification, genetics, tagging) should be conducted in these regions, as has been previously recommended by the Scientific Committee. In making this recommendation, the Workshop **recognises** the practical difficulties of working in these areas and also **recognises** the ongoing efforts off Chukotka referred to earlier in the report.

(5) Should the possibility that a Sakhalin whale might be killed in the Chukotka harvest be incorporated in the model(s)?
There is only limited information on this topic, but none of the three whales that were tagged off Sakhalin and migrated into the eastern North Pacific travelled through the area where the Chukotka harvest is conducted. It was also noted that the evidence from the Sakhalin feeding area is that abundance is increasing in the face of the >100 whales that are taken in that harvest each year. Given this the Workshop **agrees** that such a scenario does not

warrant inclusion as a full hypothesis. However, there is some merit in including some options in the context of a sensitivity test.

(6) Should multiple migratory pathways in the western North Pacific be incorporated into the model(s)?
Park (2001) suggested that up to three migratory routes (east coast of the Korean Peninsula, the Pacific coast of Japan, and the east coast of the Sea of Japan) were used by western North Pacific (WNP) gray whales in the past. However, no recent sightings of gray whales off the Korean Peninsula exist, despite shore-based and vessel-based sighting surveys conducted between 2003 and 2011 (Kim *et al.,* 2013). There are 14 records of gray whales from Japan since 1990; the majority of these (n=12) are from the Pacific coast of Japan (Weller and Brownell, 2012; Kato *et al.,* 2013). However, only limited genetic (Kanda *et al.,* 2010) and photo-identification (Weller *et al.,* 2008) data are available from these areas, and it is currently not possible to evaluate whether the use of multiple migratory routes led to sub-structuring of the Asian breeding stock in the past. This hypothesis is depicted and described in the schematic 5b (see Annex E). However, given the lack of available data from the Asian migratory routes, the Workshop **agrees** that this hypothesis should be given low priority.

3.4 Recommendations for hypotheses for inclusion in the modelling framework
The Workshop examined the hypotheses described in Annex F. It **agrees** that Hypotheses 1 and 2 (from SC65a) were not consistent with available data and should no longer be considered. It also **agrees** that hypotheses for which little or no data (other than catch records) are available to assess plausibility should be considered to be of low priority for inclusion in the modeling framework (Hypotheses 3b, 3d, 5b, 6a, 6c). Finally, it **agrees** that low priority should be assigned to hypotheses that would be represented in the modelling framework in the same way as other hypotheses (Hypotheses 4a, 4b, 6b, and 6c; see hypothesis 7 for details).

Following this evaluation, the Workshop **recommends** that the following three hypotheses be considered a high priority for inclusion in the initial modeling framework.

Hypothesis 3a
Two breeding stocks (Asia and Mexico) may exist, although the Asian stock may have been extirpated. Whales show matrilineal fidelity to feeding grounds, and the Mexico stock includes three feeding sub-stocks: PCFG, NBS/SCH-NCH-G of AK [hereafter, Northern], and Sakhalin.

Hypothesis 3e
Identical to hypothesis 3a except that the Asian breeding stock is extant and feeds off both coasts of Japan, Korea, and in the northern Okhotsk Sea west of the Kamchatka Peninsula. All whales off Sakhalin overwinter in the eastern North Pacific.

Hypothesis 5a
Identical to hypothesis 3a, except that the whales that feed off Sakhalin include both whales that are part of the Asian stock and remain in the WNP year-round, and whales that are part of the Mexican stock and migrate to the eastern North Pacific (ENP).

Hypothesis 3c should be included as a sensitivity test. This hypothesis incorporates the possibility that a Sakhalin whale may occasionally move through the NBS-SCHK region and thus will have a chance of being taken in the Chukotka harvest.

3.5 Recommendations for future data collection and/or analyses
The practicality and utility of the recommendations presented in SC/A14/NPGW01 were evaluated. One recommendation was to develop Single Nucleotide Polymorphisms (SNP) assays for use with gray whales. These assays would allow integration of genetic data between labs as well as over time, increasing the utility of such data for future analyses. In addition, this approach could be utilized with low-quality samples, such as bone and baleen, which could facilitate analysis of any historic samples identified. The Workshop **recommends** that a SNP panel be developed for use with gray whales and considers this task a high priority for future work. It was noted that while development of SNP assays would be valuable, some analyses, such as evaluating relatedness among sampled animals, would necessitate the identification of several hundred loci. Until such a SNP panel is developed, nuclear analyses of relatedness would likely require that SNP and microsatellite data be combined. Conducting a gray whale genome project, which was one of the recommendations of SC/A14/NPGW01, would allow SNP loci to be identified and would generate data that could be useful in addressing a wide range of questions. However, the cost and utility of such an approach is greater than that required by other methods used to identify SNPs (e.g., Next Generation Sequencing), and thus this approach is considered a lower priority in terms of evaluating stock structure.

Another high priority for future genetic studies of stock structure is to increase the sample numbers and sample coverage for the eastern North Pacific stock of gray whales. While a high proportion of the whales using the Sakhalin feeding ground have been sampled, the proportion of the eastern North Pacific stock that has been

sampled is low. In addition, few or no samples have been collected from some parts of the range of eastern North Pacific stock. The Workshop **recommends** additional sampling and photo-identification efforts be conducted in key areas, such as the northern Chukchi, with the goal of evaluating whether additional structure exists on feeding areas used by the ENP stock.

Genetic analyses of samples derived from the bones or baleen of pre-depletion western North Pacific gray whales was also recommended in SC/A14/NPGW01. Few known sources of such specimens have been identified, and finding additional samples would be difficult. It is unlikely that significant progress could be made in the near future. However, a smaller-scale project aimed at reviewing museum collections, archeological literature, and records of whaling station locations would be valuable in evaluating whether such samples exist. For such a project to be successful, it would be beneficial to identify scientists, ideally in countries bordering the range of gray whales in the western North Pacific, to conduct such work. This work should be considered a medium priority task for the future.

The Workshop noted the important contribution of the telemetry information provided and **recommends** further work in all areas, especially off Chukotka, Sakhalin and Kamchatka.

The Workshop **recommends** that existing acoustic data be analyzed for the presence of gray whale calls. Such an analysis would provide valuable information on gray whale distribution as well as on the presence of gray whales north of the Aleutians during winter months, and this work should be considered a medium priority task for the future.

4. REMOVAL DATA (TAKING INTO ACCOUNT DISCUSSIONS UNDER ITEM 2)

4.1 Commercial catches [post 1850]

4.1.1 Western North Pacific

Before the beginning of modern commercial whaling in this region, there was a long but poorly documented history of gray whale exploitation by hand harpoon and netting. In Japan, gray whales were probably hunted by hand harpoon from the late 16th century and they were definitely taken by net whaling beginning in the late 17th century (Omura, 1984). Net whalers took 50-60 gray whales annually from 1675-1890 (Omura, 1984) and between1891-1899 they took at least 44 in Korea (16, 15 and 13 in 1890/91, 1891/92 and 1898/99 respectively; Park, 1987; Kato and Kasuya, 2002) and at least 29 in Japan (Omura, 1984). Japanese net whaling ended around 1900, at approximately the same time that modern whaling companies were being formed.

From the 1840s to mid-1880s, American sailing vessel whalers searched the Okhotsk Sea for bowhead whales and hunted gray whales as secondary targets, taking at least a few hundred in total in that region over an approximately 40-year period (Henderson, 1984; Reeves *et al.,* 2008).

A Russian company based in Haydamak (180km east of Vladivostok) initiated modern whaling in Asian waters. This company operated off the Korean Peninsula in some winters from 1890 until 1904 (Tønnessen, 1973; Kato and Kasuya, 2002). Gray whales that were killed in this operation were transported to Japan. Yablokov and Bogoslovskaya (1984) reported that gray whales were hunted sporadically by Russians near Peter the Great Bay, Russia, during World War II (WWII) but those authors provided no numbers or details on this operation.

The first catch numbers for gray whales by modern commercial whaling listed for Japan by Kato and Kasuya (2002) was of 23+ whales in 1900. However, catching must have started at least a few years earlier - Kato and Kasuya indicate '?' in their Japan catch column for 1898 and see Omura, 1984). Andrews (1914) reported

> Captain Melson was the first whaleman to learn to take 'Devilfish' in Korean waters and it was he who laid the foundation for the winter fishery which has been so successfully prosecuted there by the Japanese for the last fifteen years.

Brownell reported that Andrews visited the Toyo Hogei Ulsan whaling station in January-February 1912, so 15 years earlier would be 1897.

Japanese whaling operations in Korean waters started in 1898 but were limited. In 1909, Toyo Hogei opened a land station at Ulsan that operated for a number of years after Japan annexed Korea in 1910.

Modern whaling operations started in Japan in 1898, but only a few gray whales were taken there after the turn of the century (Kasahara, 1950; Omura, 1984). From at least 1909 onwards, several land stations on the central-eastern and south-eastern coasts of Korea were operated by Japan until 1945 at the end of WWII (Kasahara, 1950; Kato and Kasuya, 2002).

Kasahara (1950) reported that smaller catches were made in western Korea (Yellow Sea) and catches totalling at least 244 from 1911 to 1927 were made in north-eastern Korea (Broughton Bay, 40°N). The catch record is particularly poor and incomplete for the period 1898-1910, which is unfortunate since the available catch record

suggests that substantial numbers of gray whales were taken during those years. For example, at least 125 gray whales were taken in 1907 and 193 in 1912, which could mean that significant numbers were also taken in the years before 1907 and from 1907-1911. By the 1930s, total annual catches of western gray whales had declined to fewer than 50 (Kato and Kasuya, 2002).

The only known 'sizeable' catches of gray whales after WWII were by Korean whalers off southeastern Korea (Brownell and Chu, 1977). According to Brownell, post-WWII Records of bycatch and direct catches in Japanese waters probably total fewer than 20.

Twentieth century catch data compiled primarily by Bradford and Brownell from published sources are summarised in Table 4. The full Table is given as Annex F.



Fig. 5. Land stations (closed circles) used by modern whaling fleets in Korean waters (taken from Kato and Kasuya, 2002).

Table 4

Twentieth century catches for the western North Pacific by year based upon published sources. For details see Annex F.

Year	China	China?	Japan	Korea	Korea?	Russia	Unknown	Total
1900			2	23				25
1902				9			5	14
1906				59			11	70
1907				125				125
1908				26				26
1909				83	1			84
1910			1	37				38
1911			2	119				121
1912				25			193	218
1913							131	131
1914			19	139				158
1915			9				130	139
1916			1	77				78
1917				66	2			68
1918				101	2		1	104
1919				46				46
1920			10	65				75
1921			2	76				78
1922				38	2			40
1923				27				27
1924				14			4	18
1925				10				10
1926				10		1		11
1927				9			1	10
1928				9				9
1929				11			1	12
1930				30				30
1931				10				10
1932				7				7
1933				1				1
1942				1		1		2
1943				1				1
1945				5				5
1948				9				9
1949		1		4				5
1951				7				7
1952				1				1
1953	4			7				11
1958	1			7				8
1959			1	7				8

1960		1		8				9
1961				3				3
1963				2				2
1964				3				3
1965				4				4
1966				5				5
1968			1					1
1996			1					1
Total	**5**	**2**	**49**	**1326**	**7**	**2**	**477**	**1868**

Although it is known that modern whaling for gray whales in the western North Pacific started in the 1890s and that some catches of gray whales were made in Korean waters, catch data are extremely sparse for years prior to 1904. Because of the likelihood (explained above) that substantial catches were made in at least some years between 1890 and 1910, the Workshop **recommends** that an investigation or investigations be carried out to obtain information on whaling effort (e.g. numbers of vessels, captains, stations) and other aspects (e.g. suspension of effort due to the Sino-Japanese War), by year, that could be used to estimate catches for these years by inference, interpolation or extrapolation using the known catches in 1907 and 1913 as a starting point (see Reeves and Smith, 2010). Such a study will require participation by researchers with appropriate language abilities – i.e. at least Japanese, Russian and Norwegian.

4.1.2 Eastern North Pacific

An agreed catch series for commercial catches and special permit catches of eastern North Pacific gray whales 1846-2009 is available from the IWC SC meeting in 2010 (IWC, 2011; JCRM 12, Suppl., p 145 and Appendix 3).

Ilyashenko reported that he had learned from a Russian fishery agency official in the Russia embassy in North Korea that the whaling catcher boat (as pictured on a postage stamp from 19xx – *fide* RLB) is no longer in operation. Only dolphins are hunted nowadays in North Korea and this hunting is done from military vessels.

4.1.3 Future

The Workshop **agrees** that modelling exercises will assume no commercial catches in the future.

4.2 Aboriginal subsistence catches

4.2.1 Past

WESTERN PACIFIC

There is little information on aboriginal subsistence whaling for western gray whales. Maritime Koryak people along the north-eastern Okhotsk Sea hunted whales, presumably including both bowhead and gray whales (Krupnik, 1984).

EASTERN PACIFIC

The aforementioned catch series agreed in 2010 for the eastern North Pacific (JCRM 12, Suppl., p 145 and Appendix 3) includes aboriginal catches, very crudely estimated from an unpublished compilation of literature by Mitchell and Reeves (in 1990) for 1600 to around the 1940s, and estimated with somewhat more precision thereafter through 2009 from a variety of sources. Reported catches since 2009 will need to be added to update that series.

4.2.2 Future

The current block quota for aboriginal subsistence whaling of gray whales is 744 for 2013-2018 (no more than 140 in any one year). No hunting of gray whales in Alaska is currently permitted and none is planned or foreseen. No hunting by the Makah in Washington State is currently permitted but the Tribe is continuing its efforts to obtain a quota for four removals per year. The Workshop **agrees** that modelling exercises should consider the range of catches used in the AWMP trials (IWC, 2011). Assumptions on allocations of removals will need to be made for the various stock structure hypotheses.

4.2 Incidental catches in fishing gear

4.2.1 Past

Like other cetaceans, gray whales are susceptible to entanglement or entrapment in various types of fishing gear. Several gray whales are known to have died in fishing gear (mainly set nets) in Japan – 1 in 1955, 1 in 1970, and 4 from 2005-2007 (Weller *et al.* 2008). Another died in 1996 from being harpooned and entangled in harpoon lines used to catch Dall's porpoises off Japan.

Based on a collection of digital and film images of gray whales off Sakhalin, Bradford *et al.* (2009) estimated that 20.0% (30 of 150) of whales identified from 1995-2004 had detectable anthropogenic scarring, with 18.7% (n = 28) determined to have been previously entangled in fishing gear at least once. However, Brownell noted that this rate is underestimated as photographs were not available for all areas of each whale.

In the eastern North Pacific, at least tens of gray whale deaths have been documented in gillnets (e.g. for salmon and herring), seine nets, net pens, longlines and pot or trap lines since the 1970s (Heyning and Lewis, 1990; Baird *et al.* 2002; Scordino and Mate, 2011). Carretta noted that about three fishery-related deaths or serious injuries to gray whales are reported in US waters each year. Most documentation is from opportunistic reports rather than systematic fishery observer programs. From 1990-2013 some 18,000 fishing sets were observed in the California offshore drift gillnet fishery (about 15% observer coverage) and inshore set gillnet fishery (5-10% coverage but not observed every year) but only four entanglements of gray whales were documented.

Carretta acknowledged that observed and reported bycatch represents only a fraction of the likely actual bycatch. Punt and Wade (2012), for example, estimated that only 3.9-13% of gray whales that die in a given year end up stranding and being reported. Carretta drew attention to SWFSC data suggesting that only about a quarter of the carcasses of common bottlenose dolphins that die in California each year are recovered, this despite the fact that these dolphins spend about 95% of their time in nearshore waters within 500m of land.

4.2.2 Future

As part of the AWMP *Implementation Review* for eastern gray whales, existing data were reviewed and scenarios of future removals determined (IWC, 2013). The Workshop **agrees** that this approach should be updated (see Item 4.5) for the whole North Pacific. Assumptions on allocations of removals will need to be made for the various stock structure hypotheses.

4.3 Ship strikes

4.3.1 Past

No records are available of ship strike mortality of gray whales in the western North Pacific. However, a small percentage of the whales photo-identified off Sakhalin (n = 3, or 2.0%) showed evidence of having survived at least one vessel strike (Bradford *et al.* 2009).

Laist *et al.* (2001) reported that of the various large whale species reported struck by ships, gray whales were one of the most frequently hit. Carretta reported that in addition to fishery-related deaths and serious injuries, approximately two gray whale deaths and/or serious injuries are attributed to ship strikes each year in US waters. These data reflect the most recent 5-year time period reported in US marine mammal stock assessment reports[5].

4.3.2 Future

As part of the AWMP *Implementation Review* for eastern gray whales, existing data were reviewed and scenarios of future removals determined (IWC, 2013). The Workshop **agrees** that this approach should be updated (see Item 4.5) for the whole North Pacific. Assumptions on allocations of removals will need to be made for the various stock structure hypotheses.

4.5 Recommended time series for use in modelling framework

The Workshop **agrees** that the determination of time series of removals cannot be completed until the work outlined under Item 4 has been reported. For initial runs, this should be agreed at SC65b.

5. ABUNDANCE AND TRENDS

5.1 Review of available data and analyses

5.1.1 Western North Pacific

5.1.1.1 INDIVIDUAL IDENTIFICATION (PHOTO AND GENETIC)

The Russia-US team has been collecting gray whale photo-id data near Piltun lagoon from 1994 to the present. Since 2008, the project has been run solely by the Kamchatka Branch of the Pacific Institute of Geography (Burdin *et al.*, 2013). The IBM team (Institute of Marine Biology, Vladivostok) has been collecting photo-id data off Sakhalin since 2002 as part of the Sakhalin Energy/Exxon Neftegas Limited (ENL) Joint Programme (Tyurneva *et al.*, 2013). Gray whale photo-id data have also been collected off south-eastern Kamchatka since 2006 (Tyurneva *et al.*, 2013).

The last time the catalogues were compared (using data through 2011), there was a total of 223 distinct whales in the Sakhalin catalogues, of which 187 were common to both catalogues (IUCN, 2013). Of the 150 distinct whales in the Kamchatka catalogue, 86 were found in at least one of the Sakhalin catalogues.

As of the 2013 season, the Russia-US Sakhalin catalogue contained 225 whales, which is probably more than the total number of whales currently alive in the Sakhalin population. Of these whales, 155 have been sexed genetically from biopsies.

[5] http://www.nmfs.noaa.gov/pr/sars/species.htm

An assessment using the Russia-US data through 2011 was presented in SC/65a/BRG27. Cooke's model had been updated to allow:

(i) individual heterogeneity in sampling probability;
(ii) time lags in the effects of environmental variability on population parameters;
(iii) immigration of 'foreign' whales (i.e. whales whose mothers were not in the Sakhalin population).

The standard AIC criterion for goodness of fit of the model to the data was used to determine which of those new factors were to be included in the final model choice. As in previous assessments, the sampling probability was found to be significantly stage-dependent: highest for mothers with calves and lowest for non-calf immature animals. Allowing, additionally, for individual heterogeneity in sampling probability resulted in a very substantial improvement in the fit of the model to the data, but it had only a small effect on estimates of population size and demographic parameters. Significant inter-annual fluctuations were found in both calving rates and calf survival rates, but no evidence was found of any net trend in these parameters over time. The best fit to the data was obtained by introducing a 2-year time lag into the correlation between calving rates and calf survival rates, i.e. a low (high) calf survival rate from year t to year t+1 tends to be associated with a low (high) calving rate in year t+2. There was little evidence for immigration: the level of immigration was estimated to be zero or negligible in recent years, but immigration earlier in the period could not be excluded.

As reported by IUCN (2013), the selected model was also fitted to: (a) the Russia-US data set, (b) the combined Russia-US and IBM Sakhalin data set and (c) all three data sets combined (Russia-US, IBM and Kamchatka, but only including whales seen at least once off Sakhalin). Estimates of key population parameters for each of the three data sets are listed in Table 5. The estimates of population size over time are shown in Fig. 6 for (i) the population aged 1+ (i.e. all animals except calves) and (ii) mature females only.

Table 5 – to come from Cooke

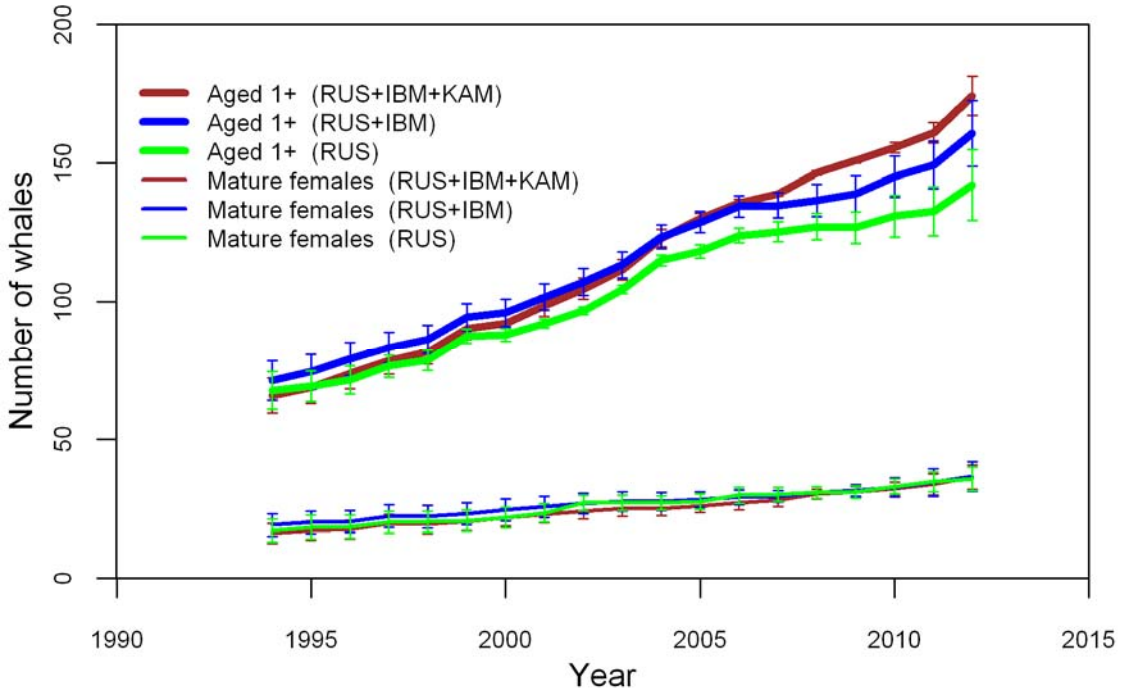

Fig. 6. Estimated population trends for the Sakhalin gray whale population for (i) aged 1+ animals (all animals except calves) and (ii) mature females only, for three data sets: (a) Russia-US(RUS) only; (b) RUS and IBM; (c) RUS, IBM and Kamchatka.

Combining the three data sets without considering potential differences between them may not be a valid approach. In particular, it is noted that relatively few subadult animals are included in the Sakhalin catalogues, and there is an indication that these may be better represented in the Kamchatka catalogue. Work is in progress to extend the model to allow for differences between data sets and locations, and to allow explicitly for the fact that

whales were selected on the basis of having been seen at least once off Sakhalin. In the meantime, the estimates of population growth rate (3.4% ± 0.5%) and other demographic parameters obtained from fitting only to the Russia-US data set should be considered the best currently available for the Sakhalin feeding aggregation.

5.1.1.2 SIGHTINGS

The sightings work off Sakhalin Island undertaken as part of the Sakhalin Energy/ENL joint programme (e.g. see summaries in IUCN WGWAP reports) is not designed to estimate abundance but provides information on density and distribution for a portion of each summer season and can be used to examine changes in these by year.

5.1.1.3 PREVIOUS ANALYSES, MODELS AND ASSUMPTIONS (INCLUDING HISTORICAL CATCH SERIES)

An initial effort to model the population dynamics of gray whales in the WNP including historical catch was made by Bradford (2003). Mark-recapture survival estimates, in combination with other life history parameters, were used to calculate a current (1997-2002) population growth rate of gray whales feeding off Sakhalin Island, Russia, which were assumed to represent the western population of gray whales. This growth rate estimate and historical catch data were applied to a 20th century back calculation of the western gray whale population. Bayesian statistics were used to estimate model parameters and indices of population status. A mark-recapture estimate of current (2002) abundance off Sakhalin was treated as a model input to project the population using the backwards method described by Butterworth and Punt (1995). Back calculation results indicated that the western gray whale population should currently be growing at its maximum net recruitment rate, has an undefined carrying capacity, is currently at most between 8-9% of its original size, and has been highly depleted for over half of the 20th century. This assessment can be considered invalidated given the connection between at least some Sakhalin whales and the ENP.

5.1.3 Eastern North Pacific

5.1.3.1 INDIVIDUAL IDENTIFICATION (PHOTO AND GENETIC)

Individual photo-identification data have been collected from the Mexican lagoons and all the way to northern Alaska near Barrow, but mark-recapture abundance estimates have been produced only for the PCFG, defined spatially from 41°-52°N and temporally from 1 June – 30 November. The data, estimation methods and results are described in SC/A14/NPGW03. A collaborative survey effort was conducted from 1998-2012 that covered survey regions between 41°N-52°N (Northern California (NCA) to Northern British Columbia (NBC)). Additional data collected in 1996-1997 with less extensive effort was included to improve the earlier estimates in the time series. The current estimated abundance for 2012 excluding transient whales is 209 (SE=15.4). The annual survival estimate of adults was 0.963 (SE=0.0079) using whales first seen prior to 1999. For whales first seen after 1999, the post first-year survival estimate of adults was 0.905 – a relatively low value which reflects both mortality and permanent emigration from the PCFG by whales that initially entered this population in 1999 or later at the time of or after the 1999-2000 stranding event[6]. Calf survival estimates are first-year survival estimates which can include permanent emigration of calves associated with mothers that were transient and calf mortality within the photo-id season. The calf survival estimates ranged from 0.35 to 0.9 for calves with minimum tenure of 1 to 125 days. The average was 0.54 (SE=0.047).

5.1.3.2 SIGHTINGS

Counts of southbound migrating whales off California at Granite Canyon form the basis of abundance estimation for the eastern North Pacific stock of gray whales. Previous assessments (1967-2007) have estimated detection probability (*p*) from the detection/non-detection of pods by two independent observers (Laake *et al*., 2012). However, tracking distinct pods in the field can be difficult for single observers, resulting in biased estimates of pod sizes that needed correcting, and matching observations of the same pod by both observers involved key assumptions. Due to these limitations, a new observation approach has been adopted wherein a paired team of observers work together and use a computerized mapping application to track and enumerate distinct pods and tally the number of whales passing during watch periods (Durban *et al.,* 2013). This approach has produced consistent counts over four recently monitored migrations (2006/7, 2007/8, 2009/10 and 2010/11), with an apparent increase in p compared to the previous method. To evaluate p and estimate abundance in these four years, counts from two independent stations of paired observers operating simultaneously were compared using a hierarchical Bayesian 'N-mixture' model to estimate p and abundance without the challenge of matching pods between stations. The overall average detectability po= 0.80 (95% Highest Posterior Density Intervals [HPDI] =0.75-0.85) varied with observation conditions, observer effects and changes in whale abundance during the migration. Abundance changes were described using Bayesian model selection between a parametric model for a normally distributed common migration trend and a semi-parametric model that estimated the time trends independently for each year; the resultant migration curve was a weighted compromise between models, allowing for key departures from the common trend. The summed estimates of migration abundance ranged from 17,820

[6] Darling commented that he was undertaking some analysis to examine the interpretation of the 1999-200 data.

(95% HPDI = 16,150-19,920) in 2007/8 to 21,210 (95% HPDI = 19,420-23,230) in 2009/10, consistent with previous estimates and indicative of a stable population.

5.1.3.3 PREVIOUS ANALYSES, MODELS AND ASSUMPTIONS (INCLUDING HISTORICAL CATCH SERIES)

Population models including historical catch have been constructed for the ENP as a single stock by Punt and Wade (2010) and for the PCFG as a plausible stock by Punt and Moore (2013). Punt and Wade (2010) constructed an age- and sex-structured population dynamics model which was fitted using Bayesian methods to data on the catches and abundance estimates for the ENP stock. They concluded that this stock was at its optimum sustainable population (OSP) level with probability 0.884. Punt and Moore (2013) constructed a deterministic, age- and sex-structured model that consisted of two groups (the 'north' group and the PCFG), which were assumed to be separate for purposes of the analysis, but with possible immigration (permanent movement) between them. With variants of the model, the probability that the PCFG was at OSP ranged from 0.35 on the low end (models F and G) to 0.88 on the high end. They concluded that additional data were needed to obtain better empirical estimates of bycatch mortality and net annual immigration rates, and to reduce uncertainty in Maximum Sustainable Yield Rate (MSYR) and Maximum Net Productivity Level (MNPL) that would potentially improve inferences about the likelihood of the PCFG being at OSP.

5.1.4 Consideration of integrated approach taking into account discussions under Item 2

The Workshop **agrees** that initially, a simple modelling approach will be used that will take into account the above information on abundance and trends (see Item 8). The Workshop also **recommends** that the existing ASAMM data should be analysed to examine trends in relative abundance over the longest period possible to assist in the modelling exercise.

6. POPULATION PARAMETERS

6.1 Review of available data and analyses

A number of biological parameters have been estimated for North Pacific gray whales or could be estimated from currently available data. These estimates are both model-derived and empirical and are summarised in Table 6. Abundance estimates from data collected off California have been used a number of times to model eastern gray whale population dynamics (Cooke, 1986; Lankester and Beddington, 1986; Punt and Butterworth, 2002; Reilly, 1981; Wade, 2002). The model-derived parameter estimates presented in Table 6 reflect the recent modelling effort by Punt and Wade (2012).

6.2 Consideration of integrated approach taking into account discussions under Item 2

The Workshop **agrees** that for the initial modelling purposes, the same values as used in the AWMP trials will be used for the eastern side of the North Pacific; for the western North Pacific, the values from Sakhalin can be used. This will need to be revisited by the Scientific Committee at a later stage.

7. HUMAN ACTIVITIES (OTHER THAN DIRECT REMOVALS) THAT MAY (OR MAY IN THE FUTURE) AFFECT STATUS

7.1 Habitat degradation and modification e.g. by climate change

Sue Moore briefly summarised the impact of climate change on gray whale Arctic habitats, especially the dramatic loss of volume and seasonal areal extent of sea ice Jeffries *et al.,* 2013. Compared to the 1980s, the Pacific Arctic sector (NBS/SCh) is now ice-free roughly 1-2 weeks earlier each spring, and sea ice forms there about 3-4 weeks later each autumn. So gray (and other baleen) whales have 1-1.5 months longer to feed in ice-free habitat. In addition, the loss of sea ice appears to be accompanied by an increase in primary production in the Pacific Arctic sector[7], which may result in more prey for gray and other baleen whales. Finally, a step-change in inflow of Pacific water through the Bering Strait (50% increase in volume, 2001-2011) may be transporting prey (especially krill) into the SCh and NCh gray whale habitats.

Ilyashenko reported that hunters in Chukotka are having difficulty hunting gray whales because the whales stay farther offshore as ice cover declines (ice is now often >10km offshore in northern Chukotka).

7.2 Industrial activities

The dramatic reduction of sea ice in the Arctic has been accompanied by an upsurge in industrial activities in the Pacific Arctic sector (NBS/SCh), particularly with regard to commercial shipping and oil and gas exploration. Commercial ship passage between Europe and China can be roughly 12 days shorter along the Northern Sea Route (NSR) compared to a route through the Suez Canal. However, because great uncertainties remain regarding

[7] http://www.arctic.noaa.gov/report12/primary_productivity.html

reliable transit along the NSR, it remains unclear whether the NSR is likely to develop into a major shipping artery. This matter was covered extensively at the IWC Arctic Impacts workshop (cite report). Oil and gas exploration, including seismic surveys and destinational ship transits, will increase the risks of ship strikes (especially at narrow passages such as Bering Strait) and toxic spills (including oil) and bring more underwater noise to the region. These matters were also discussed at the Arctic Impacts workshop and are also discussed at annual meetings of the SC/E group (ref. SC 65a).

Table 6
Biological parameter information by sub-area

Parameter	Mexico lagoons	32-41° (CA)	41-52° (PCFG)	Kodiak	Chukotka	East Kamchatka	Sakhalin
First-year calf survival	Photo data available, Urbán *et al.*	0.711 (90% PI=0.423-0.950)[2] Punt and Wade, 2012					
Post-weaning calf survival			Mark-recapture estimates available, Calambokidis *et al.*; Photo data available Darling *et al.*.			Photo data available Tyurneva *et al.*	0.67 (SE=0.07)[2]- Cooke *et al.*, 2013; 0.717 (95% CI=0.579-0.824)[1] Bradford, 2011[1]
Non-calf survival	Photo data available, Urbán *et al.*.	0.981 (90% PI=0.957-0.997)[2] Punt and Wade, 2012	0.963 (SE=0.0079)[2] - SC/A14/NPGW03; Photo data available, Darling *et al.*	Photo data available? Wynne *et al.*.		Photo data available Tyurneva *et al.*	0.975 (SE=0.005)[2] Cooke *et al.*, 2013; 0.973 (95% CI=0.954-0.984)[1]-Bradford 2011
Age at sexual maturity		9 med (6-12)[1] both sexes Rice and Wolman (1971), Rice (1990)			7 med (6-8)[1] (females), Blokhin and Tiupeleyev 1987; Catch data available, Blokhin *et al.*		
Age at first reproduction	7 (n=1)[1] Swartz *et al.*.					Photo data available? Tyurneva *et al.*	11.5 (SE=1.1)[2] Cooke *et al.*, 2013; 7, 9, 10, 11 (*n*=4) Bradford *et al.*
Pregnancy rate	0.48 (95% CI=0.463-0.498)[1], Jones and Swartz, 1990; Hormone data available, Urbán *et al.*	0.46[1] Rice and Woman (1971)	Biopsy data available Calambokidis *et al.*		0.44[1]- Blokhin 1984a, 1987; Catch data available, Blokhin *et al.*		
Calving interval	2.11 (SD=0.4)[1] (1972-1982) – Jones,1990; 2.44 (SD=0.61)[1] (2006-2013), Urbán *et al.*		Photo data available Calambokidis *et al.*, Darling *et al.*			Photo data available Tyurneva *et al.*	2.9 (SE=0.18), 2.7 (SE=0.16), or 2.5 (SE=0.13)[1] (1995-2003) Bradford *et al.*. 2008; Photo data available, Weller *et al.*.
Sex ratio	0.564 male (neonate)[1] IWC 1993[3]	0.5 male (foetal) and 0.625 male (neonate)[1,3]- Rice (1990); 0.52 male (all age classes)[1] and 0.506 male (foetal)[1] Rice and Wolman (1971)	Photo data available Calambokidis *et al.*, Darling *et al.*.		Catch data available, Blokhin *et al.*		0.61 male (SE=0.05) (neonate)[2] Cooke *et al.*. 2013 0.591 male (calf)[1] Lang *et al.*.
Conception date		5 Dec mean (late Nov – early Jan)[1] - Rice and Wolman 1971					
Calving date	27 Jan med (late Dec – early Mar)[1]- Rice *et al.*. 1981						

[1]Observed or estimated from data (includes mark-recapture); [2]Population dynamics model-based estimate; [3]Attributed to Jones and Swartz 1983, but this value was not reported there; [4]Combines fetuses and neonates from breeding, migration, and feeding areas

As in the case of Item 7.1, the Workshop recognised that this agenda item also applies to non-Arctic portions of the gray whale's range (certainly including Sakhalin Island and coastal regions of Korea, Japan and China). A number of anthropogenic threats to gray whales in the western North Pacific give cause for concern. For instance, incidental takes in fishing gear throughout the range may pose a threat to gray whales as discussed under Item 4.3. Near-shore industrialization and shipping congestion throughout the migratory corridor(s) represent additional risks by increasing the likelihood of exposure to pollutants and ship strikes as well as a general degradation of the habitat. Finally, the summer feeding area off Sakhalin Island is a region rich with offshore oil and gas reserves. Two major offshore oil and gas projects now directly overlap or are in near proximity to this important feeding area, and more development is planned there and in other parts of the Okhotsk Sea that include the migratory routes of these whales. Operations of this nature have introduced new sources of underwater noise, including seismic surveys, as well as increasing ship traffic and the risk of oil spills. Considerable information has been published in reports of the IWC SC, the report of the 2008 IUCN rangewide workshop, and various reports by the IUCN gray whale panels (see http://www.iucn.org/wgwap/).

7.3 Other

Military activities, research and tourism have also increased in the Arctic and elsewhere in the gray whale's range but no new information on these issues was presented at this Workshop.

7.4 Consideration of how these may be incorporated into a modelling framework

In an ecological context, the impacts of human activities on gray whales must be incorporated as an additional level of habitat variability coupled to that of climate change. The whales experience 'one habitat', which reflects the combined outcome of 'natural' variability and human activities. With regard to gray whale population structure and status, the potential for increased lethal takes (by ship strike) and habitat alteration and degradation (by increased offshore activities) in the Pacific Arctic sector is recognized, but for now impossible to quantify. The Workshop **agrees** that further consideration as to how to incorporate these factors into the modelling framework should take place after the initial simple modelling has been undertaken (see Item 8).

8. DEVELOP MODELLING APPROACH/SCENARIOS

The development of a population dynamics model for North Pacific gray whales will necessarily be an iterative process. The first step is to develop an age- and sex-aggregated model which includes multiple stocks (two or three depending on the hypothesis under consideration). The aim for developing this model will be primarily to understand whether sufficient data are available to justify the various stock structure hypotheses and whether parameterization of the model based on the associated hypotheses can provide reasonable fits to the data. The data included in the first step model will be the catches by area and month and the trends in 1+ abundance for the Sakhalin feeding area, the PCFG and the counts off southern California. The model will mimic the assumptions regarding how catches off North America and Chukotka are allocated to breeding stock.

The estimable parameters of the first step model will be the initial sizes of each breeding stock, the rate of increase of each stock in the limit of zero population size, and the levels of immigration and emigration into and out of the PCFG. The proportion of each stock which is found in each area will initially be pre-specified, but some of these parameters will be treated as estimable in the second and subsequent steps. The first step model should initially try to start the model projections for the system at unfished equilibrium. However, the fits to the data may be very poor unless allowance is made, for example, for changes in carrying capacity over time. Consequently, model runs should be produced when the model is initialized in a more recent year. The first step model should explore assumptions regarding the dynamics prior to the 1990s of the whales that feed off Sakhalin.

The results of the initial model fits will be reviewed by the Scientific Committee and this review may lead to refinement of the stock structure hypotheses, including rejection of some hypotheses which are clearly inconsistent with the available data.

The second step in the modelling process, assuming that the Scientific Committee considers the first phase a success, would be to extend the model to include age and sex structure and to include data on mixing proportions based on telemetry and genetics data. Subsequent steps may be required depending on how well it is possible to mimic the available data, and to explore the impact of future catches and other human activities.

The Workshop established an intersessional working group with members Punt (chair), Bradford, Cooke, Donovan, Lang, Mate and Weller to develop a set of model specifications for the first step in the modelling process.

9. WORKPLAN UP TO 2014 IWC ANNUAL MEETING AND BEYOND

9.1 Prior to SC65b

Develop the mathematical specifications for an age- and sex-structured model and identify data gaps (Punt, with help from the intersessional working group).

9.2 During SC65b

(1) Implement the age- and sex-structured model for one hypothesis as a proof-of-concept (Punt).

(2) Refine the specifications of the age- and sex-structured model.

(3) Develop detailed terms of reference for the 2nd workshop.

9.3 After SC65b

Use the age- and sex-structured model to explore the remaining hypotheses.

10. RECOMMENDATIONS

10.1 Conduct a preliminary comparison of photographically and genetically identified gray whales in Mexico, off central California and in the PCFG with a focus on mothers and calves.

Objectives

(1) Improve assessment of internal recruitment to the PCFG by identifying PCFG whales known to have given birth in Mexico (would increase the sample size of known PCFG mothers).
(2) Improve estimates of calf survival for PCFG whales by identifying mothers with calves on wintering grounds and during migration and determining whether the calves were ever sighted again.
(3) Improve determination of the number of known reproductive PCFG females that have been biopsied. This would come about two ways: 1) the comparison would reveal some biopsied PCFG whales that were not previously known to be reproductive females and 2) some PCFG whales that match to Mexico but have not been biopsied in the PCFG may prove to have been biopsied in Mexico.

Tasks

(1) Conduct a rapid comparison of the approximately 1,500 photo-identified gray whale mothers known to have been accompanied by calves in Mexico from 2010-2014 and off central California from 2012-2014 to a subset of the catalogue (maintained by Cascadia Research Collective, CRC) consisting of known PCFG whales photo-identified in multiple years. This work would be carried out by the primary CRC photo-matcher who is familiar with PCFG whales and he/she would examine all Mexico/central California mothers for any that are recognized and then compare any familiar whales to the catalogue to verify the match. When a match is found, the calf of the mother will be compared to the full catalogue (all whales) maintained by CRC.
(2) Conduct a simultaneous comparison by matchers at UABCS of the approximately 50 known PCFG mothers to the 1,500 Mexico mothers with calves. This will both provide an independent check on the comparison above and help explain some of the long gaps between calves observed with PCFG mothers – e.g. the female did have a calf in a given year but it was missed.

10.2 Develop Single Nucleotide Polymorphisms (SNP) assays for use with gray whales

Objectives

The development of a SNP panel be developed for use with gray whales would:

(1) allow integration of genetic data between labs as well as over time, increasing the utility of such data for future analyse;

(2) allow work with low-quality samples, such as bone and baleen, which could facilitate analysis of any historic samples identified.

10.3 Increase the sample numbers and sample coverage for the eastern North Pacific stock of gray whales

Objectives

While a high proportion of the whales using the Sakhalin feeding ground have been sampled, the proportion of the eastern North Pacific stock that has been sampled is low. In addition, few or no samples have been collected from some parts of the range of eastern North Pacific stock. Such studies are essential to improve comparisons amongst areas, better examine stock structure in the feeding grounds and improve stock structure hypotheses to allow for improved conservation and management via modelling.

Methods
Efforts should be made wherever practical to increase additional sampling and photo-identification efforts in key areas, such as the northern Chukchi, with the goal of evaluating whether additional structure exists on feeding areas used by the ENP stock.

10.4 Improve abundance and trend estimates for the PCFG by identifying and using additional photographic sources (Calambokidis, Darling and Laake)
Objectives
It is important to know the degree to which there was large-scale recruitment into the PCFG during the period prior to around 1998 (which would have to have been from an external source) to evaluate the status of the PCFG. The previous AWMP trials have made assumptions about a pulse increase in recruitment to PCFG. This was because broad-scale collaborative photo-ID sampling of a large portion of the PCFG began in 1998, shortly before the large-scale gray whale mortality event in 1999. Abundance trend models show a sharp increase at the beginning of the sampling that extends through the early 2000s. The addition of some of the partial data available from 1996 and 1997 did not allow for accurate abundance estimates in those years but it did cause the estimates for 1998 to increase somewhat.

Method
It is known that some additional identification photographs from 1996 and 1997 are available from other investigators, naturalists and opportunistic sources. These should be identified and investigated to see if they can inform the trend analysis of the PCFG and thereby improve understanding of recruitment for this population.

10.5 Compare photographs of gray whales from areas of the Okhotsk Sea and elsewhere in Asia with the Sakhalin and Kamchatka catalogues (e.g Weller, Bradford, Tyurneva…)
Objectives
To better understand the stock structure and movements of gray whales on the western side of the North Pacific.

Method
Photographs have been taken of gray whales encountered in other parts of the Okhotsk Sea aside from Sakhalin Island (e.g. Shantar Archipelago, Kuril Islands, Magadan) and have been archived by both the Russia-U.S. western gray whale research program and the Institute of Marine Biology (IBM), Vladivostok. Subsets of these photographs have been compared previously by both teams to individuals photographed off Sakhalin Island (e.g. Weller *et al.* 2002, 2003), but a combined matching effort has not been attempted. The Workshop **recommends** that all available photographs of gray whales outside of Sakhalin in the Okhotsk Sea (and potentially other parts of the western Pacific) be catalogued and matched against the two Sakhalin catalogues.

10.6 Putting bounds on the proportion of Sakhalin whales that migrate to the eastern North Pacific in winter (Cooke)
Objective
In order to further questions of stock structure and whether 'true' western gray whales regularly feed off Sakhalin, it is of great interest to determine what proportion of Sakhalin gray whales migrate to the eastern North Pacific. In statistical terms, the question is what bounds, or confidence limits, can be placed on the proportion that migrates to the eastern North Pacific.

Data sources
The three sources of data are: telemetry, photo-id and genetic. The provisional results obtained so far include:

Data source	Matches	Comparison
Telemetry	3	Sakhalin whales tracked to E. Pacific (out of 3 tagged for whish transmissions lasted sufficiently long)
Photo-identification of individuals	5	Sakhalin whales matched to PNW catalogue
	17	Sakhalin whales matched to Mexican catalogue
	3	Sakhalin whales matched to other ENP catalogues
Genetic identification of individuals	3	Sakhalin whales matched to ENP samples

The interpretation of the genetic and photo-id data requires specifying the sizes of the samples in which the matches were found. Because this varies over the years, the sample sizes by year are needed.

Data required for analysis
For each year of each catalogue (at least the Sakhalin, Mexican and Pacific Northwest):

(1) number of distinct whales photo-identified that year;
(2) number of new whales photo-identified that year; and

(3) for each match between Sakhalin and another catalogue, years for each catalogue in which that whale was photo-identified.

In the case of the Pacific Northwest (PNW) catalogue, whales deemed to belong to PCFG should be omitted. Other catalogues can be included where practicable.

Genetic identification data should be summarized in a similar way to the photo-id data, but the sample sizes are generally lower.

Proposed analysis
The proposed analysis is to apply a capture-recapture model to each source of data to yield a combined likelihood for the proportion *p* of Sakhalin whales that migrate to the eastern North Pacific in winter. Two models will be considered:

(1) each Sakhalin whale migrates to the eastern North Pacific with a probability *p* each year

(2) a fraction *p* of Sakhalin whales migrates to the eastern North Pacific each winter; the rest do not.

Other models can be considered if the data warrant this. The results will be expressed in terms of confidence intervals for *p*.

10.7 Continued development of the population model for the Sakhalin feeding area
The Workshop **strongly encourages** the continued development and publication of the Cooke approach. It **reiterates** the importance of careful incorporation of all relevant data from Sakhalin and Kamchatka into the model (e.g. see IWC, 2013).

10.8 Continued telemetry studies
The IWC Scientific Committee has several times reiterated the great importance of further telemetry studies, particularly off Sakhalin, Kamchatka and in the northern areas such as Chukotka. This work not only can inform on migration routes and usage but also on determining the likelihood of whales from various areas being taken in hunts, fishing gear or ship strikes. The Workshop **reiterates** this and **recommends** that such work be undertaken.

10.9 Improved estimates of western North Pacific catches 1890-1910 (to come from Brownell and Reeves)
Objective
To determine whether it is possible, and if so to estimate, the likely large catches for the years 1890-1910 in the western North Pacific around the Korean Peninsula.

Method
Carry out a literature/museum/logbook investigation to obtain information on whaling effort (e.g. numbers of vessels, captains, stations) and other aspects (e.g. suspension of effort due to the Sino-Japanese War), by year, that could be used to estimate catches for these years by inference, interpolation or extrapolation using the known catches in 1907 and 1913 as a starting point (see Reeves and Smith, 2010). Such a study will require participation by researchers with appropriate language abilities – i.e. at least Japanese, Russian and Norwegian.

10.10 Improved estimates for future ship strikes and bycatches throughout the whole North Pacific (Scordino and Carreta)
Objective
To develop future removal series to be used in modelling for the entire North Pacific.

Approach
To extend the approach to determine future non-deliberate removals used for the AWMP trials (e.g. see Scordino and Mate, 2011; IWC 2013) and update this for the whole North Pacific. Assumptions on allocations of removals will need to be made for the various stock structure hypotheses.

10.11 Develop plans for a second workshop to review the results of the initial modelling exercise
The Workshop **recommends** that the Scientific Committee begins to plan for a second workshop to review the modelling results recommended from the present workshop as part of the process towards meeting the long term objective of improving conservation and management of this species.

11. ADOPTION OF REPORT

Most of the report text and the recommendations were agreed and adopted on the last day of the Workshop. Additional drafting and editing work was conducted after the Workshop and all participants were given the opportunity to review and comment by e-mail before the report was finalised. This version was completed on 13

May 2014 although some participants had yet to comment. The Chair thanked the participants for their enthusiasm to participate in all aspects of this wide-ranging workshop, whatever their primary disciplines. He noted that this was an important step to understanding the status of gray whales throughout the North Pacific and for determining management and conservation priorities. He also re-iterated thanks for the wonderful facilities provided by the SWFSC. The Workshop participants thanked the Chair for steering them through a long and complex agenda, with good humour and fairness.

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Annex A

List of Participants*

Scott Baker
Oregon State University, USA.

John Bickham
Department of Forestry and Natural Resources and Center for the Environment, Purdue University.

Amanda Bradford
NOAA, Hawaii.

Robert Brownell Jr.
Southwest Fisheries Science Center, La Jolla, CA USA.

John Calambokidis
Cascadia Research, California.

Jim Carretta
Southwest Fisheries Science Center, La Jolla, CA USA.

Justin Cooke
IUCN Cetacean Specialist Group.

Jim Darling
Whale Trust, Canada.

Donna Darm
NOAA fisheries

Greg Donovan
IWC Secretariat

Valentin Ilyashenko
Russian Federation.

Jeff Jacobsen
Humboldt State University, Arcata, CA USA.

Jeff Laake
The National Marine Mammal Laboratory (NMML).

Aimee Lang
Southwest Fisheries Science Center, La Jolla, CA USA.

Karen Martien
Southwest Fisheries Science Center, La Jolla, CA USA.

Bruce Mate
Marine Mammal Institute, Oregon State University, OR USA.

Jeff Moore
Southwest Fisheries Science Center, La Jolla.

Sue Moore
NOAA Fisheries, WA, USA.

Wayne Perryman
Southwest Fisheries Science Center, La Jolla.

Andre Punt
University of Washington, Seattle, WA USA

Randy Reeves
Okapi Research, Canada

Lorenzo Rojas-Bracho
National Institute of Ecology, Mexico

Jon Scordino
Makah Fisheries Management, Neah Bay, USA.

Michael Scott
Inter-American Tropical Tuna Commission, La Jolla, CA USA.

Barbara Taylor
Southwest Fisheries Canter, La Jolla, USA.

Jorge Urbán
Universidad Autónoma de Baja California Sur (UABCS), Mexico.

Dave Weller
Southwest Fisheries Science Center, La Jolla, CA USA.

*Full addresses to be added later

Annex B
Agenda

1. INTRODUCTORY ITEMS

1.1 Convenor's opening remarks

1.2 Election of Chair

1.3 Appointment of rapporteurs

1.4 Adoption of Agenda

1.5 Documents and data available

2. SUMMARY OF POPULATION MODELLING APPROACHES THAT HAVE BEEN OR MAY BE RELEVANT FOR NORTH PACIFIC GRAY WHALES

2.1 AWMP (including Pacific Coast Feeding Group)

2.2 Western North Pacific (Cooke model)

3. STOCK STRUCTURE AND MOVEMENTS

3.1 Summary of existing hypotheses

3.2 Review of available data and analyses

- 3.2.1 Genetic data on population structure
- 3.2.2 Osteological data comparing populations
- 3.2.3 Individual identification data (photo and genetic)
- 3.2.4 Telemetry data
- 3.2.5 Removals data
- 3.2.6 Sightings data
- 3.2.7 Biological data
- 3.2.8 Ecology and behaviour
- 3.2.9 Other

3.3 Discussion of possible population structure hypotheses

3.4 Recommendations for hypotheses for inclusion in the modelling framework

3.5 Recommendations for future data collection and/or analyses

4. REMOVAL DATA

4.1 Commercial catches [post 1850]

- 4.1.1 Western North Pacific
- 4.1.2 Eastern North Pacific
- 4.1.3 Future

4.2 Aboriginal subsistence catches

- 4.2.1 Past
- 4.2.2 Future

4.3 Incidental catches in fishing gear

- 4.2.1 Past
- 4.2.2 Future

4.4 Ship strikes

- 4.3.1 Past
- 4.3.2 Future

4.5 Recommended time series for use in modelling framework

5. ABUNDANCE AND TRENDS

5.1 Review of available data and analyses

- 5.1.1 Western North Pacific
  - 5.1.1.1 Individual identification (photo and genetic)
  - 5.1.1.2 Sightings
  - 5.1.1.3 Previous analyses, models and assumptions (including historical catch series)
- 5.1.3 Eastern North Pacific
  - 5.1.3.1 Individual identification (photo and genetic)
  - 5.1.3.2 Sightings
  - 5.1.3.3 Previous analyses, models and assumptions (including historical catch series)
- 5.1.4 Consideration of integrated approach taking into account discussions under Item 2

6. POPULATION PARAMETERS

6.1 Review of available data and analyses

6.2 Consideration of integrated approach taking into account discussions under Item 2

7. HUMAN ACTIVITIES (OTHER THAN DIRECT REMOVALS) THAT MAY (OR MAY IN THE FUTURE) AFFECT STATUS

7.1 Habitat degradation and modification e.g. by climate change

7.2 Industrial activities

7.3 Other

7.4 Consideration of how these may be incorporated into a modelling framework

8. DEVELOP MODELLING APPROACH/SCENARIOS

9. WORKPLAN UP TO 2014 IWC ANNUAL MEETING AND BEYOND

9.1 Prior to SC65b

9.2 During SC65b

9.3 After SC65b

10. RECOMMENDATIONS

11. ADOPTION OF REPORT

Annex C

List of Documents

SC/A14/NPGW01. Bickham, J., Dupont, J., Broker, K. Status of the western North Pacific gray whale: review of stock structure hypotheses and genetic approaches. 17pp.

SC/A14/NPGW02. Bickham, W. J. The challenge of identifying management units in large, vagile marine animals: meta-analysis reveals why conservation geneticists should think smart not big. 34pp.

SC/A14/NPGW03. Calambokidis, J., Laake, J., and Perez, A. Updated analysis of abundance and population structure of seasonal gray whales in the Pacific Northwest, 1996-2012. 76pp.

Annex D

Summary of genetic data and analyses

Table 1
Available samples by study

Region	Reference	Samples*	Time Period	Type of samples	Month 1	2	3	4	5	6	7	8	9	10	11	12	Utilized mtDNA?	mtDNA bps sequenced	Utilized microsatellites?	# of microsatellite loci	Comments
Baja Mexico, all three lagoons	Urban in process	450	2013-2014	Biopsies		x	x										Y (In progress)		N		Approximately 50% of samples processed
Baja Mexico, Bahia Balenas	Goerlitz et al. 2003	2	1996	Biopsies			x										Y	302	N		Urban confirmed that this is a different sample set from Alter et al. 2009
Baja Mexico, Bahia Magdalena lagoon	Alter et al. 2009	32	2001-02, 2005-2006	Biopsies		x	x										Y	442	Y	9	
Baja Mexico, Offshore, San Jose del Cabo	Goerlitz et al. 2009	1	1996	Biopsies			x										Y	302			Urban confirmed that this is a different sample set from Alter et al. 2009
Baja Mexico, Ojo de Liebre lagoon	Alter et l. 2009	24	2001-02, 2005-2006	Biopsies		x	x										Y	442	Y	9	
Baja Mexico, Ojo de Liebre lagoon	Goerlitz et al. 2009	14	1997	Biopsies		x	x										Y	302	N		Urban confirmed that this is a different sample set from Alter et al. 2009
Baja Mexico, San Ignacio lagoon	Alter et al. 2009	56	2001-02, 2005-2006	Biopsies		x	x										Y	442	Y	9	
Baja Mexico, San Ignacio lagoon	Goerlitz et al. 2009	66	1996, 1997	Most biopsies, 4 strandings		x	x										Y	302	N		Urban confirmed that this is a different sample set from Alter et al. 2009
ENP (not specified)	Alter et al. 2007	42															N		N		Incl. sequences from mtDNA cyt B, seven nuclear introns, and one X-linked region.
Migratory, CA/OR/WA (89), AK (9), Chukotka (5)	LeDuc et al. 2002	104	1979-2000	Strandings (91), harvest (6), bycatch (2), biopsies (21)	x	x	x	x	x	x	x	x	x	x	x	x	Y	523	N		Analysis also included n=16 Steeves et al samples, grouped with ENP stratum
Pacific Northwest, 41-52 (not ided as PCFG)	Lang et al. 2011, Pers. Comm.	33	1996-2012	Biopsies					x	x	x	x	x	x	x		Y	523	Y	12	
Pacific Northwest, 41-52	Alter et al. 2012	16	150-2690 ybp	Bones from middens													Y	383	N		

Region	Reference	Samples*	Time Period	Type of samples	Month												Utilized mtDNA?	mtDNA bps sequenced	Utilized microsatellites?	# of microsatellite loci	Comments
					1	2	3	4	5	6	7	8	9	10	11	12					
Pacific Northwest, 41-52	Ramakrishnan et al. 2001	45		Biopsies													Y	523	N		Includes Steeves et al. samples from Pacific Northwest; not all samples correlated with photoid (i.e. may not be PCFG)
Pacific Northwest, 41-52, PCFG	Lang et al. 2014, Lang pers comm.	134	1996-2012	Biopsies	x	x		x	x	x	x	x	x	x	x	x	Y	523	Y	23	
Pacific Northwest, 41-52, PCFG	D'Intino et al. 2012	82		Biopsies							x	x	x	x	x		N		Y	15	Likely overlap with Frasier et al., which provides mtDNA data.
Pacific Northwest, 41-52, PCFG	Frasier et al. 2011	40	1995-2006	Biopsies							x	x	x	x	x		Y	345	N		
Pacific Northwest, 41-52, PCFG	Steeves et al. 2001	16	1995-1996	Biopsies						x	x	x	x	x	x		Y	311	N		These samples likely used in Frasier et al. and D'Intino et al.
Alaska, Kodiak	Lang pers com	6	2001, 2005	Biopsies							x	x					Y	523	N		
Alaska, Barrow	Lang et al. 2014, Lang pers comm.	23	1997-1998, 2000, 2002, 2010-2011	Biopsies, Tagging, Strandings							x	x	x				Y	523	Y	12	Only Lang et al. 2014 samples processed for 12 loci.
Russia, Chukotka	Kanda et al. 2010	7	2008	Harvest						x	x	x	x	x			Y	486	N		
Russia, Chukotka	Meschersky et al. 2012	84		Harvest													Y	555	N		Also 1137 bp of cyt B sequence
Russia, Chukotka	Ilyashenko pers comm.	~150		Harvest													N		N		
Russia, Chukotka	Lang et al. 2014	75	1994, 2001, 2003-2005	Harvest							x	x	x	x	x		Y	523	Y	12	
Russia, Koryak coast	Meschersky et al. 2012	16	2010-2011	Biopsies													Y	555	N		Also 1137 bp of cyt B sequence
Russia, Koryak coast	Lang et al. 2014	17	2010	Biopsies						x							Y	523	Y	12	Likely same samples as Meschersky et al. 2011
Russia, Sakhalin Island	Meschersky et al. 2012	14	2010-2011	Biopsies													Y	555	N		Also 1137 bp of cyt B sequence
Russia, Sakhalin Island	Lang reported	155	1995-2007, 2010-2011	Biopsies							x	x	x				Y	523	Y	23	
Russia, Sakhalin Island	LeDuc et al. 2002	45	1995-1999	Biopsies						x	x	x	x	x			Y	523	N		These samples also included in Lang et al. studies
Russia, Sakhalin Island	Bickham et al. 2013	6	2011	Biopsies						x	x	x	x	x			Y		N		Cytochrome B sequences also generated; these individuals also sampled as part of LeDuc et al. 2002 and Lang et al. studies

					Month															
Region	Reference	Samples*	Time Period	Type of samples	1	2	3	4	5	6	7	8	9	10	11	12	Utilized mtDNA?	mtDNA bps sequenced	Utilized microsatellites?	# of microsatellite loci	Comments
Russia, SE Kamchatka	Meschersky et al. 2012	17	2010-2011	Biopsies													Y	555	N		Also 1137 bp of cyt B sequence
Russia, SE Kamchatka	Lang pers comm.	16	2004, 2010-2011	Biopsies						x	x	x					Y	523	Y	12-23	
Japan, Pacific coast	Kanda et al. 2010	5	1995-2007	Strandings, Bycatch	x			x	x		x	x					Y	486	N		
Japan, Sea of Japan coast	Kanda et al. 2010	1	1996	Strandings Bycatch					x								Y	486	N		
China	Lang Pers. Comm.	2*	1996, 2011	Strandings, Bycatch											x	x	Y*	523	Y*	23	The 1996 sample failed to produce useable DNA when extracted.

Table 2

Summary of genetic analyses, including regions compared, sample sizes (n), number of mtDNA haplotypes (Nb haps), mtDNA haplotype diversity (h), number of mtDNA haplotypes shared between areas (Nb shared), and results of comparisons between strata for both mtDNA (p-values in parentheses for F_{ST} and Φ_{ST}) and microsatellites (p-values in parentheses for F_{ST}).

Reference	Stratum 1				Stratum 2				mtDNA				Microsatellites	
	Region	n	Nb haps	h	Region	n	Nb haps	h	Nb shared	F_{ST}	Φ_{ST}	Exact Test	F_{ST}	Exact Test/Chi-square
Mexico (within lagoons)														
Goerlitz et al. 2003	Laguna San Ignacio (LSI) cows	42			LSI single females	11				0.027 (p=0.044)	0.088 (p=0.034)			
Mexico (lagoons v. outside lagoons)														
Goerlitz et al. 2003	LSI cows	42			non-lagoon females	25				0.064 (p<0.01)	0.041 (p=0.043)			
Goerlitz et al. 2003	LSI single females	11			non-lagoon females	25				0.07 (p<0.01)	0.003 (p=0.34)			
Goerlitz et al. 2003	LSI males	13			non-lagoon males	28				0.08 (p<0.01)	-0.03 (p=0.8)			
Goerlitz et al. 2003	Ojo de Liebre (OdL) cows	10			non-lagoon females	25				0.074 (p<0.01)	-0.03 (p=0.82)			
Mexico (between lagoons)														
Goerlitz et al. 2003	LSI cows	42			OdL cows	10				0.03 (p=0.08)	0.013 (p=0.27)			
Alter et al. 2009	Ojo de Liebre	24	13	0.942	Laguna San Ignacio	56	20	0.948		0.0174 (p=0.89)			0.0168 (p=0.99)	p=0.806
Alter et al. 2009	Laguna San Ignacio	56	20	0.948	Bahia Magdalena	32	20	0.9587		0.0150 (p=0.92)			0.0057 (p=0.025)	p<0.0001
Alter et al. 2009	Ojo de Liebre	24	13	0.942	Bahia Magdalena	32	20	0.9587		0.0177 (p=0.77)			0.0217 (p=0.99)	p=0.163
North Pacific														
Alter et al. 2007														
Sakhalin v. CA & NBS (CA->WA)														
LeDuc et al. 2002	Sakhalin	45	10	0.7	ENP	120	33	0.95	7	0.087 (p<0.001)	0.117 (p<0.001)	p<0.001		
PCFG: Pacific Northwest, 41-52 (ancient) v. WNP														
Alter et al. 2012	South* - middens	16	9	0.933	WNP	45	10	0.7	2	0.2794 (p<0.001)				
PCFG: Pacific Northwest, 41-52 (ancient) v. ENP														

Alter et al. 2012	South* - middens	16	9	0.933		ENP		120	33	0.95		6		0.1004 (p<0.001)				
														PCFG: SOUTH				
Ramakrishnan et al. 2001	South*	45	20	0.93														
PCFG v. NBS & N. Chukchi																		
Lang et al. 2014	PCFG	71	23	0.945		Northern Feeding		106	32	0.952		19		0.012 (p<0.0045)	0.012 (p=0.0740)	0.0067		0.000 (p=0.5269)	0.3491
PCFG v. NBS																		
Lang et al. 2014	PCFG	71	23	0.945		Chukotka		71	23	0.953		18		0.010 (p=0.0349)	0.020 (p = 0.0386)	0.0254		0.001 (p=0.2539)	0.3503
PCFG v. Mexico																		
D'Intino et al. 2012	PCFG	82				Mex lagoons		51										0.001 p = 0.489	
PCFG v. CA (CA->AK)																		
Frasier et al. 2011	PCFG	40	18	0.928		ENP		105	28	0.95		18		0.0125 (p = 0.0303)	0.0311 (p = 0.0259)				
Steeves et al. 2001	PCFG	16	11			ENP		41	19			5			-0.007 (p<0.51)				
Sakhalin																		
Bickham et al. 2013	Sakhalin	6	4/3*															
Lang et al. 2010	Sakhalin	142	22	0.77														
Sakhalin v. NBS & N. Chukchi																		
Lang et al. 2011	Sakhalin	142	22	0.77		Northern Feeding		106	32	0.952		20		0.086 (p<0.0001)	0.152 (p<0.0001)	p<0.000		0.01 (p=0.001)	p=0.001
Sakhalin v. CA (CA->AK)																		
Lang 2010	Sakhalin	142	22	0.77		ENP (CA - AK)		122	34	0.956		20		0.065 (p<0.001)	0.100 (p=0.001)	p<0.000		0.008 (p=0.001)	p=0.001
Sea of Japan & Pacific coast of Japan																		
Kanda et al. 2010	Japan	6	5															

* "South" refers to samples collected within the season (June – November) and range (41-52° N) of the PCFG but not necessarily linked to a whale photographically identified as being part of the PCFG.

Annex E

Summary of catch data for the western North Pacific

Minimum numbers and details of western gray whales caught during the 20th century (from Bradford, 2003). Years are displayed continuously until 1966, the reported end of modern whaling for western gray whales. Highlighted rows represent total yearly minimum catches.

Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1900	?	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	23	Kato and Kasuya (2002) from Park (1987)
1900	?	Kawajiri, Yamaguchi	Sea of Japan	Japan	Japanese	?	2	Omura (1984) from Tada (1978)
1900							25	
1901							?	Kato and Kasuya (2002) from Park (1987)
1902	?	Jangjeon	Sea of Japan	Korea	Russian	Modern	9	Kato and Kasuya (2002) from Park (1987)
1902	?	Unknown	Unknown	Unknown	Unknown	Modern	5	Kato and Kasuya (2002) from Park (1987)
1902							14	
1903							?	Kato and Kasuya (2002)
1904							?	Kato and Kasuya (2002)
1905							?	Kato and Kasuya (2002)
1906	Nov-Mar	Ulsan	Sea of Japan	Korea	Japanese?	Modern	59	Kato and Kasuya (2002) from Park (1987)
1906	?	Unknown	Unknown	Unknown	Unknown	Modern	11	Kato and Kasuya (2002) from Park (1987)
1906							70	
1907	Nov-Mar	Ulsan	Sea of Japan	Korea	Japanese?	Modern	125	Kato and Kasuya (2002) from Park (1987)
1907							125	
1908	Nov-Mar	Ulsan	Sea of Japan	Korea	Japanese?	Modern	26	Kato and Kasuya (2002) from Park (1987)
1908							26	
1909	Dec	Ulsan	Sea of Japan	Korea	Japanese	Modern	65	Andrews (1914)
1909	Dec	Chan Chien Dogo	Sea of Japan	Korea	Japanese	Modern	18	Andrews (1914)
1909	Dec	Hidokatsu	Sea of Japan?	Korea?	Japanese	Modern	1	Andrews (1914)
1909							84	
1910	Jan	Ulsan	Sea of Japan	Korea	Japanese	Modern	32	Andrews (1914)
1910	Feb	Ulsan	Sea of Japan	Korea	Japanese	Modern	3	Andrews (1914)
1910	Mar	Ulsan	Sea of Japan	Korea	Japanese	Modern	1	Andrews (1914)
1910	Feb	Oshima, Nagasaki	Tsushima Strait	Japan	Japanese	Modern	1	Andrews (1914)
1910	Mar	Chan Chien Dogo	Sea of Japan	Korea	Japanese	Modern	1	Andrews (1914)
1910							38	
1911	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	106	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1911	Nov-Apr	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	13	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1911	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	2	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1911							121	
1912	Mar	Chan Chien Dogo	Sea of Japan	Korea	Capt. Melsom	Modern	2	Andrews (1914), Mizue (1951)
1912	Jan	Ulsan	Sea of Japan	Korea	Japanese	Modern	23	Andrews (1914)
1912	?	Unknown	Unknown	Unknown	Unknown	Modern	193	Kato and Kasuya (2002), Omura (1988) from Kasahara (1950)
1912							218	
1913	?	Unknown	Unknown	Unknown	Unknown	Modern	131	Kato and Kasuya (2002), Omura (1988) from Kasahara (1950)
1913							131	
1914	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	109	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1914	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	30	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1914	Oct?	Ayukawa, Miyagi	Pacific	Japan	Japanese?	Modern	3	Mizue (1951), Brownell and Chun (1977)
1914	Jul?	Nemuro, Hokkaido	Pacific	Japan	Japanese?	Modern	1	Kasahara (1950), Mizue (1951), Brownell and Chun (1977), Kato and Kasuya (2002)
1914	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	15	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1914							158	

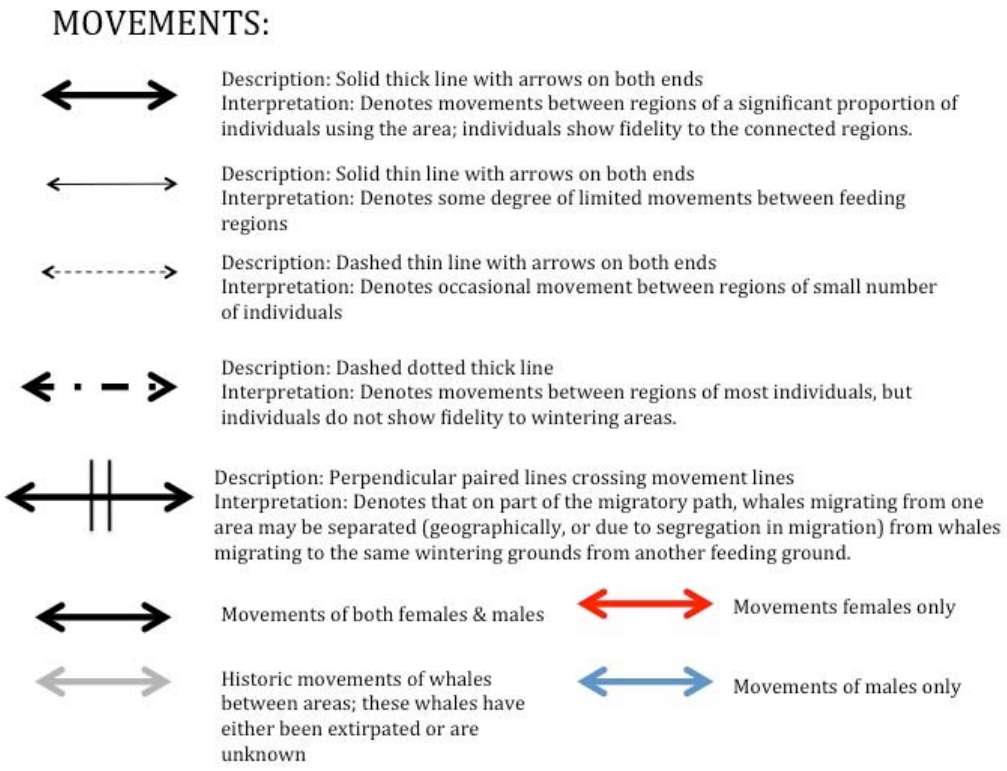
Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1915	?	Area XII-XIV	Unknown	Unknown	Japanese?	Modern	130	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1915	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	9	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1915							139	
1916	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	36	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1916	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	41	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1916	?	Area II, III, or IV	Unknown	Japan	Unknown	Modern	1	Kasahara (1950)
1916							78	
1917	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	53	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1917	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	13	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1917	?	Area XIV	Yellow Sea	Korea?	Japanese?	Modern	2	Kasahara (1950), Wang (1984), Omura (1988), Kato and Kasuya (2002)
1917							68	
1918	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	91	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1918	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	10	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1918	?	Area XIV	Yellow Sea	Korea?	Japanese?	Modern	2	Kasahara (1950), Wang (1984), Omura (1988), Kato and Kasuya (2002)
1918	?	"Other"	Unknown	Unknown	Unknown	Modern	1	Kato and Kasuya (2002) from Kasahara (1950)
1918							104	
1919	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	35	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1919	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	11	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1919							46	
1920	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	51	Kasahara (1950), Kato and Kasuya (2002)
1920	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	14	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1920	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	10	Kasahara (1950), Kato and Kasuya (2002)
1920							75	
1921	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	23	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1921	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	53	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1921	?	North Kyushu	Korea Strait?	Japan	Unknown	Modern	2	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1921							78	
1922	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	19	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1922	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	19	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1922	May?	Area XIV	Yellow Sea	Korea?	Japanese?	Modern	2	Kasahara (1950), Mizue (1951), Wang (1984), Omura (1988), Kato and Kasuya (2002)
1922							40	
1923	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	4	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1923	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	23	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1923							27	
1924	?	Ulsan	Sea of Japan	Korea	Japanese?	Modern	1	Kato and Kasuya (2002) from Emoto Log
1924	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	13	Kasahara (1950), Omura (1988), Kato and Kasuya (2002)
1924	?	Unknown	Unknown	Unknown	Unknown	Modern	4	Kato and Kasuya (2002) from Kasahara (1950)
1924							18	
1925	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	10	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1925							10	
1926	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	9	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1926	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	1	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1926	May?	Sakhalin	Sea of Okhotsk	Russia	Unknown	Modern	1	Kasahara (1950), Mizue (1951), Kato and Kasuya (in press)
1926							11	
1927	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	6	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1927	Nov-May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	3	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)

Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1927	?	Area III	Sea of Okhotsk	Unknown	Unknown	Modern	1	Kasahara (1950), Kato and Kasuya (in press)
1927							10	
1928	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	9	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1928							9	
1929	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	11	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1929	?	Area XIV	Yellow Sea	Unknown	Japanese?	Modern	1	Kasahara (1950), Wang (1984), Omura (1988), Kato and Kasuya (in press)
1929							12	
1930	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	30	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1930							30	
1931	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	10	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1931							10	
1932	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	Modern	7	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1932							7	
1933	Nov-Apr	Ulsan	Sea of Japan	Korea	Japanese?	modern	1	Kasahara (1950), Omura (1988), Kato and Kasuya (in press)
1933							1	
1934							?	Kato and Kasuya (in press) from Kasahara (1950)
1935							?	Kato and Kasuya (in press) from Kasahara (1950)
1936							?	Kato and Kasuya (in press) from Kasahara (1950)
1937							?	Kato and Kasuya (in press) from Kasahara (1950)
1938							?	Kato and Kasuya (in press) from Kasahara (1950)
1939							?	Kato and Kasuya (in press) from Kasahara (1950)
1940							?	Kato and Kasuya (in press) from Kasahara (1950)
1941							?	Kato and Kasuya (in press) from Kasahara (1950)
1942	?	Ulsan	Sea of Japan	Korea	Japanese?	Modern	1	Kato and Kasuya (in press) from Emoto Log
1942	?	Otomae, Kurils	Unknown	Russia	Japanese?	Modern	1	Kasahara (1950), Mizue (1951), Brownell and Chun (1977), Kato and Kasuya (in press)
1942							2	
1943	?	Ulsan	Sea of Japan	Korea	Japanese?	Modern	1	Kato and Kasuya (in press) from Emoto Log
1943							1	Kato and Kasuya (in press) from Emoto Log
1944							?	Kasahara (1950) and Kato and Kasuya
1945	Jan	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	3	Kato and Kasuya (in press) from Emoto Log
1945	May	Jangjeon	Sea of Japan	Korea	Japanese?	Modern	2	Kato and Kasuya (in press) from Emoto Log
1945							5	
1946							?	Brownell and Chun (1977), Kato and Kasuya (in press)
1947							?	Brownell and Chun (1977), Kato and Kasuya (in press)
1948	Jan?	Ulsan	Sea of Japan	Korea	Korean?	Modern	9	Brownell and Chun (1977), Kato and Kasuya (in press) from Park (1987)
1948							9	
1949	?	Ulsan	Sea of Japan	Korea	Korean?	Modern	4	Brownell and Chun (1977), Kato and Kasuya (in press)
1949	Sep	Area XIV	Yellow Sea	China?	Chinese	Modern	1	Kato and Kasuya (in press) from Wang (1978)
1949							5	
1950							?	Brownell and Chun (1977), Kato and Kasuya (in press)
1951	?	Ulsan	Sea of Japan	Korea	Korean?	Modern	7	Brownell and Chun (1977), Kato and Kasuya (in press)
1951							7	
1952	?	Ulsan	Sea of Japan	Korea	Korean?	Modern	1	Brownell and Chun (1977), Kato and Kasuya (in press)
1952							1	
1953	?	Ulsan	Sea of Japan	Korea	Korean?	Modern	7	Brownell and Chun (1977), Kato and Kasuya (in press)
1953	Mar-Jun	Wailuo Harbor, Lui Zhou Peninsula	South China Sea?	China	Chinese?	?	4	Wang (1984)
1953							11	

Year	Month	Location	Water Body	Country	Whalers	Method	Catch	Source
1954							?	Brownell and Chun (1977), Kato and Kasuya (in press)
1955							?	Brownell and Chun (1977), Kato and Kasuya (in press)
1956							?	Brownell and Chun (1977), Kato and Kasuya (in press)
1957							?	Brownell and Chun (1977), Kato and Kasuya (in press)
1958	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	7	Brownell and Chun (1977), Kato and Kasuya (in press)
1958	Jun	Yantai, Shandong	Yellow Sea	China	Chinese	Modern	1	Kato and Kasuya (in press) from Wang (1978)
1958							8	
1959	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	7	Brownell and Chun (1977), Kato and Kasuya (in press)
1959	Jun	Southeast Honshu	Pacific	Japan	Japanese	Modern	1	Nishiwaki and Kasuya (1970), Brownell and Chun (1977)
1959							8	
1960	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	8	Brownell and Chun (1977), Kato and Kasuya (in press)
1960	Apr	Area XIV	Yellow Sea	China?	Chinese	Modern	1	Kato and Kasuya (in press) from Wang (1978)
1960							9	
1961	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	3	Brownell and Chun (1977), Kato and Kasuya (in press)
1961							3	Brownell and Chun (1977), Kato and Kasuya (in press)
1962							?	Brownell and Chun (1977), Kato and Kasuya (in press)
1963	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	2	Brownell and Chun (1977), Kato and Kasuya (in press)
1963							2	Brownell and Chun (1977), Kato and Kasuya (in press)
1964	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	3	Brownell and Chun (1977), Kato and Kasuya (in press)
1964							3	Brownell and Chun (1977), Kato and Kasuya (in press)
1965	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	4	Brownell and Chun (1977), Kato and Kasuya (in press)
1965							4	Brownell and Chun (1977), Kato and Kasuya (in press)
1966	Dec-May	Ulsan	Sea of Japan	Korea	Korean?	Modern	5	Brownell and Chun (1977), Kato and Kasuya (in press)
1966							5	Brownell and Chun (1977), Kato and Kasuya (in press)
1968	Feb	Shingu, Wakayama	Seto Inland Sea?	Japan	Japanese	?	1	Nishiwaki and Kasuya (1970), Omura (1984), Brownell and Chun (1977), Kato and Kasuya (in press)
1996	May	Suttu, Hokkaido	Sea of Japan	Japan	Japanese	Hand Harpoon	1	Brownell and Kasuya (1999), Kato and Kasuya (in press)

Annex F

Stock structure hypotheses



AREAS:

Wintering Regions:

(1) MEX: wintering area(s) in the Mexican lagoons and offshore waters of Baja California
(2) ?AS: wintering area(s) in the western North Pacific; the location is unknown but suspected to be near the South China Sea

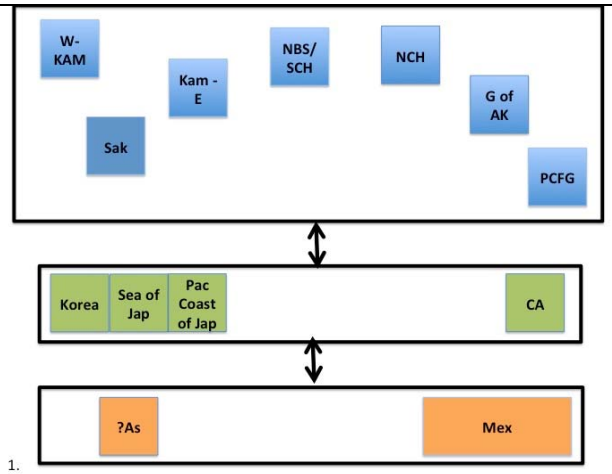
Migratory Routes:

- CA: the migratory route that extends from the feeding area north of the Aleutians to the Mexican wintering area(s). This route is also refered to as the ENP migratory route. Of note, this migratory route passes through the PCFG feeding region, although it is not depicted as such in the schematic to avoid confusion about where whales are feeding versus migrating.
- KOREA, SEA OF JAP, PAC COAST OF JAP: These are potential migratory routes in the WNP. Although it is possible that all three of these routes (mainland coast of Korea, Sea of Japan coast of Japan, and the Pacific coast of Japan) were utilized in the past, it is not possible to identify which routes connected with specific feeding regions; therefore these routes are grouped together in most schematics.
- NCP: this region was designated to identify an area to the west of the CA route that might be used by whales largely by whales migrating from Sakhalin. This region was removed from the schematics following the discussion.

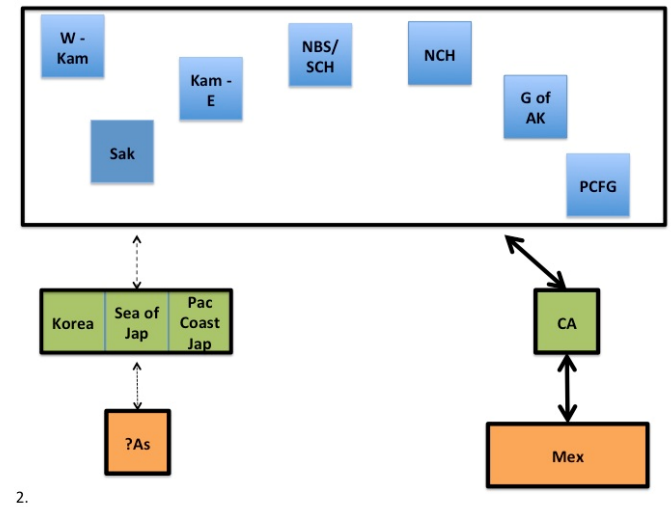
Feeding regions:

- PCFG: feeding range used by the Pacific Coast Feeding Group. This area extends from the coast of northern CA (41° N) to western Vancouver Island (52° N).
- G of AK: the Gulf of Alaska region
- NCH: the northern portion of the Chukchi Sea, including Wrangel Island in the west to Barrow, AK in the east.
- NBS/SCH: the northern Bering and southern Chukchi Seas, including the Chukotka Peninsula and St. Lawrence Island
- KAM-E: includes the coastal regions of southeastern Kamchatka, Russia, including Vestnik Bay and Olga Bay
- KAM-W: includes waters to the west of Kamchatka in the Sea of Okhotsk, incorporating Shelikov Gulf, Taui Bay (Magadan area), and the Shantar Islands region. Excludes the northeastern coast of Sakhalin Island, which is considered separately.
- SAK: waters off the northeastern coast of Sakhalin Island.

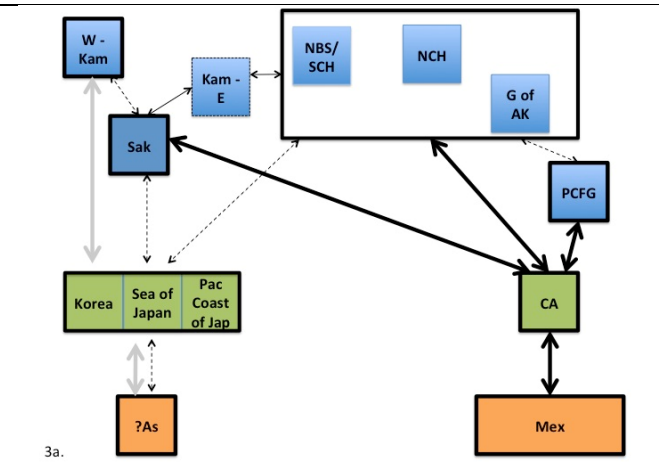
HYPOTHESES CONSIDERED



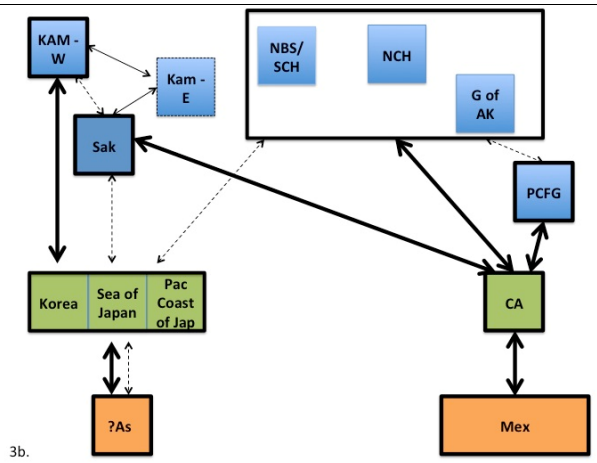
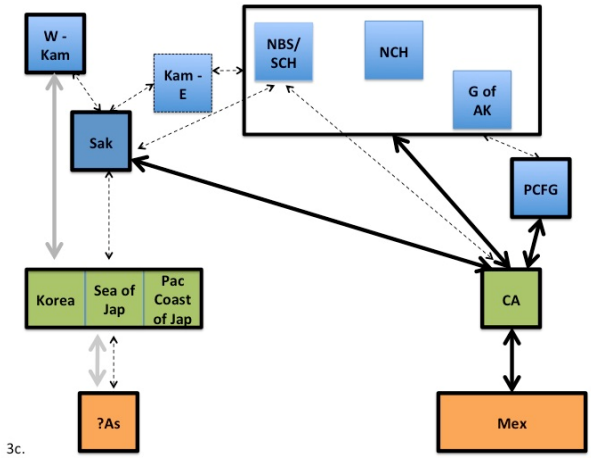
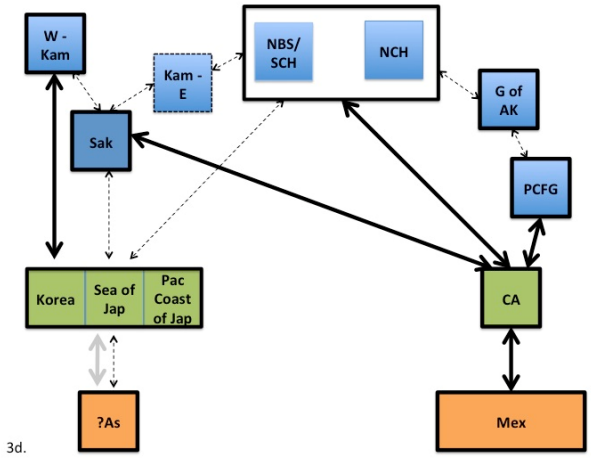
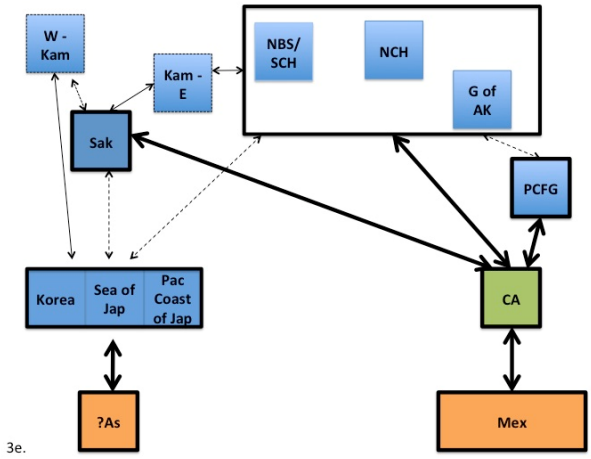
1. Panmixia with no matrilineal fidelity to feeding grounds – persistent
All gray whales in the North Pacific (both currently and historically) are part of a single breeding stock, and whales choose feeding regions randomly.

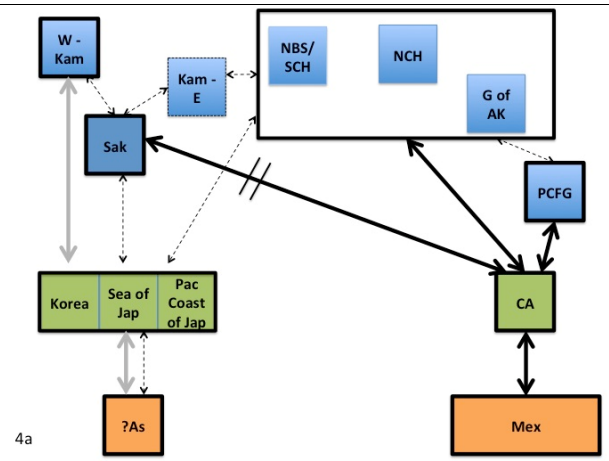


2. Panmixia with no matrilineal fidelity to feeding grounds – post-exploitaiton
Two breeding stocks (Asia and Mexico) may have existed in the past. The Asian stock may have been extirpated by commercial whaling, or, if extant, it includes whales that utilize unidentified areas in the WNP. Currently all known feeding regions for gray whales in the North Pacific are utilized by a single breeding stock (Mexico), and whales choose feeding regions randomly.



3. Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating
(3a) Two breeding stocks (Asia and Mexico) may exist, although the Asian stock, which included whales that feed west of the Kamchatka Peninsula in the Okhotsk Sea and utilized migratory routes and wintering grounds in the WNP, may have been extirpated. The Mexico stock includes three feeding sub-stocks: PCFG, NBS/SCH-NCH-G of AK [hereafter, Northern], and Sakhalin. The whales that feed off eastern Kamchatka are a mixed-stock aggregation including whales from both the Sakhalin and Northern feeding sub-stocks. Occasional movements of whales occur between 1) Sakhalin and the feeding region (W-Kam), migratory routes, and wintering grounds of the potentially extirpated Asian stock, 2) the Northern feeding area and the Asian migratory routes and wintering grounds, and 3) the PCFG and the Northern feeding region.

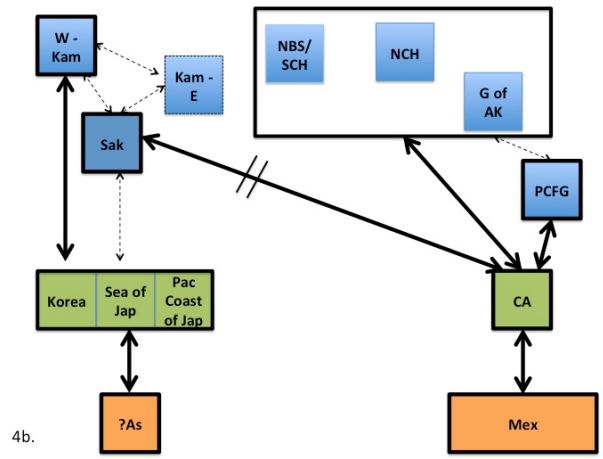
 3b.	(3b) Identical to 3a, except that the Asian stock is considered to be extant and to feed in the Okhotsk Sea west of the Kamchatka Peninsula as well as off the coast of eastern Kamchatka. Thus the eastern coast of Kamchatka is used by a mixed-stock aggregation of the Sakhalin feeding sub-stock (part of the Mexican breeding stock) and the W-Kam feeding stock (of the Asian breeding stock).
 3c.	(3c) Identical to 3a except that on occasion whales migrating between the Sakhalin feeding region and Mexico travel through the NBS/SCHK region.
 3d.	(3d) Identical to 3a except that the Gulf of Alaska region is considered a separate feeding sub-stock of the Mexico breeding stock.
 3e.	(3e) Identical to 3a except that the Asian breeding stock is extant and feeds off both coasts of Japan, Korea, and in the northern Okhotsk Sea west of the Kamchatka Peninsula. This scenario is also similar to 3b, with two exceptions: 1) that the coast of Korea and both coasts of Japan are used as feeding areas rather than migratory routes, and 2) that the KAM-E region is not used by whales that are part of the Asian stock.



4a

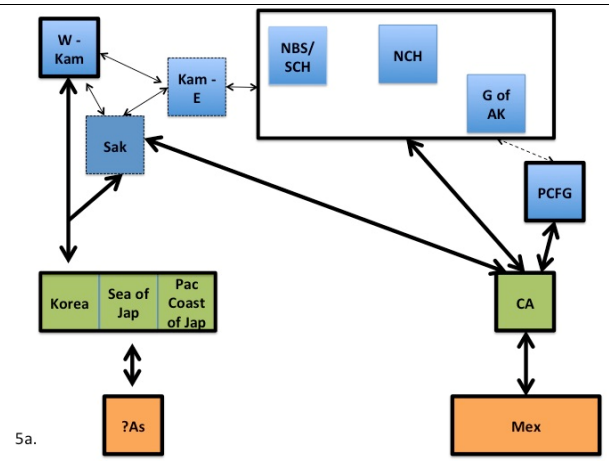
4. Maternal feeding ground fidelity, one migratory route/wintering ground used by Sakhalin whales, non-random mating

(4a) Identical to 3a except that the whales that travel from Sakhalin to Mexico are still in the western portion of their migration during the late November to mid-December period that Rice & Wolman (1971) identified as the first breeding period.



4b.

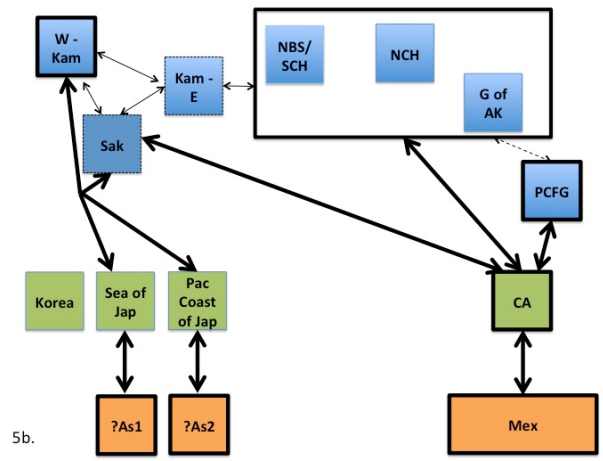
(4b) Identical to 3b except that the whales that travel from Sakhalin to Mexico are still in the western portion of their migration during the late November to mid-December period that Rice & Wolman (1971) identified as the first breeding period.



5a.

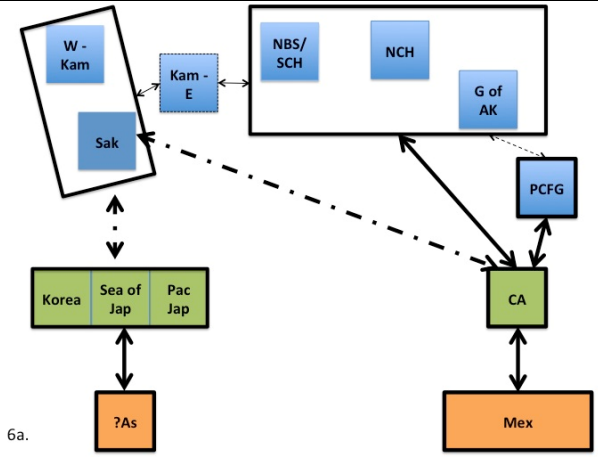
5. Maternal feeding ground fidelity, two migratory routes/wintering grounds used by Sakhalin whales, random mating

(5a) There are two breeding stocks (Asia and Mexico). The Mexico stock includes three feeding sub-stocks: PCFG, Northern, and Sakhalin feeding sub-stocks. All of the whales that are part of the Asian stock feed off Sakhalin, the eastern coast of Kamchatka, and the Sea of Okhotsk west of the Kamchatka Peninsula. Thus Sakhalin is utilized by a mixed-stock aggregation of the Sakhalin feeding sub-stock of the Mexico breeding stock and by whales that are part of the Asian breeding stock. KAM-E is also used by mixed-stock aggregation of the Northern feeding sub-stock of the Mexican breeding stock and by the whales that are part of the Asian stock.



5b.

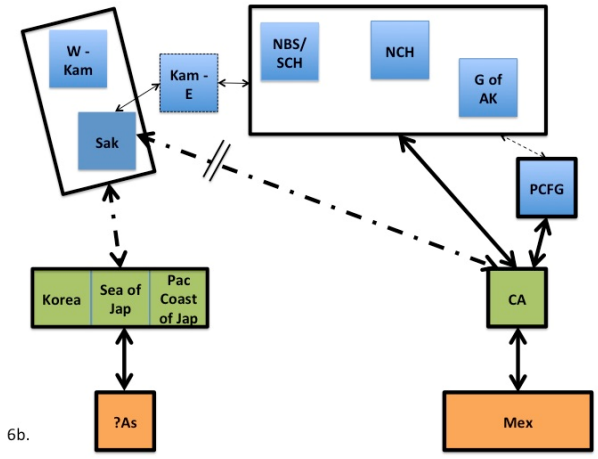
(5b) Identical to 5a except that the whales that remain in the WNP year-round show fidelity to two different migratory routes/wintering grounds. Thus there are two breeding sub-stocks of the Asian stock. Of note, although the arrows indicate the Sea of Japan coast of Japan and the Pacific coast of Japan as the two migratory routes, this schematic could apply to any two of the three possible routes.



6a.

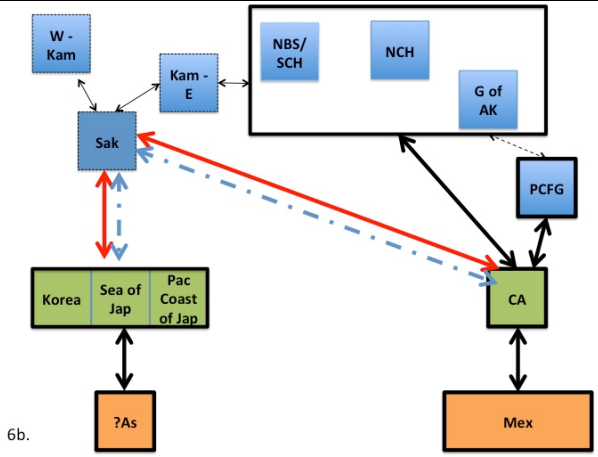
6. Maternal feeding ground fidelity, Sakhalin whales use two migratory routes/wintering grounds but show no fidelity to them, random mating

(6a) One breeding stock exists in the North Pacific, as all whales utilize migratory routes and wintering grounds in the ENP in at least some years. Three feeding sub-stocks exist: Sakhalin-WKam, Northern, and PCFG. Eastern Kamchatka is utilized by two feeding sub-stocks (Sak-WKam and Northern).



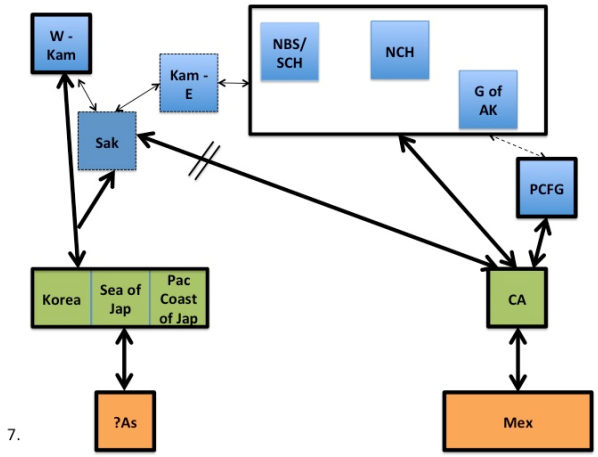
6b.

(6b) Identical to 6a, except that when Sakhalin whales choose to migrate to the ENP they breed largely with each other. This results in two breeding stocks – one includes whales from the PCFG and Northern feeding sub-stocks that migrate to Mexico and largely breed with each other, and the other includes all whales that feed off Sakhalin and breed largely with each other whether on the ENP or WNP migratory routes/wintering grounds [This hypothesis was originally referred to as 7a during the workshop].



6b.

(6c) Identical to 6a except that females that feed off Sakhalin exhibit fidelity to two migratory routes/wintering grounds, while males use both migratory routes/wintering grounds. This would result in two breeding sub-stocks (???): one includes the Sakhalin females that always migrate and overwinter in the WNP and Sakhalin males (which provide their only mating opportunities), and the second includes the same Sakhalin males as well as the whales belonging to the PCFG and Northern feeding sub-stocks [this hypothesis was originally labelled hypothesis 8 by the intersessional email group].



7.

7. Maternal fidelity to feeding grounds, Sakhalin whales show fidelity to two migratory routes/wintering grounds, non-random mating

Two breeding sub-stocks utilize the Mexican wintering grounds – one breeding sub-stock that feeds off Sakhalin (e.g. contains one feeding sub-stock) and one breeding sub-stock that feeds in the Northern and PCFG regions (i.e. comprises two feeding sub-stocks). An additional Asian breeding stock exists; these whales feed off Sakhalin and in the Okhotsk Sea west of the Kamchatka Peninsula. Thus Sakhalin and Kamchatka-East are used by mixed-stock aggregations [This schematic was originally referred to as 7b during the workshop].

Report of the Third Workshop on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales

Report of the Third Workshop on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales[1]

The Workshop was held at the Southwest Fisheries Science Center (SWFSC), La Jolla, California from 18-20 April 2016. The list of participants is given as Annex A.

1. INTRODUCTORY ITEMS

1.1 Convenors' opening remarks

Donovan and Punt (co-Convenors) welcomed the participants to the Workshop. They thanked Weller and the SWFSC for yet again hosting this meeting, the third in a series of workshops examining the rangewide status of North Pacific gray whales (and see IWC, 2015b; 2016). The output from this process is intended to assist in the updating of the IUCN/IWC western gray whale Conservation Management Plan[2] and the general provision of conservation and management advice for North Pacific gray whales.

1.2 Election of Chair

Donovan was elected Chair.

1.3 Appointment of rapporteurs

Weller, Lang and Punt were appointed rapporteurs with assistance from the Chair and others as appropriate.

1.4 Adoption of Agenda

The adopted agenda is given as Annex B.

1.5 Documents and data available

The list of documents is given as Annex C. Annex G provides an updated schematic of present knowledge of North Pacific gray whale distribution and migration.

2. PROGRESS ON 'NON-MODELLING' RECOMMENDATIONS AND NEW DATA

2.1 Update on comparison of identified gray whales in Mexico, off central California and in the PCFG with a focus on mothers and calves

Weller presented an update of information on photo-identification and related research that has been conducted since the two previous Workshops (IWC, 2015b; 2016). The comparison of gray whales identified off Mexico to those identified off Sakhalin and Kamchatka is unchanged from the earlier paper (Urbán R. *et al.*, 2013). A new research undertaking involves comparing gray whale photo-identification images collected opportunistically mostly by commercial whale watching boats off the US west coast to existing catalogues from Sakhalin Island and the PCFG (Weller, pers. comm.).

Table 1 provides an update of the information on available photo-identification data for the North Pacific from that developed at the first Workshop (IWC, 2015b).

Continued efforts to collect shore-based photo-identification images of mother-calf pairs passing by central California concurrent to the annual NOAA calf count continued in 2015, resulting in a catalogue that now spans the period 2012-15 (Weller, pers. comm.) Finally, in 2015 and 2016 a remotely operated hexacopter was used during the NOAA calf count to obtain aerial images of mother-calf pairs to examine length, girth and body condition (Perryman, pers. comm.).

2.2 Comparison of photographs (and genetic material) of gray whales from areas of the Okhotsk Sea and elsewhere in Asia with the Sakhalin and Kamchatka catalogues

Annex D provides a summary of gray whale photo-identification and genetic matching within the western North Pacific. Based on the reported results, two sets of mixing proportions were generated and used in the age structured model described in table 3 of SC/A16/GW02. Table 3a of that paper lists data for the eastern Sea of Japan/Pacific coast of Japan that are based on 'definite' matches/non-matches and table 3b includes the 'likely' matches/nonmatches.

2.3 Development of Single Nucleotide Polymorphisms (SNP) assays for use with gray whales

Table 2 summarises the available samples available for genetic analyses – this is an update to the table presented in the first rangewide Workshop (IWC, 2015b).

Bickham noted that whole genome sequencing of two whales sampled off Sakhalin Island and one whale sampled off Barrow, Alaska, had been completed. These sequences were used to identify 96 SNP loci linked to genes with known functions. Using primers designed from the sequence surrounding these SNPs, 36 biopsies representing 29 gray whales sampled off Sakhalin between 2011 and 2013 were successfully genotyped at 88 of these gene-associated markers, 2 molecular sexing markers and 2 mitochondrial markers. A report detailing these results will be provided for review at SC/66b, and both the genome and primer sequences will be made publicly available through the National Center for Biotechnology Information, allowing researchers in other labs to use this SNP panel in future gray whale studies. Genotyping of samples collected from Sakhalin whales in 2014 and 2015 is planned, and Bickham and his team are trying to identify additional samples from the eastern North Pacific to facilitate a comparative analysis in the future. Such an analysis has the potential to identify differences between Sakhalin whales that overwinter in the eastern North Pacific and any that remain in the western North Pacific year-round.

The Workshop thanked Bickham for this information and looked forward to the full paper that would be presented at SC/66b. In discussion, it was noted that environmental changes have probably resulted in several cycles of splitting and merging between eastern and western North Pacific gray whales over the past 100,000 years, which could affect the magnitude of any such differences, and thus the likelihood that they would be detected.

Lang reported that additional efforts to identify SNP loci in gray whales were underway at SWFSC. Genotyping by-sequencing (GBS) is being conducted on samples (n=190) collected from PCFG whales, whales feeding off Sakhalin Island, and whales feeding north of the Aleutians. GBS utilises a highly multiplexed approach that includes the use of restriction enzymes to reduce genome complexity and is

[1]Presented to the Scientific Committee meeting as SC/66b/Rep07.
[2]*https://www.iucn.org/wgwap/rangewide_initiative/; https://iwc.int/current-future-conservation-management-plans.*

Table 1
Photo-identification data for North Pacific gray whales.

Location	Photos	Catalogue size	Years	Season(s)
Mexico lagoons	Yes	7,000+ IDs	2006-present*;	Primarily Jan.-Apr.
Mexico offshore	Yes	No catalogue; <100 IDs	2007-13	Primarily Jan.-Apr.
California (31-41°N)	Yes	No catalogue; opportunistic/whalewatchers	-	South/northbound migration
Central California	Yes	<150 IDs; shore-based mother/calves	2012-present	North migration Apr.-May
PCFG (41°-52°N)	Yes	>1,500 IDs	Primarily 1980s-2000s*	Primarily Jun.-Nov. opportunistic year round
Aleutians (52°N)	?	N/A	N/A	N/A
Kodiak	Yes	<250 IDs	2002-12 some annual gaps; 2015	Primarily Aug.-Sep.
US Bering Sea	Yes	<10 IDs; opportunistic (St Lawrence Island)	2012	Aug.
Chukchi-Beaufort Sea	Yes	<40 IDs	2013	Aug.-Sep.
Chukotka	No	A catalogue is being developed	N/A	N/A
East Kamchatka	Yes	<160 IDs	2004-12	Primarily Jul.-Aug.
Okhotsk Sea, west of Kamchatka	Yes	No catalogue; opportunistic	1990s-2000s	N/A
Sakhalin	Yes	<250 IDs	1994-present (no data in 1996)	Primarily Jul.-Oct.
Korea	No	N/A	N/A	N/A
Japan: Pacific	Yes	No catalogue; <10 IDs	1990s-2000s	N/A
Japan: Sea of Japan	Yes	No catalogue; 1 ID	2014	Mar.-Apr.
China	Yes	No catalogue; 1 ID	2011	Nov.

*Some data to 1970s.

predicted to result in hundreds to thousands of genotyped SNP markers. These samples have been submitted for sequencing and the resulting data are expected to be available in the next month. Although SNPs identified using this approach are intended to be a random subset from the genome, it was noted that comparison of these sequence data with the genome data generated in Bickham's study could provide information on whether these SNPs are associated with identified genes.

The Workshop thanked Lang for this information. There was some discussion of what might be learned by comparing samples collected during the early field efforts off Sakhalin Island, when photo-identification studies indicated that the feeding ground was used by 100 or fewer whales, to samples collected more recently when the abundance was higher (*ca* 170). It was noted that at least for the Russia-US research programme, efforts were made to avoid sampling individuals more than once, such that samples collected in later years of the study, when many of the individuals had already been biopsied, were not necessarily representative of the whales using the Sakhalin feeding ground during those years. However, it was noted that it would be worthwhile to explore other approaches (e.g. using close kin approaches to estimating abundance) to augment mark-recapture estimates of abundance as well as the use of effective population size estimators, to explore whether changes in abundance over time based on photo-identification data were also reflected in the genetic data.

2.4 Updated information from the eastern North Pacific

Weller provided an update on a recent survey, the Collaborative Large Whale Survey (CLaWS), conducted jointly by the SWFSC and the Alaska Fisheries Science Center. This survey, which took place between 9 July and 9 November 2015, was devoted to the assessment of several large whale species off the US and Canadian west coast between northern California and Kodiak, Alaska. A major component of this effort was the completion of the first range-wide assessment of gray whale feeding grounds south of the Aleutians. Photo-identification images of ~140 individuals were obtained, and 92 biopsies were collected. The majority of photo-identifications and biopsies were obtained off the coast of British Columbia, with a smaller proportion collected off Kodiak, Alaska. Although the coastal waters between the US-Canadian border and Kodiak, Alaska were covered twice during the survey, no gray whales were sighted within this area.

Processing of the gray whale photo-identification data collected on CLaWS is near completion, and the resulting catalogue will be sent to Cascadia for comparison with their catalogue of whales sighted within the PCFG range. In discussion, it was noted that B. Gisborne, who typically surveys the southern and western portion of Vancouver Island, reduced his survey effort during the 2015 season; as such, the data from CLaWS from that area will be particularly valuable in filling in this gap in survey effort.

A recent analysis shows that a high number of calves (36 of 56) born to known PCFG mothers seen prior to 2013 have been documented returning to the PCFG area (Perez *et al*., 2015).

Counts of southbound migrating whales off California form the basis of abundance estimation for the eastern North Pacific stock of gray whales. Previous assessments span the period 1967-2011. The summed estimate of migration abundance in 2011 was 20,990 (95% HPDI=19,230-22,900). Two new field counts, for the 2014/15 and 2015/16 migrations respectively, have been completed and will serve as the basis for updated estimates of abundance to be presented at the 2017 Scientific Committee meeting (Weller, pers. comm.).

The Workshop thanked Weller for this important new information and looked forward to receiving the full report of the CLaWS cruise in due course. It emphasised the value of conducting photographic comparisons with all catalogues in the North Pacific in addition to the catalogue of animals from the PCFG range.

2.5 Updated abundance and trend estimates for the PCFG by identifying and using additional photographic sources

Laake reported that an updated abundance estimate for the PCFG, incorporating data from 2013 and 2014, is in preparation. This will add to the previously reported time-series of estimates between 1996 and 2012.

The Workshop welcomed this news, but agreed that for the purposes of the present work, the previous estimates would be used (and see Item 4).

Table 2

Summary of available samples of gray whales (not all have been analysed and there may be some overlap between studies included here). When known, the number of individuals (*I*) sampled is included in parentheses after the total number of whales sampled.

Region	Reference	*N (I)*	Years	Months
Mexico				
Baja California, Bahía Ballenas	Goerlitz *et al.* (2003)	2	1996	Mar.
Baja California, Bahía Magdalena	Alter *et al.* (2009)	34 (32)	2001-02, 2005-06	Feb.-Mar.
Baja California, Bahía Magdalena	Martinez, pers. comm.	119	2012-14	-
Baja California, offshore, San Jose del Cabo	Goerlitz *et al.* (2003)	1	1996	Mar.
Baja California, Ojo de Liebre lagoon	Alter *et al.* (2009)	24	2001-02, 2005-06	Feb.-Mar.
Baja California, Ojo de Liebre lagoon	Goerlitz *et al.* (2003)	14	1997	Feb.-Mar.
Baja California, Ojo de Liebre lagoon	Martinez, pers. comm.	85	2012-14	-
Baja California, San Ignacio lagoon	Alter *et al.* (2009)	57 (56)	2001-02, 2005-06	Feb.-Mar.
Baja California, San Ignacio lagoon	Goerlitz *et al.* (2003)	66	1996, 1997	Feb.-Mar.
Baja California, San Ignacio lagoon	Martinez, pers. comm.	97	2012-14	-
Baja California, San Ignacio lagoon	D'Intino *et al.* (2013)	51 (40)	1996-97	-
Eastern North Pacific (not specified)	Alter *et al.* (2007)	42	-	-
Migration				
CA/OR/WA (89), AK (9), Chukotka (5)	LeDuc *et al.* (2002)	104	1979-2000	All
PCFG/South				
Pacific Northwest, (not identified as PCFG)	Lang *et al.* (2014)	27 (21)	1996-2012	July-Nov.
Pacific Northwest	Alter *et al.* (2012)	16	150-2690 ybp	?
Pacific Northwest (not yet compared with photo data)	Lang, pers. comm.	158	2011-15	All except Mar.
PCFG Pacific Northwest	Ramakrishnan *et al.* (2001)	45	-	?
Pacific Northwest	Lang *et al.* (2014)	113 (71)	1996-2010	Apr.-Dec.
Pacific Northwest	D'Intino *et al.* (2013)	86 (59)	1996-2010	Jul.-Nov.
Pacific Northwest	Frasier *et al.* (2011)	40	1995-2006	Jul.-Nov.
Pacific Northwest	Steeves *et al.* (2001)	16	1995-96	Jun.-Nov.
Southeast Alaska				
Alaska, Kodiak	Lang, pers. comm.	18	2001, 2005, 2015	Jul.-Sep.
Northeast Chukchi Sea				
Alaska, Barrow	Lang *et al.* (2014)	17 (14)	1997-98, 2000, 2002, 2010	Jul.-Sep.
Alaska, Barrow	Quakenbush, pers. comm.	5	2011	Aug.
Northern Bering Strait/Southern Chukchi Sea				
Russia, Chukotka	Kanda *et al.* (2010)	7	2008	Jun.-Oct.
Russia, Chukotka	Meschersky *et al.* (2015)	112 (86)	2001, 2003-05, 2007-08, 2010	-
Russia, Chukotka	Ilyashenko, pers. comm.	~150	-	-
Russia, Chukotka	Lang *et al.* (2014)	75 (71)	1994, 2001, 2003-05	Aug.-Nov.
Russia, Koryak	Meschersky *et al.* (2015)	21 (17)	2010	Jun.-Aug.
Russia, Koryak	Lang *et al.* (2014)	21 (17)	2010	Jun.
Sakhalin				
Russia, Sakhalin Island	Meschersky *et al.* (2015)	22 (21)	2010-11	-
Russia, Sakhalin Island	Lang, reported	198(156)	1995-2007, 2010-11	Jul.-Sep.
Russia, Sakhalin Island	LeDuc *et al.* (2002)	45	1995-99	Jun.-Oct.
Russia, Sakhalin Island	Bickham *et al.* (2015)	35 (28)	2011-13	Aug.-Sep.
Russia, Sakhalin Island	Bickham, pers comm.	39	2014-15	Aug.-Sep.
East Kamchatka				
Russia, SE Kamchatka	Meschersky *et al.* (2015)	24 (19)	2004, 2010-11	-
Russia, SE Kamchatka	Lang, pers. comm.	25 (17)	1999, 2004, 2010-11	Jun.-Aug.
Pacific side of Japan				
Japan, Pacific coast	Kanda *et al.* (2010)	5	1995-2007	Jan., Apr.-May, Jul.-Aug.
Sea of Japan				
Japan, Sea of Japan coast	Kanda *et al.* (2010)	1	1996	May
Asia				
China	Lang, pers. comm.	2*	1996, 2011	Nov.-Dec.

2.6 Updated estimates for past and future ship strikes and bycatches throughout the North Pacific

In discussion of the bycatch time-series (hereafter used to include ship strikes, entrapments and entanglements) for the western North Pacific (WNP), it was agreed that only records from 1990 through 2014 would be included given that effort to detect stranded whales was lower prior to that time period. Upon review of the available records, it was agreed to include the four whales entangled off Japan between 2005 and 2007 (Kato *et al.*, 2013) in the time series, as well as the whale bycaught in the Taiwan Strait off China in 2011 (Wang *et al.*, 2015). Details of the WNP bycatch time series are included in Table 3.

Fisheries interactions off Sakhalin Island were also discussed. The histories of fisheries, primarily for salmon, in proximity to the Sakhalin feeding ground are unclear. In recent years, however, there has been a notable increase in set nets in the inshore feeding area and pot gear in the offshore fishing area. No direct observations of bycatch have been recorded off Sakhalin since research efforts began in 1997 but the following cases were noted:

(1) a photo-documented entanglement of a whale in 2012 that was subsequently sighted in 2013 free of the entangling line (Weller *et al.*, 2014);
(2) a dead stranded whale near Chayvo in 2009 (WGWAP-7 2009);

Table 3
Records of gray whales in the WNP that are included in the WNP bycatch time-series.

Date (mm/dd/yy)	Location	Length (m)	Sex	Comment	Reference
5/11/2005	Tomiyama (Tokyo Bay), Chiba, Pacific coast of Japan (35°04'N-139°49'E)	7.81	F	Juvenile	Kato *et al.* (2014)
7/15/2005	Enoshima, Onagawa, Miyagi, Pacific coast of Japan (38°23'N-141°37'E)	12.79	F	-	Kato *et al.* (2014)
7/15/2005	Enoshima, Onagawa, Miyagi, Pacific coast of Japan (38°23'N-141°37'E)	7.75	F	Calf of the adult female from same date	Kato *et al.* (2014)
1/18/2007	Sanriku, Ofunato, Iwate, Pacific coast of Japan (39°09'N-141°54'E)	9.19	F	-	Kato *et al.* (2014)
11/5/2011	Fujian Province, Taiwan Strait, China	13.1	F	-	Wang *et al.* (2015)

(3) a weathered whale carcass found by a hunter on 10 October 2010 on the southeastern coast of Sakhalin (WGWAP-14 2014); and
(4) a verbal report from fisherman working off northeastern Sakhalin of a bycaught whale suspected, but not confirmed, to be a gray whale (WGWAP-14 2014).

With respect to case (3), the hunter who photographed the carcass estimated that it was 8m long. Line associated with the carcass, as shown in photographs, led experts to conclude that entanglement could not be ruled out as the cause of death (37 entanglement experts were contacted via the IWC's entanglement experts' network). Features of the carcass shown in photographs were used by Brownell (pers. comm.) to identify the animal as a gray whale.

The Workshop concluded that although these several cases suggest that fisheries interactions are occurring off Sakhalin, the paucity of available information makes further assessments of this issue difficult. It is clear, however, that in recent years the presence of salmon and pot gear has increased on and near the feeding areas off Sakhalin and therefore is of elevated concern.

The Workshop understood that there was a possibility of a more detailed study of fisheries off Sakhalin being undertaken in the context of the IUCN Western Gray Whale Advisory Panel (WGWAP). The Workshop **encourages** such a study.

3. PROGRESS REPORT ON MODELLING-RELATED ISSUES

The Workshop used the terminology and associated assumptions as agreed during the 2nd Workshop on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales (IWC, 2016).

(1) *Breeding stocks*. There are up to two extant breeding stocks (Western and Eastern).
(2) *Feeding aggregations*. The eastern breeding stock consists of up to three feeding aggregations depending on hypotheses: Western Feeding Group (WFG), Pacific Coast Feeding Group (PCFG) and 'North'. There is dispersal between the PCFG and North feeding aggregations, but the WFG is demographically independent of the other two feeding aggregations (i.e. there is no permanent movement of animals from the North or PCFG to the WFG).
(3) *Sub-areas*. The model includes 11 geographic sub-areas to explain the movements of gray whales in the North Pacific:
   (a) Vietnam-South China Sea [VSC];
   (b) Korea and western side of the Sea of Japan [KWJ];
   (c) eastern side of the Sea of Japan and the Pacific coast of Japan [EJPJ];
   (d) off northeastern Sakhalin Island [SI];
   (e) areas of the Okhotsk Sea not otherwise specified [OS];
   (f) East Kamchatka and the Kuril Islands [EKK];
   (g) the Northern Bering and Chukchi Sea [BSCS];
   (h) Southeast Alaska [SEA];
   (i) British Columbia to Northern California [BCNC];
   (j) California [CA]; and
   (k) Mexico [M].

The model also includes two 'latent' sub-areas used to link model predictions to observed indices of abundance. These are denoted Calif-3 and BC-BCA-3.

The Workshop focussed on the three priority stock structure hypotheses selected by the Scientific Committee at the 2014 Annual Meeting (IWC, 2015a). These can be summarised (and see Fig. 1) as follows.

(1) *Hypothesis 3a*. Although two breeding stocks (Western and Eastern) may once have existed, the Western stock is assumed to have been extirpated. Whales show matrilineal fidelity to feeding grounds, and the Eastern stock includes three feeding sub-stocks or feeding aggregations: PCFG, Northern Bering Sea (NBS)/ Southern Chukchi (SCH)-Northern Chukchi-Gulf of Alaska ('Northern') and WFG.
(2) *Hypothesis 3e*. Identical to hypothesis 3a except that the Western breeding stock is extant and feeds off both coasts of Japan and Korea and in the northern Okhotsk Sea west of the Kamchatka Peninsula. All of the whales feeding off Sakhalin overwinter in the eastern North Pacific
(3) *Hypothesis 5a*. Identical to hypothesis 3a except that the whales feeding off Sakhalin include both whales that are part of the Western stock and remain in the western North Pacific year-round, and whales that are part of the Eastern stock and migrate to the eastern North Pacific.

3.1 Updated bounds on the proportion of Sakhalin whales that migrate to the eastern North Pacific

Comparisons of photo-identification catalogues collected in Mexico and off Sakhalin, supplemented by results of whales tagged in Sakhalin, have previously been used to estimate confidence bounds on the proportion of adult Sakhalin whales that do not migrate to breeding grounds in Mexico (Cooke, 2015). The earlier results showed that inferences could be sensitive to assumptions about the extent to which immature animals join the migration. This was because the matching rate between animals observed in the WNP and the ENP was significantly lower for immature gray whales than for adult gray whales.

SC/A16/GW06 used data on the reproductive status of migrating gray whales collected off California by Rice and Wolman (1971) to refine the bounds on the proportion of

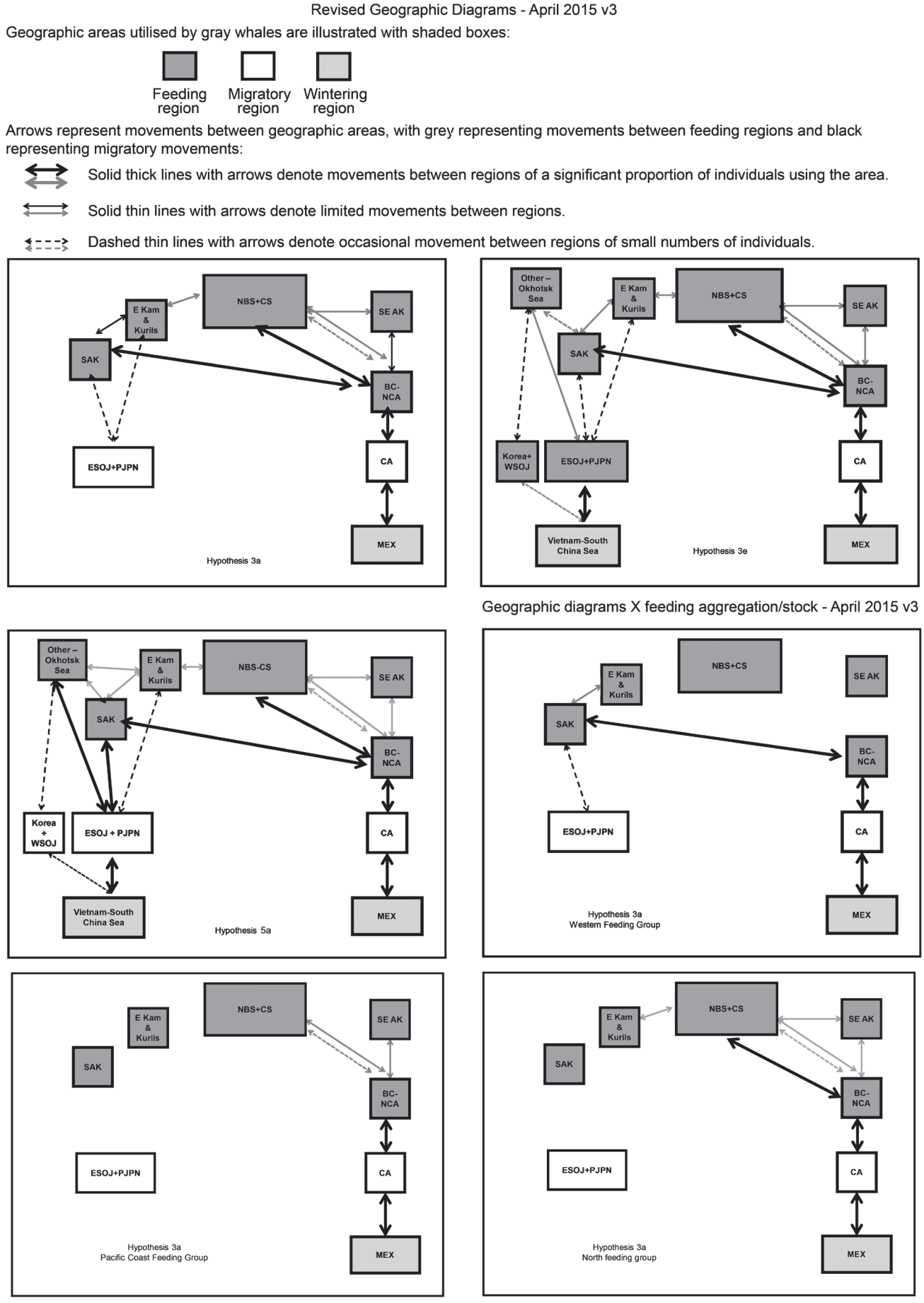
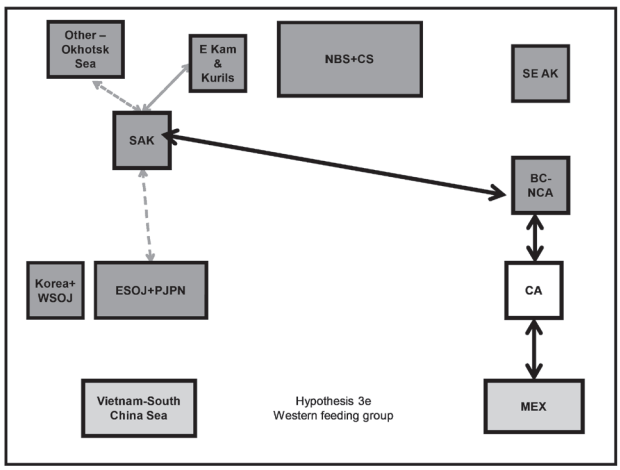
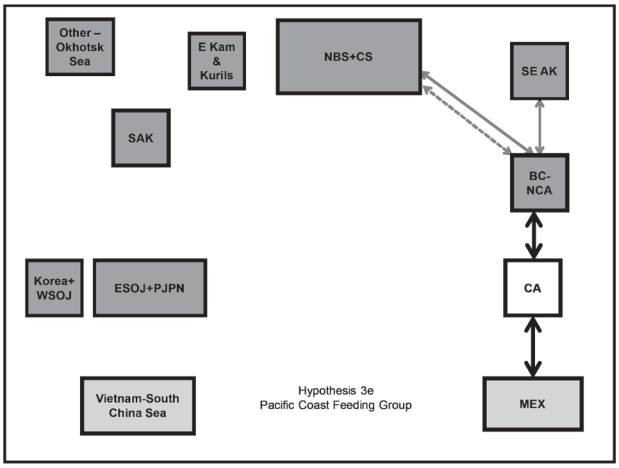


Fig.1. Stock structure hypotheses.


Other – Okhotsk Sea
E Kam & Kurils
NBS+CS
SE AK
SAK
BC-NCA
Korea+ WSOJ
ESOJ+PJPN
CA
Vietnam-South China Sea
Hypothesis 3e
Western feeding group
MEX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E Kam & Kurils
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SE AK
SAK
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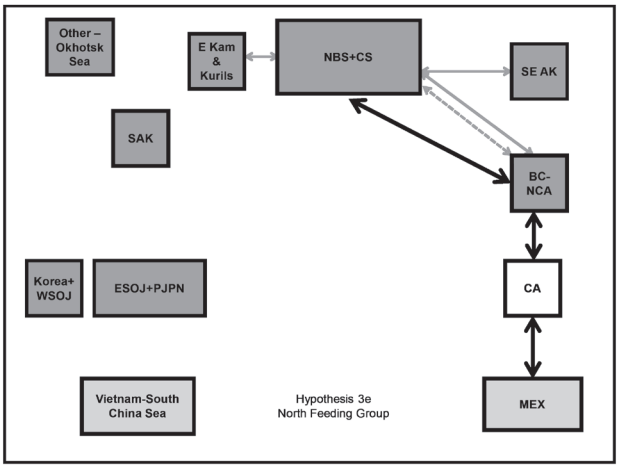
Korea+ WSOJ
ESOJ+PJPN
CA
Vietnam-South China Sea
Hypothesis 3e
Pacific Coast Feeding Group
MEX


Other – Okhotsk Sea
E Kam & Kurils
NBS+CS
SE AK
SAK
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Korea+ WSOJ
ESOJ+PJPN
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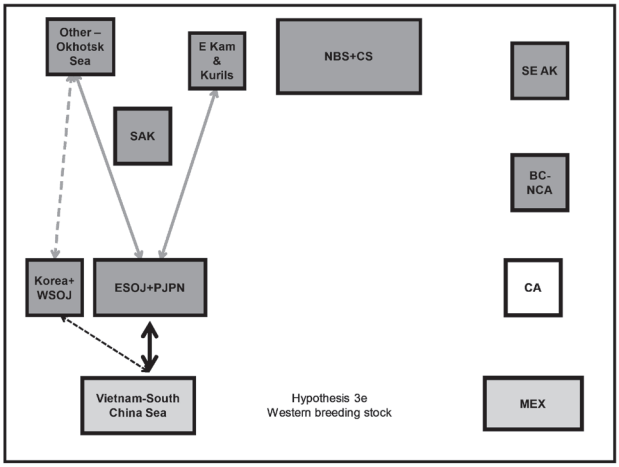
Vietnam-South China Sea
Hypothesis 3e
North Feeding Group
MEX


Other – Okhotsk Sea
E Kam & Kurils
NBS+CS
SE AK
SAK
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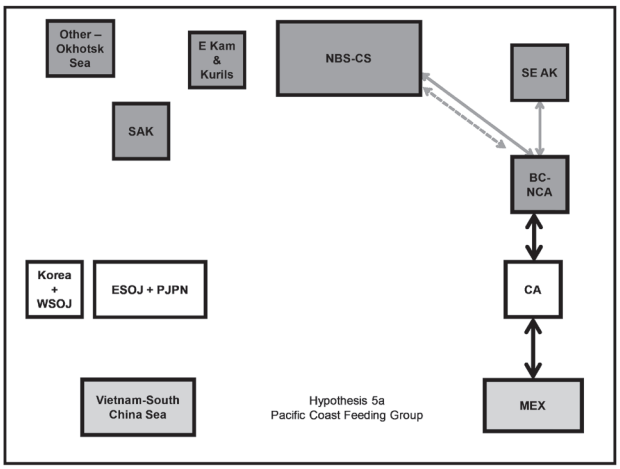
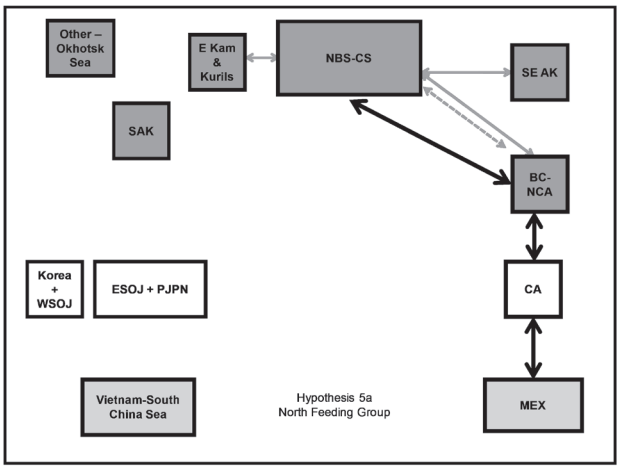
Korea+ WSOJ
ESOJ+PJPN
CA
Vietnam-South China Sea
Hypothesis 3e
Western breeding stock
MEX


Other – Okhotsk Sea
E Kam & Kurils
NBS-CS
SE AK
SAK
BC-NCA
Korea + WSOJ
ESOJ + PJPN
CA
Vietnam-South China Sea
Hypothesis 5a
Pacific Coast Feeding Group
MEX


Other – Okhotsk Sea
E Kam & Kurils
NBS-CS
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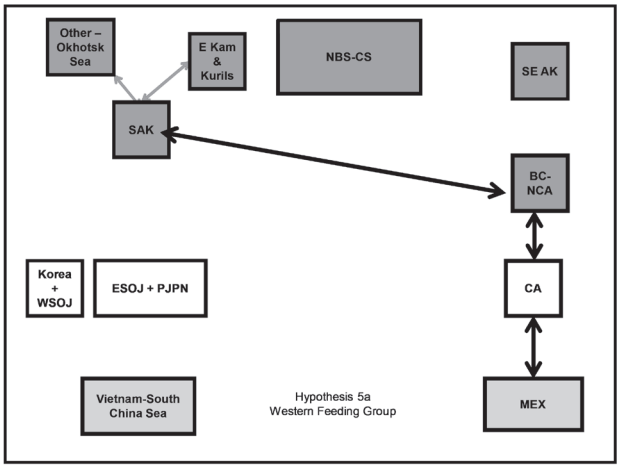
SAK
BC-NCA
Korea + WSOJ
ESOJ + PJPN
CA
Vietnam-South China Sea
Hypothesis 5a
North Feeding Group
MEX


Other – Okhotsk Sea
E Kam & Kurils
NBS-CS
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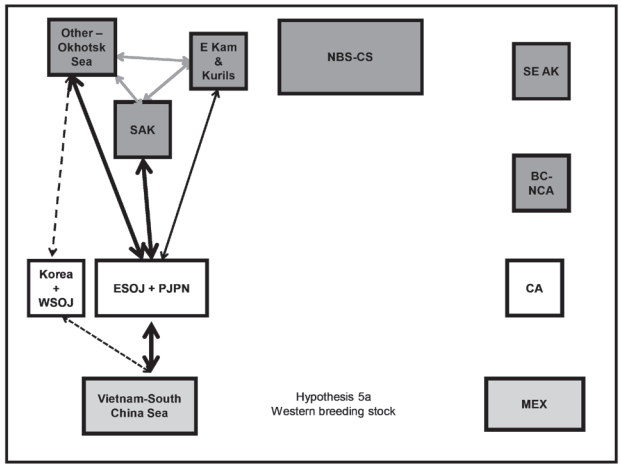
BC-NCA
Korea + WSOJ
ESOJ + PJPN
CA
Vietnam-South China Sea
Hypothesis 5a
Western Feeding Group
MEX


Other – Okhotsk Sea
E Kam & Kurils
NBS-CS
SE AK
SAK
BC-NCA
Korea + WSOJ
ESOJ + PJPN
CA
Vietnam-South China Sea
Hypothesis 5a
Western breeding stock
MEX

Sakhalin whales that undertake the migration. The revised bounds are not appreciably narrower: between 30% and 100% of mature (aged 7+) Sakhalin whales are estimated to migrate to the ENP. The proportion of immature whales undertaking the migration may be somewhat less. The existence of a breeding ground outside the ENP is thus neither confirmed nor excluded by this new analysis.

The Workshop thanked Cooke for his work in updating the analysis as requested by the previous Workshop. It looks forward to further updates to the estimated bounds when analyses of data on additional confirmed matches and non-matches become available. The Workshop **agreed** that further consideration should be given at SC/66b to whether the analyses should continue to be limited to only those animals included in the Mexican catalogue.

3.2 Development of an age- and sex-structured model

SC/A16/GW02 outlined a sex- and age-structured population dynamics model that can represent the stock hypotheses developed during the previous Workshops (IWC, 2015b; 2016). The model allows for multiple breeding stocks, each of which may consist of several feeding aggregations, multiple feeding and wintering grounds, as well as migratory corridors. Animals can move permanently between feeding aggregations in a pulse or diffusively. The values for the parameters of the model can be estimated by fitting it to data on trends in relative and absolute abundance, in addition to mixing proportions based on mark-resight data, bycatch rates, and estimates of numbers immigrating into the PCFG.

4. UPDATE ON MODELLING FRAMEWORK AND INITIAL RUNS

4.1 Progress on modelling

The modelling framework (SC/A16/GW02) was modified from that presented to the 2015 meeting of the Scientific Committee in that allowance was made for the dispersal rate between the 'north' and 'PCFG' feeding aggregations to be density dependent. Assuming that the dispersal rate is constant over time leads to poor fits to the abundance estimates for the PCFG feeding aggregation (models 12A, 12B and 12C in SC/A16/GW02) and this change was made to address this. In addition, uncertainty was quantified using a bootstrap procedure. SC/A16/GW02 provided example applications of the model based on the three priority stock structure hypotheses (see above). It also provided results for model variants that could be considered further to capture uncertainty regarding the assumptions of the model. SC/A16/GW02 also provided examples of projections in which the subsistence catches for the BSCS subarea (the Chukotka hunt) and the BCNC sub-area (the Makah hunt) are based respectively on the *Gray Whale* and *PCFG SLA*s (*Strike Limit Algorithms*) and where fishing effort (and hence bycatch rate by area) were constant into the future.

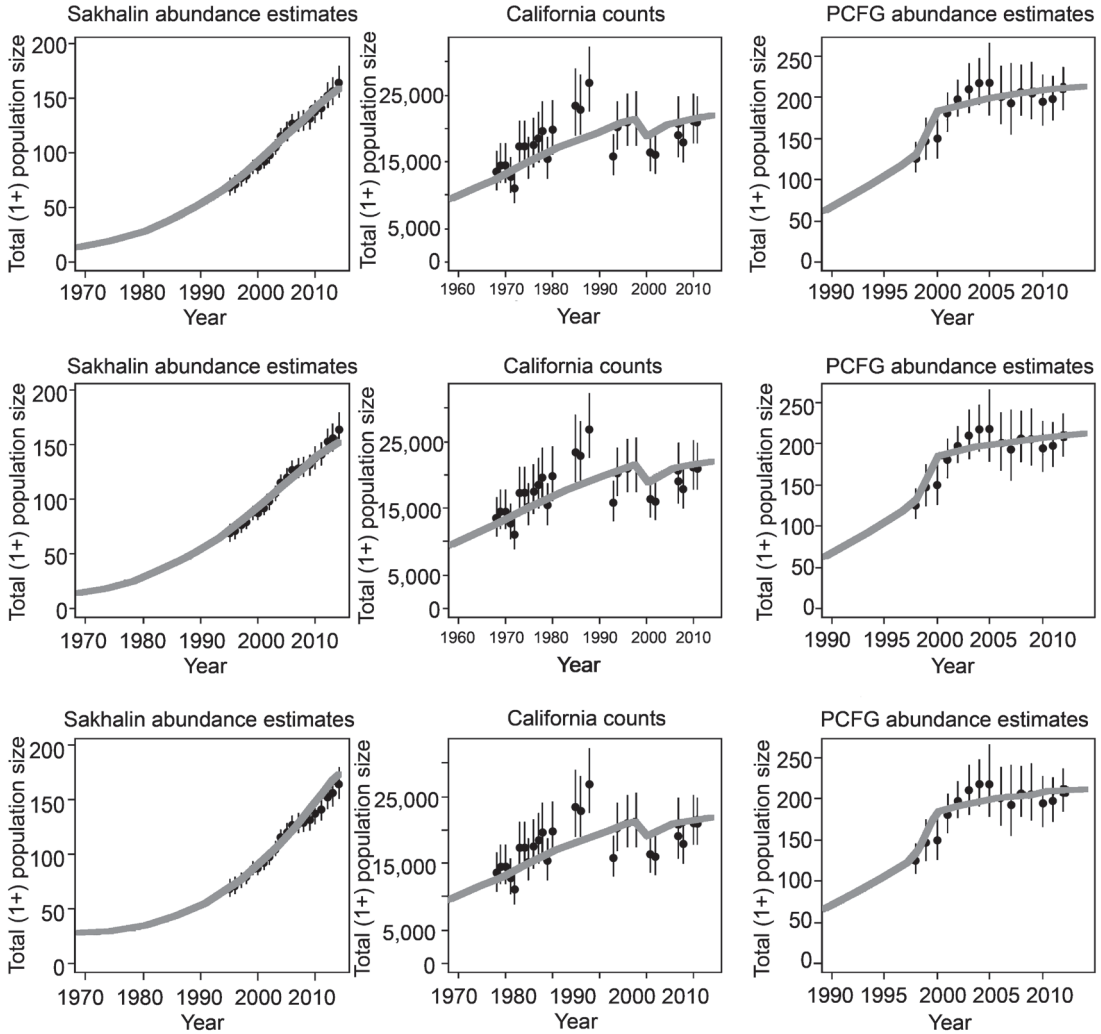


Fig. 2. (a) The plot for the areas with abundance data showing the abundance estimates and their 90% confidence intervals, the fit of the model to the actual data ('deterministic'; solid black lines), and the median and 90% intervals from the 100 replicates (solid grey line and shaded area respectively). The results in this figure pertain to the reference case model. Results are shown for stock hypotheses 3a, 3b and 5a on the upper, middle and lower panels respectively.

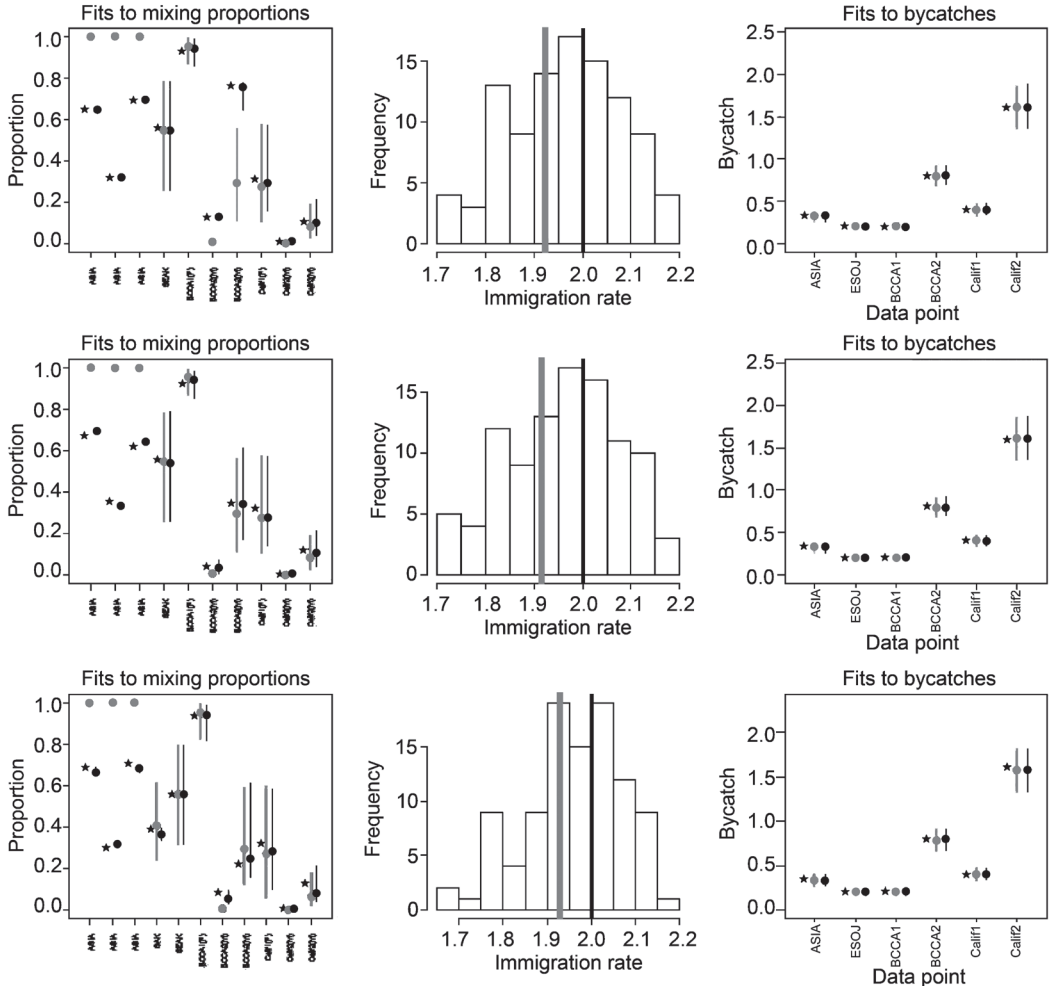


Fig. 2. (b) Summary of the fits to the data on mixing proportions (left column), immigration rate (centre column), and bycatch rates (right panel) for the reference case model. The grey dot and intervals show the median and 90% intervals for the bootstrap data sets, the stars are the fit of the model to the actual data ('deterministic'), and the black dots and lines are median and 90% intervals from the 100 replicates. The histogram in the centre plot show the bootstrap distribution for the immigration rates in the model (the black line is the median of the target values and the grey line the result of the fit to the actual data). The results in this figure pertain to the reference case model. Results are shown for stock hypotheses 3a, 3b and 5a on the upper, middle and lower panels respectively.

SC/A16/GW02 provided three diagnostics plots to assist with the evaluation of the conditioning of the models (see Fig. 2a-c for examples).

(1) The abundance estimates and their 90% confidence intervals, with the fit of the model to the actual data ('deterministic'; solid black lines), and the median and 90% intervals from the 100 replicates (solid grey line and shaded area respectively).
(2) Fits to the data on mixing proportions, immigration rate, and bycatch rates. The grey dot and intervals show the median and 90% intervals for the bootstrap data sets, the stars are the fits of the model to the actual data ('deterministic'), and the black dots and lines are median and 90% intervals from the 100 replicates. The histogram in the centre plot shows the bootstrap distribution for the immigration rates in the model (the black line is the median of the target values and the grey line the result of the fit to the actual data).
(3) Time-trajectories of numbers of mature females by breeding stock/feeding aggregation. The black line is the fit of the model to the actual data ('deterministic'; solid black lines), and the solid grey line and shaded area respectively are the median and 90% intervals from the 100 replicates.

The Workshop noted that the model was generally able to mimic the time-series of abundance estimates and the bycatch rates well. One exception was that the model failed to capture the decline in abundance from 1998 to 2000, even though the model includes a parameter to account for additional mortality. It also failed to mimic well the change in abundance estimates from 1987/88 to 1992/93. The Workshop noted several hypotheses for the latter result, including that migratory behaviour may have changed between 1987/88 and 1992/93 (e.g. differing proportions migrating past the central California census depending upon body condition), but agreed not to change the model without independent data to corroborate this (e.g. data on body condition are available for the years 1997-2003 and 2012 and there are ongoing (since 2015) efforts to collect such data).

The 'deterministic' fit to the immigration rate was close to the pre-specified value. The model predictions of mixing rates for the EJPJ sub-area suggested that 2/3 of the animals in this area were from the Western Feeding Ground (WFG), which is expected given that two of the three identified animals were WFG animals. In general, the model mimics the mixing proportions but some of the fits were poor.

The Workshop requested additional diagnostic plots be developed to show the model predictions of immigration over time as well as the time-trajectories of bycatch. Examples of these figures are shown in Fig. 3.

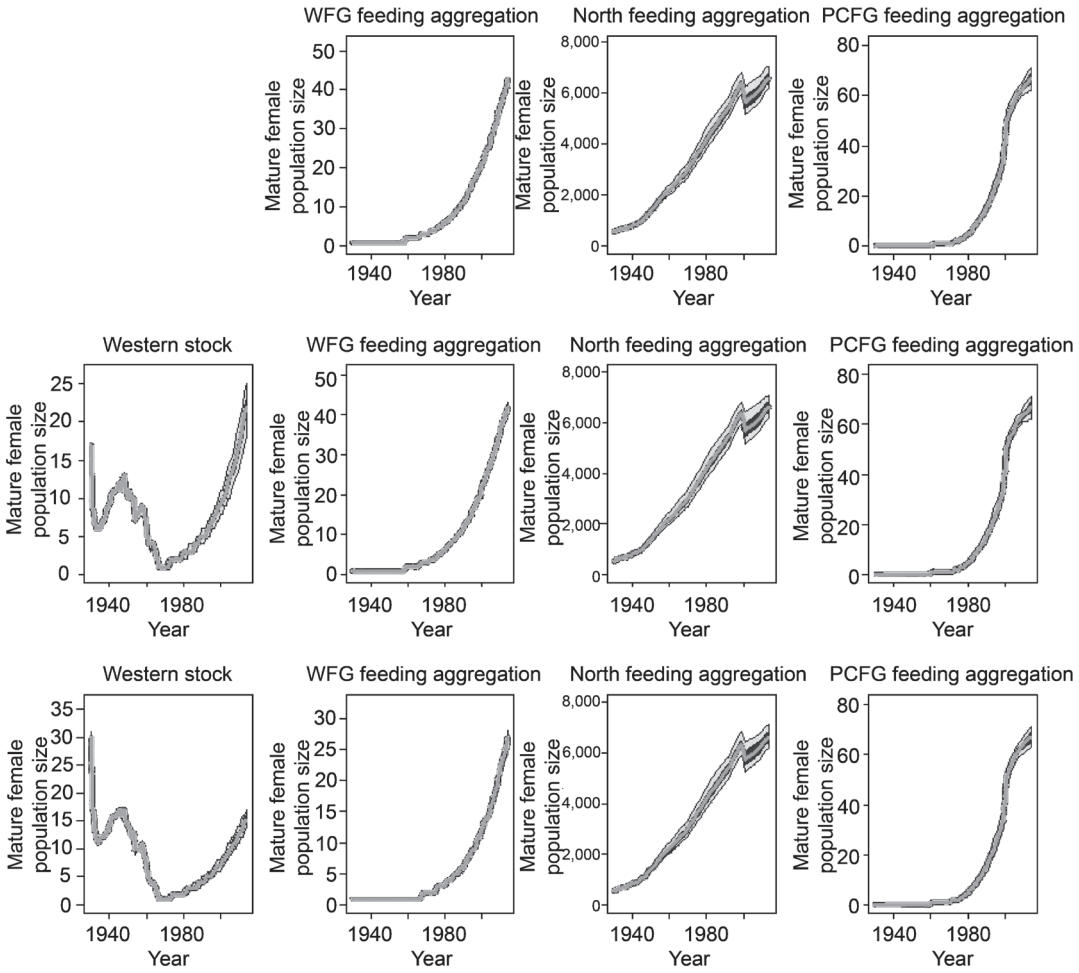


Fig. 2. (c) Time-trajectories of numbers of mature females by stock/feeding aggregation and stock hypothesis (3a, 3b and 5a on the upper, middle and lower panels respectively) for the reference case model. The black line is the fit of the model to the actual data ('deterministic'; solid black lines), and the solid grey line and shaded area respectively are the median and 90% intervals from the 100 replicates.

In conclusion, the Workshop thanked Punt for his thorough work and agreed that these plots provided an appropriate basis for evaluating model performance. It **agreed** that the plot showing the fit to the mixing proportions should be modified to include all the mixing proportions (so the sum of the observed mixing proportions adds to 1 across stocks for each sub-area). The Workshop **encouraged** SWFSC to examine the body condition data mentioned above in relation to the annual ice condition data.

4.2 Finalise data sets by stock structure hypothesis

4.2.1 Removals and abundance estimates

The Workshop agreed to make two changes the time-series of historical removals:

(1) the catches for 2014 in the BSCS sub-area should be 43 males and 81 females (C. Allison, pers. comm.); and
(2) the catch series for EJPJ sub-area should include the catch of 1 (unknown sex) as discussed in Brownell and Kasuya (1999).

Most of the analyses in SC/A16/GW02 were based on annual estimates of the number of dead animals due to bycatch and ship strikes (sensitivity to this was explored to five times this number). As in previous Workshops, the Workshop **reiterated** that the number of dead animals would underestimate, probably considerably, the actual number of animals killed due to bycatch and ship strikes. The Workshop therefore **agreed** to four scenarios regarding based on:

(a) the numbers reported as dead;
(b) the numbers reported as dead or 'seriously injured' *sensu* Carretta *et al.* (base-case); and
(c) four times the numbers reported as dead;
(d) ten times the numbers reported as dead.

The value of four was based on Carretta *et al.* (2016) estimate of the fraction of carcasses recovered of coastal common bottlenose dolphins (0.25, 95% CI=0.20 -0.33), while the value of ten was based on the results of Punt and Wade (2012), who estimated that between 3% and 14% of gray whales that died during the 1999-2000 mortality event were reported.

The bycatches used in the modelling were extended to include bycatch for the BCSC sub-area and were separated between the feeding (June-November) and migratory (December-May) periods for the SEA sub-area (Table 1). Annex D documents the basis for the estimates of bycatch for the VSC and EJPJ sub-areas while Annex E documents the basis for the bycatch/ship strike estimates for the eastern sub-areas. The estimates of bycatch for the VSC and EJPJ sub-areas are assumed to pertain to years 1990-2014, as the reporting of strandings, ship strikes and bycatches off Japan is likely to have been more consistent since 1990.

4.2.2 Abundance estimates

The analyses in SC/A16/GW02 were based on updated abundance estimates and their associated variance covariance matrix for the Sakhalin sub-area based on the

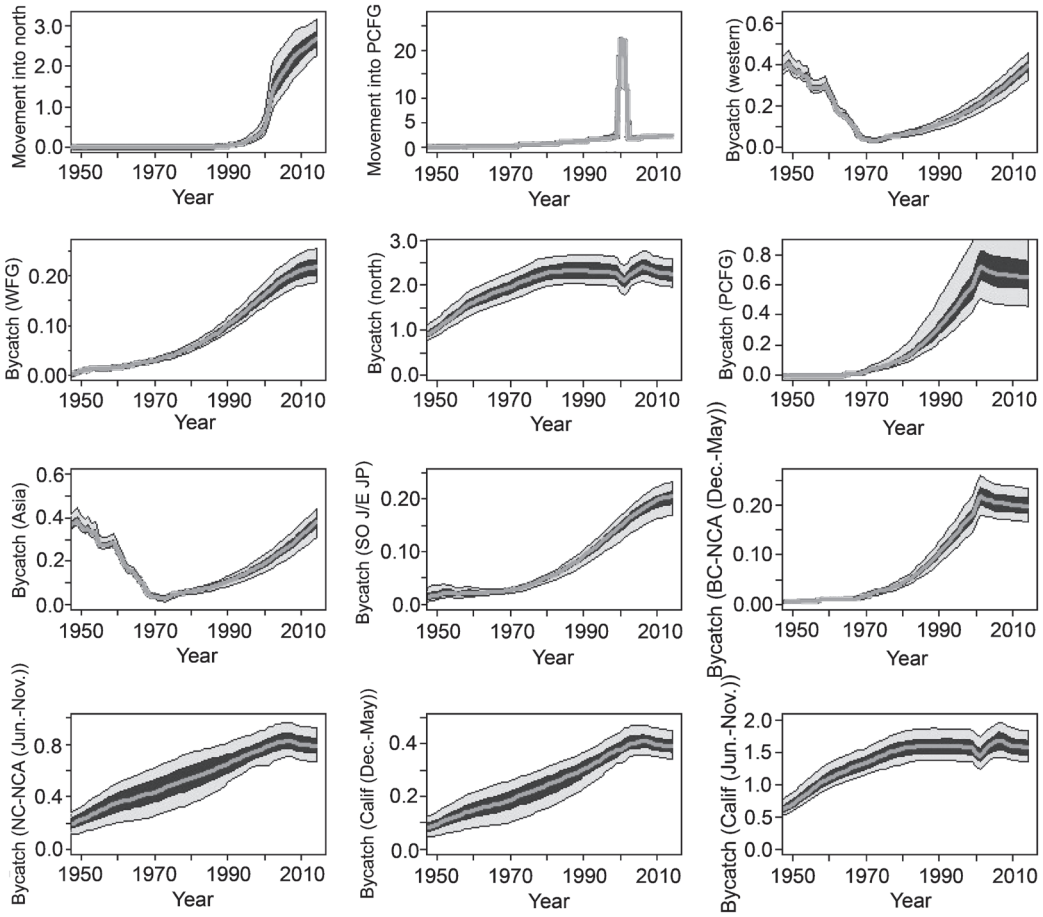


Fig. 3. Time-trajectories of: (a) number dispersing between the 'north' and PCFG' feeding aggregations; (b) bycatch by stock/feeding aggregation; and (c) bycatch by sub-area. The black line is the fit of the model to the actual data ('deterministic'; solid black lines), and the solid grey line and shaded area respectively are the median and 90% intervals from the 100 replicates. The results here pertain to stock structure hypothesis 3e.

Table 4

Scenarios regarding bycatch.

Sub-area	Years	Numbers dead	Dead and serious injury	Numbers dead x 4	Numbers dead x 8
VSC	1990-2014	1/25	??	4/25	8/25
EJPJ	1990-2014	4/25	??	16/25	32/25
SI	1997-2014	1.5/18	??	6/18	12/18
BSCS					
SEA (Jun.-Nov.)					
SEA (Dec.-May)					
BCNC (Jun.-Nov.)					
BCNC (Dec.-May)					
CA (Jun.-Nov.)					
CA (Dec.-May)					

Bayesian version of the model developed by Cooke (e.g. see the report of WGWAP-16). The Workshop **endorsed** use of these abundance estimates as provided in Annex F. Other abundance estimates agreed in IWC (2016) are also provided in Annex F.

4.2.3 Mixing proportions

SC/A16/GW05 provided an update for the availability of PCFG whales by region and season using the database of whale sightings maintained by the Cascadia Research Collective for sightings through 2014. Availability was calculated as the number of observations of whales meeting the IWC definition for PCFG whales (IWC, 2015b) divided by the total number of gray whale observations. Observations were defined as a uniquely identified whale photographically identified by day. Small changes in availability were calculated for PCFG whales in the summer feeding season and migratory season in the northern California to British Columbia region and central and southern California in the feeding season as compared to the values reported in Scordino *et al.* (2014).

The Workshop reviewed the data on the stock identity of animals caught off Japan and **agreed** with the two scenarios (base-case: definite matches/non-matches; sensitivity: definite and likely matches non-matches; table 2a in SC/A16/GW02).

The Workshop thanked Scordino for the updated analyses in SC/A16/GW02, and **agreed** to modify the mixing rates to the values suggested in SC/A16/GW05. Given that the collection of photographs in the CA sub-area during the migration season (December-May) is not random but targeted towards PCFG whales, the Workshop **agreed**

Table 5

Data on mixing proportions (definite and likely matches/non-matches only) to be used when conditioning the models.

Sub-area	Year	Stock concerned	Estimate (assumed SD)
EJPJ	2007[d]	WFG	1 (0.1)
EJPJ	2012[d]	Western	1 (0.1)
EJPJ	2015[d]	WFG	1 (0.1)
EJPJ	2005[l]	Western	1 (0.1)
EJPJ	2007[l]	Western	1 (0.1)
SI	2012	Western	0.40[a] (0.1)
SEA (Jun.-Nov.)	2012	PCFG	0.559 (0.15)
BCNC (Jun.-Nov.)	2012	PCFG	0.951 (0.05)
BCNC (Dec.-May)	2012	WFG	0.002 (0.05)
BCNC (Dec.-May)	2012	PCFG	0.339 (0.15)
CA (Jun.-Nov.)	2012	PCFG	0.472 (0.15)

[a]Stock structure hypothesis 5a only (changed in sensitivity analysis).
[d]Definite; [l]Likely.

Table 6

Factors considered in the model scenarios. The bolded values are the base-levels.

Factor	Levels
Model fitting related	
Stock hypothesis	**3a, 3e, 5a**
Proportion of 'Western' stock in Sakhalin sub-area	**0** (stock hypotheses 3a, 3e), **0.33** (stock hypothesis 5a), 0.70
$MSYR_{1+}$ (western)	As for WFG
$MSYR_{1+}$ (north)	**4.5%**, 5.5%, Estimated (common); estimate (separately)
$MSYR_{1+}$ (WFG)	**4.5%**, 5.5%, Estimated (common); estimate (separately)
$MSYR_{1+}$ (PCFG)	2%, **4.5%**¸ Estimated (common); estimate (separately)
Matches	Definite; Definite+Likely (Table 2)
Immigration into the PCFG	**0, 2**, 4
Bycatches and ship strikes	Numbers dead, M/SI, numbers dead x 4; x numbers dead x 10
Pulse migrations into the PCFG	10, **20**, 30
Bycatch off Sakhalin	**1.5**, 3
Projection-related	
Northern need in final year (from 150 in 2014)	**340**, 530
Struck and lost rate	25% **50%**, 75%
Future effort	**Constant**, Increase by 100% over 100 years
Probability of mismatching a north whale, p_1	**0.01**
Probability of mismatching a PCFG, p_2	0.05 (trials)
PCFG harvest month	**Migratory**

to modify the catch mixing matrix for this combination of sub-area and season so that it is assumed that all animals are equally vulnerable to capture. It also **agreed** that all animals should be assumed to be equally vulnerable to capture, or proportionately to abundance for all areas noted in Table 5 (and see Annex E).

The final mixing proportions are given in Table 5.

4.3 Further development of trials to reflect uncertainty and anthropogenic removals

4.3.1 Base-case models and sensitivity tests

The Workshop **agreed** to the following changes to specifications the base-case model:

(a) the SEA sub-area should be divided into feeding and movement seasons given different bycatch rates in this sub-area seasonally (Table 5); and
(b) the proportion of animals in Sakhalin that are Western stock animals should be set to 0.33 (table 3 of SC/A16/GW06).

The Workshop reviewed the set of factors on which trials could be based suggested in SC/A16/GW06 and made the following changes (see Table 6):

(a) the alternative value for the proportion of Western stock animals in the SI sub-area was changed to 0.33 based on table 3 of SC/A16/GW06;
(b) scenarios in which $MSYR_{1+}$ is estimated should be considered for two cases, one in which $MSYR_{1+}$ is assumed to be the same for all feeding aggregations and the other in which $MSYR_{1+}$ differs among feeding aggregations;
(c) the higher alternative number of 'north' animals immigrating into the PCFG feeding aggregation was reduced from 8 to 4 based upon information provided by Laake, and the fact that the value of 8 provided a poor fit[3] - the case of 8 was retained for the trial involving estimated MSYR to examine whether this might improve the fit;
(d) the scenarios regarding bycatches and ship strikes was updated (see Item 4.2.2);
(e) the assumption that dispersal is not density-dependent was dropped as this assumption leads to poor fits to the available data (SC/A16/GW02); and
(f) two scenarios regarding the bycatch off Sakhalin were added (see Annex F).

Table 7 lists the trials. The bulk of the trials involve one change from the base-case models. Trials 16-20 involve two changes to the base-case trials. Trial 16 involves two changes that should make achieving conservation objectives

[3]The immigration rate of 0 is consistent with observations that internal recruitment into the PCFG has been high in recent years (Perez *et al*., 2015).

Table 7
The trial specifications.

Trial	Description/stock hypothesis	PCFG in BSCS	$MSYR_{1+}$ North	$MSYR_{1+}$ PCFG	$MSYR_{1+}$ WFG	% Western in Sakhalin	PCFG immigration	PCFG pulse	Bycatch multiplier
1A	Reference 3a	No	4.5%	4.5%	4.5%	0	2	20	1
1B	Reference 3e	No	4.5%	4.5%	4.5%	0	2	20	1
1C	Reference 5a	No	4.5%	4.5%	4.5%	0.33	2	20	1
2A	Lower MSYR PCFG 3a	No	**4.5%**	**2%**	**4.5%**	0	2	20	1
2B	Lower MSYR PCFG 3e	No	**4.5%**	**2%**	**4.5%**	0	2	20	1
2C	Lower MSYR PCFG 5a	No	**4.5%**	**2%**	**4.5%**	0.33	2	20	1
3A	Higher MSYR WFG and North 3a	No	**5.5%**	**5.5%**	**4.5%**	0	2	20	1
3B	Higher MSYR WFG and North 3e	No	**5.5%**	**5.5%**	**4.5%**	0	2	20	1
3C	Higher MSYR WFG and North 5a	No	**5.5%**	**5.5%**	**4.5%**	0.4	2	20	1
4C	Higher Western breeding stock in Sakhalin 5a	No	4.5%	4.5%	4.5%	**0.7**	2	20	1
5A	Alternative matches 3a	No	4.5%	4.5%	4.5%	0	2	20	1
5B	Alternative matches 3e	No	4.5%	4.5%	4.5%	0	2	20	1
5C	Alternative matches 5a	No	4.5%	4.5%	4.5%	0.33	2	20	1
6A	Lower PCFG Immigration 3a	No	4.5%	4.5%	4.5%	0	**0**	20	1
6B	Lower PCFG Immigration 3e	No	4.5%	4.5%	4.5%	0	**0**	20	1
6C	Lower PCFG Immigration 5a	No	4.5%	4.5%	4.5%	0.33	**0**	20	1
7A	Higher PCFG Immigration 3a	No	4.5%	4.5%	4.5%	0	**4**	20	1
7B	Higher PCFG Immigration 3e	No	4.5%	4.5%	4.5%	0	**4**	20	1
7C	Higher PCFG Immigration 5a	No	4.5%	4.5%	4.5%	0.33	**4**	20	1
8A	Lower Pulse into PCFG 3a	No	4.5%	4.5%	4.5%	0	2	**10**	1
8B	Lower Pulse into PCFG 3e	No	4.5%	4.5%	4.5%	0	2	**10**	1
8C	Lower Pulse into PCFG 5a	No	4.5%	4.5%	4.5%	0.33	2	**10**	1
9A	Higher pulse into PCFG 3a	No	4.5%	4.5%	4.5%	0	2	**30**	1
9B	Higher pulse into PCFG 3e	No	4.5%	4.5%	4.5%	0	2	**30**	1
9C	Higher pulse into PCFG 5a	No	4.5%	4.5%	4.5%	0.33	2	**30**	1
10A	Bycatch x 4 3a	No	4.5%	4.5%	4.5%	0	2	20	**4**
10B	Bycatch x 4 3e	No	4.5%	4.5%	4.5%	0	2	20	**4**
10C	Bycatch x 4 5a	No	4.5%	4.5%	4.5%	0.33	2	20	**4**
11A	Bycatch x 10 3a	No	4.5%	4.5%	4.5%	0	2	20	**10**
11B	Bycatch x 10 3e	No	4.5%	4.5%	4.5%	0	2	20	**10**
11C	Bycatch x 10 5a	No	4.5%	4.5%	4.5%	0.33	2	20	**10**
12A	Bycatch = 3 in SI 3a	No	4.5%	4.5%	4.5%	0	2	20	**2 for SI**
12B	Bycatch = 3 in SI 3e	No	4.5%	4.5%	4.5%	0	2	20	**2 for SI**
12C	Bycatch = 3 in SI 5a	No	4.5%	4.5%	4.5%	0.33	2	20	**2 for SI**
13A	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0	2	20	1
13B	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0	2	20	1
13C	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0.33	2	20	1
14A	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0	2	20	1
14B	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0	2	20	1
14C	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0.33	2	20	1
15A	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Est**	**Est**	**Est**	0	2	20	1
15B	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Est**	**Est**	**Est**	0	2	20	1
15C	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Est**	**Est**	**Est**	0.33	2	20	1
16A	Lower PCFG immigration & higher bycatch 3a	No	4.5%	4.5%	4.5%	0	**0**	20	**4**
16B	Lower PCFG immigration & higher bycatch 3e	No	4.5%	4.5%	4.5%	0	**0**	20	**4**
16C	Lower PCFG immigration & higher bycatch 5a	No	4.5%	4.5%	4.5%	0.33	**0**	20	**4**
17A	MSYR estimated and lower pulse 3a	No	**Est**	**Est**	**Est**	0	2	**10**	1
17B	MSYR estimated and lower pulse 3e	No	**Est**	**Est**	**Est**	0	2	**10**	1
17C	MSYR estimated and lower pulse 5a	No	**Est**	**Est**	**Est**	0.33	2	**10**	1
18A	MSYR estimated and higher pulse 3a	No	**Est**	**Est**	**Est**	0	2	**30**	1
18B	MSYR estimated and higher pulse 3e	No	**Est**	**Est**	**Est**	0	2	**30**	1
18C	MSYR estimated and higher pulse 5a	No	**Est**	**Est**	**Est**	0.33	2	**30**	1
19A	MSYR estimated and higher immigration 3a	No	**Est**	**Est**	**Est**	0	**4**	20	1
19B	MSYR estimated and higher immigration 3e	No	**Est**	**Est**	**Est**	0	**4**	20	1
19C	MSYR estimated and higher immigration 5a	No	**Est**	**Est**	**Est**	0.33	**4**	20	1
20A	MSYR estimated and much higher immigration 3a	No	**Est**	**Est**	**Est**	0	**8**	20	1
20B	MSYR estimated and much higher immigration 3e	No	**Est**	**Est**	**Est**	0	**8**	20	1
20C	MSYR estimated and much higher immigration 5a	No	**Est**	**Est**	**Est**	0.33	**8**	20	1

for the PCFG feeding aggregation more difficult while all but one set of the remaining multi-factor trials combine estimates of feeding-aggregation-specific MSY rates with different assumptions regarding immigration into the PCFG feeding aggregation. Trial 20 explores whether it is possible to mimic the data when the immigration into the PCFG feeding aggregation is 8 and $MSYR_{1+}$ is estimated by feeding aggregation.

The Workshop examined the stock structure hypotheses developed by IWC (2015b; 2016). Most of these hypotheses are either equivalent to stock structure hypotheses 3a, 3e and 5a or there are insufficient data to parameterise them. In review, however, the Workshop decided that hypothesis 6b[4], which was initially assigned low priority because it would be represented in the same way as hypothesis 5a in the modelling framework, should be reconsidered. This hypothesis assumes that the WFG feeding aggregation, *per se*, does not exist, but that

[4]Two breeding stocks – one includes whales from the PCFG and Northern feeding sub-stocks that migrate to Mexico and largely breed with each other, and the other includes all whales that feed off Sakhalin and breed largely with each other whether on the ENP or WNP migratory routes/ wintering grounds.

whales feeding in the SI sub-area represent an extant Western breeding stock that utilises two wintering grounds (VSC and M). In discussion, it was noted that modelling this hypothesis does differ from that of hypothesis 5a, in that: (1) all catches off Japan are assumed to be Western stock animals; and (2) the abundance estimates off Sakhalin are assumed to relate only to the Western stock. Thus the Workshop **agreed** that an attempt should be made to implement this stock structure hypothesis and evaluate the conservation implications.

4.3.2 Projections

The aim of the projections is to explore the population consequences of various scenarios regarding anthropogenic removals of gray whales, with a view to informing future conservation and management. Table 6 lists the factors to be considered in the projections. The Workshop **agreed** that the projections would assumed that future subsistence whaling in the BCNC sub-area would occur during the migratory period and would be based on 'the *SLA* variant with research' (IWC, 2015b) recommended by the Scientific Committee.

It was **agreed** that the results of the projections should be summarised by:

(a) time-trajectories of mature female numbers relative to carrying capacity, catches by stock due to aboriginal whaling, and incidental catches by stock;
(b) the conservation-related metrics used for the implementation for the PCFG *SLA*; and
(c) a table for the proportion of catch of WFG whales by sub-area (20 and 100 years).

5. WORK PLAN

The following work plan was **agreed** by the Workshop, recognising that this was ambitious and would depend upon the availability of individuals.

(1) Scordino and Reeves to update and circulate to the Steering Group the bycatch values for the BCNC subarea by 25 April.
(2) Punt to distribute the diagnostic plots for the base-case trials by 30 April.
(3) Punt to fit all of models in Table 4 as well as a base-case model based on the new stock structure hypothesis and distribute the results to the Steering Group by mid-May (Punt, Donovan, Wade, Cooke, Reeves).
(4) Steering Group to provide comments on the model fits and guidance on projection runs to Punt by 20 May.
(5) Punt to conduct the projections in accordance with guidance from the Steering Group and present results to SC/66b.

6. ADOPTION OF REPORT

The report was adopted at 11:44 on 21 April 2016, subject to final editorial corrections. Donovan thanked Weller for his hard work in organising the excellent facilities and assisting with the hotel. He thanked all participants and especially the rapporteurs for their co-operative spirit. Most of all he thanked Punt for his dedicated, innovative and tireless work during both the intersessional period and the meeting itself.

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Annex A

List of Participants

USA
R.L. Brownell, Jr.
J. Laake
A. Lang
P. Wade
D. Weller

Invited Participants
J. Scordino
J. Bickham
A.E. Punt
R.R. Reeves

IWC
G.P. Donovan

Annex B

Agenda

1. Introductory items
   - 1.1 Convenor's opening remarks
   - 1.2 Election of Chair
   - 1.3 Appointment of rapporteurs
   - 1.4 Adoption of Agenda
   - 1.5 Documents and data available
2. Short report on progress on 'non-modelling' recommendations and new data since SC66a
   - 2.1 Update on comparison of identified gray whales in Mexico, off central California and in the PCFG with a focus on mothers and calves
   - 2.2 Comparison of photographs (and genetic material) of gray whales from areas of the Okhotsk Sea and elsewhere in Asia with the Sakhalin and Kamchatka catalogues
   - 2.3 Development of Single Nucleotide Polymorphisms (SNP) assays for use with gray whales
   - 2.4 Updated information from the eastern North Pacific
   - 2.5 Updated abundance and trend estimates for the PCFG by identifying and using additional photographic sources
   - 2.6 Updated estimates for past and future ship strikes and bycatches throughout the North Pacific
3. Progress report on modelling-related issues
   - 3.1 Updated bounds on the proportion of Sakhalin whales that migrate to the eastern North Pacific
   - 3.2 Development of an age- and sex-structured model
4. Update on modelling framework and initial runs
   - 4.1 Progress on modelling since SC/66a
   - 4.2 Finalise datasets by stock structure hypothesis
     - 4.2.1 Removals and abundance estimates
     - 4.2.2 Abundance estimates
     - 4.2.3 Mixing proportions
   - 4.3 Further development of trials to reflect uncertainty and anthropogenic removals
5. Work plan
6. Adoption of Report

Annex C

List of Documents

SC/A16/GW

1. Punt, A.E. Progress report on rangewide gray whale modelling.
2. Punt, A.E. A revised age-structured model for exploring the conceptual models developed for gray whales in the North Pacific.
3. Agenda for Workshop.
4. Weller, D.W., Lang, A.R. and Brownell, R.L., Jr. Gray whale photo/genetic match-no match summary in Western North Pacific: data for April 2016 IWC rangewide Workshop.
5. Scordino, J. and Calambokidis, J. Availability of PCFG whales by region during the migratory and feeding season: update with data through 2014.

Annex D

Gray Whale Photo/Genetic Match-No Match Summary in Western North Pacific

D.W. Weller, A.R. Lang and R.L. Brownell, Jr.

Table 1

Summary of information available regarding matches and non-matches (genetic or photographic) for gray whales from the western North Pacific. Due to the tsunami in 2011, it is assumed that DNA or tissue is no longer available for the genetic records marked with an asterisk. Information from: Kato *et al.*, 2015; Lang *et al.*, 2011; Weller *et al.*, 2002; 2003; 2008; 2012; 2015.

No.	Type	Date	Country	Sample	Comments
1	Genetic*	07/04/1995	Japan	Stranding Female 9.5m	Hokkaido (Pacific). Haplotype identified as G or O in Kanda *et al.* (2010). Haplotype G is found in low frequencies among both sampled Eastern North Pacific (ENP) whales and sampled Sakhalin whales (found in two individuals off Sakhalin). Haplotype O has not been found among biopsied Sakhalin individuals and is found in low frequencies among sampled ENP animals.
2	Genetic*	16/05/1996	Japan	Killed	Hokkaido (Sea of Japan). Haplotype identified as A in Kanda *et al.* (2010). Haplotype A is common in both sampled ENP and sampled Sakhalin whales (and is one of the two most commonly identified haplotypes in whales biopsied off Sakhalin).
3	Photo-ID	22/07/1997	Japan	Sighting	Kochi (Pacific). Photos unusable for matching (Kato and Tokuhiro, 1997).
4	Photo-ID	06/05/2003	Japan	Sighting	Shizuoka (Pacific). Photos unusable for matching. Two animals present.
5	Photo-ID Genetic*	11/05/2005	Japan	Entangled Female 7.81m	Chiba (Pacific). Marginal quality photo – no match to Sakhalin Russia-US catalogue. Haplotype identified as L or U in Kanda *et al.* (2010). Based on mtDNA and microsatellite data produced at SWFSC obtained from whole genome amplification products brought from Japan for analysis, this whale has haplotype U and is not a genetic match (based on microsatellites) for any of the whales the Russia-US team sampled off Sakhalin. Haplotype U has not been found in any biopsied Sakhalin whales but has been found in one individual biopsied off SE Kamchatka. This haplotype is not common among sampled ENP whales. Note that this whale and the whale entangled off Japan on 01 August 2007 (see note in record 8 below) share the same haplotype, although the microsatellite data indicates that they are not a mother-offspring pair. The possibility that these whales share an alternate relationship (e.g. maternal half-sibs) has not yet been assessed.
6	Photo-ID Genetic*	15/07/2005	Japan	Entangled Mother 12.8m	Miyagi (Pacific). Was with a calf. Photos unusable for matching. Haplotype of the adult female identified as Z in Kanda *et al.* (2010)[2]. Haplotype Z is found in only a few whales sampled in the ENP and among one individual sampled off Sakhalin
7	Photo-ID Genetic*	18/01/2007	Japan	Bycatch stranding Female 9.19m	Iwate (Pacific). Useable quality photo, match to Sakhalin Russia-US catalogue. Haplotype identified as Haplotype B in Kanda *et al.* (2010), which is consistent with haplotype data we have for this same whale when sampled off Sakhalin in 2006. Haplotype B is found in moderate frequencies in sampled ENP whales and in high frequencies among biopsied Sakhalin animals.
8	Genetic*	01/08/2007	Japan	Entangled Female 12.33m	Hokkaido (Pacific). Identified as Haplotype L or U in Kanda *et al.* (2010). Based on mtDNA and microsatellite data produced at SWFSC obtained from whole genome amplification products brought from Japan for analysis, this whale has haplotype U and is not a genetic match (based on microsatellites) for any whales sampled off Sakhalin by the Russia-US team. Haplotype U has not been found in any biopsied Sakhalin whales but has been found in one individual biopsied off SE Kamchatka. It is uncommon among sampled ENP whales. See note above in record 5 regarding this whale.

Cont.

No.	Type	Date	Country	Sample	Comments
9	Photo-ID	??/11/2011	China	Bycatch	Taiwan Strait (Pacific). Useable quality photo (left side only) – no match to Sakhalin Russia-US catalogue.
No.	Type	Date	Country	Sample	Comments
	Genetic				Identified as haplotype R in Wang *et al.* (2015) and confirmed by SWFSC. Based on SWFSC microsatellite genotypes, not a genetic match to any whale sampled off Sakhalin by the Russia-US team. This haplotype has not been identified among Sakhalin whales and is relatively uncommon among sampled ENP whales.
10	Photo-ID	12/03/2012	Japan	Sighting	Irako port, Tawara-city. Excellent quality photos – no match to Sakhalin RussiaUS catalogue.
11	Photo-ID	06/04/2014	Japan	Sighting	Teradomari. Excellent quality photos – no match to Sakhalin Russia-US catalogue. Inter-Japan match shows same whale as record 14 (Aoyagi *et al.*, 2016).
12	Photo-ID	03/2015	Japan	Sighting	Kozu Shima. Useable quality photo, match to Sakhalin Russia-US catalogue. Same whale as record 13.
13	Photo-ID	04-05/2015	Japan	Sighting	Suruga Bay. Marginal quality photos, match to Sakhalin Russia-US catalogue. Same whale as record 12.
14	Photo-ID	03/2015	Japan	Sighting	Teradomari. Fair quality photos – no match to Sakhalin Russia-US catalogue. InterJapan match shows same whale as record 11 (Aoyagi *et al.*, 2016).
15	Genetic	7/12/1996	China	Stranding	Yellow Sea. Baleen is archived at SWFSC but thus far, efforts to extract DNA from this baleen sample have failed and no genetic data has been obtained. See details in Zhao (1997).
16	Photo-ID	07/2000	Russia	Sighting	Paramushir Island, Kuril Islands (Okhotsk Sea). Good quality photos, match to Sakhalin Russia-US catalogue. Same whale as record 17.
17	Photo-ID	09/2000	Russia	Sighting	Shantar Island (Okhotsk Sea). Good quality photos, match to Sakhalin Russia-US catalogue. Same whale as record 16.
18	Photo-ID	06/2000	Russia	Sighting	Bering Island (Bering Sea). Good quality photos, match to Sakhalin Russia-US catalogue.
19	Photo-ID	01/2016	Japan	Sighting	Sagami Bay (Pacific). Fair quality photos, match to Sakhalin Russia-US catalogue. Same whale as records 12 and 13.
20	Photo-ID	02/2016	Japan	Sighting	Miyake-Jima (Pacific). Fair quality photos, match to Sakhalin Russia-US catalogue. Same whale as records 12, 13 and 19.
21	Photo-ID	03/2016	Japan	Stranding	Chiba (Pacific). Photos unusable for matching.

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Annex E

Non-whaling Anthropogenic Mortality of Gray Whales: 2016 Update

J. Scordino and R.R. Reeves

Scordino and Mate (2012) summarised bycatch and ship strike mortality from stranding databases, human-whale interaction databases and ship strike databases maintained by NOAA's Northwest Region and Southwest Region (databases did not include events in Alaska). Their summary also included bycatches and ship strikes reported by Baird *et al.* (2002) for 1990-95 in British Columbia and all reported ship strikes and bycatch events from 1978-2010 in the USA. Scordino and Mate (2012) chose to calculate annual human-caused mortality rates based on data from 1990-2010 for the USA and 1990-95 for Canada because fishing effort in the two jurisdictions was more similar in those years than earlier in the time-series and because stranding networks in the USA were well established by 1990, giving more confidence that animals stranded in the USA with signs of human-caused mortality would have been reported.

In 2014, Scordino *et al.* (2014) presented new estimates of annual bycatch and ship strike rates for the time period of 2008-12 using a classification procedure developed by NOAA (2012) to account for the uncertainty in outcome of injuries to large whales due to entanglements and ship strikes. This procedure makes it possible to prorate mortality values for injuries based on the known fates of individual whales observed with similar injuries in the past. Gray whale deaths and injuries were documented through fisheries observer programmes, self-reporting by fishermen and sailing captains, reporting by the public and examinations of dead whales on the beach in the USA and Canada. Every report was documented in a Canadian or US government database. Based on descriptions in the databases, each event was determined to have been either a death, a serious injury, or a non-serious injury, based on NOAA (2012). All US events were assessed for serious vs non-serious injury by a NOAA working group (Carretta *et al.*, 2014) and that group's results were used as the basis for scoring the events reported by Scordino *et al.* (2014) and summarised by Scordino *et al.* (2016).

Here we use data for 2007-14 from NOAA serious injury reports (Carretta *et al.*, 2013; 2014; 2015; 2016) received from James Carretta (NOAA, SWFSC, La Jolla, pers. comm.) for the US and from Paul Cottrell (Department of Fisheries and Oceans, Sydney, BC, pers. comm.) for Canada to update the input data on incidental mortality given in IWC (2016). The previous tables of ship strike and bycatch mortality in IWC (2016) incorrectly classified two observations at Valdez-Cordova as being from Southeast Alaska instead of from the Far North region; these have been rectified in the new tables provided here (Tables 1 and 2).

Table 1

Reported (observed) totals and 8-year averages of deaths and serious injuries of gray whales by region and season, 2007-14.

	Observed 2007-14		Average 2007-14	
Region	Feeding	Migration	Feeding	Migration
FN-Puget Sound	2.5	3.5	0.31	0.44
Kodiak	0	0	0.00	0.00
Southeast Alaska	1	0.75	0.13	0.09
BC-NCA	To be updated			
California	12.5	20.5	1.56	2.56

Table 2

Reported observed totals and 8-year averages of deaths of gray whales by region and season, 2007-14.

	Observed 2007-14		Average 2007-14	
Region	Feeding	Migration	Feeding	Migration
FN-Puget Sound	0	1	0.00	0.13
Kodiak	0	0	0.00	0.00
Southeast Alaska	0	0	0.00	0.00
BC-NCA	To be updated			
California	7	8	0.88	1.00

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Annex F

Specifications of the Population Model

A. BASIC CONCEPTS AND STOCK STRUCTURE

The aim of the projections is to explore the population consequences of various scenarios regarding anthropogenic removals of gray whales, with a view to informing future conservation and management. The model distinguishes 'breeding stocks' and 'feeding aggregations'. Breeding stocks are demographically and genetically independent whereas feeding aggregations may be linked through dispersal of individuals[1], though perhaps at very low rates for some combinations of feeding aggregations. Each breeding stock/feeding aggregation is found in a set of sub-areas, each of which may have catches (commercial, aboriginal or incidental), proportions of breeding stock/feeding aggregation mixing[2] in those sub-areas, observed bycatch rates[3], and indices of relative or absolute abundance. Removals may be specified to sets of months during the year for some sub-areas if the various feeding aggregations are not equally vulnerable to catches throughout the year for those sub-areas. The trials capture uncertainty regarding stock structure and MSYR, as well as uncertainty regarding bycatch and immigration.

The region concerned, the North Pacific, is divided into 11 sub-areas. The model also includes two 'latent' sub-areas used to link model predictions to observed indices of abundance. These are denoted CA-3 and BCNC3. There are up to two extant *breeding stocks* (Western and Eastern). The Eastern breeding stock consists of up to three *feeding aggregations* depending on the stock structure hypothesis: Western Feeding Group (WFG), Pacific Coast Feeding Group (PCFG) and 'North'. There is dispersal between the PCFG and North feeding aggregations, but the WFG is demographically independent of the other two feeding aggregations (i.e. there is no *permanent* movement of animals from the North or PCFG to the WFG or vice-versa).

The trials consider four stock structure hypotheses.

(1) *Hypothesis 3a*. Although two breeding stocks (Western and Eastern) may once have existed, the Western stock is assumed to have been extirpated. Whales show matrilineal fidelity to feeding grounds, and the Eastern stock includes three feeding aggregations: PCFG, Northern Bering Sea (NBS)/Southern Chukchi (SCH)-Northern Chukchi-Gulf of Alaska ('Northern') and WFG.

(2) *Hypothesis 3e*. Identical to hypothesis 3a except that the Western breeding stock is extant and migrates off both coasts of Japan and Korea and in the northern Okhotsk Sea west of the Kamchatka Peninsula. All of the whales feeding off Sakhalin overwinter in the eastern North Pacific.

(3) *Hypothesis 5a*. Identical to hypothesis 3a except that the whales feeding off Sakhalin include both whales that are part of the extant Western stock and remain in the western North Pacific year-round, and whales that are part of the Eastern stock and migrate between Sakhalin and the eastern North Pacific.

(4) *Hypothesis 6b*. This hypothesis assumes that the WFG feeding aggregation does not exist, but that whales feeding in the SI sub-area represent an extant Western breeding stock that utilises two wintering grounds (VSC and M). This hypothesis differs from hypothesis 5a, in that: (1) all removals off China and Japan are assumed to be Western breeding stock animals; and (2) the abundance estimates for Sakhalin are assumed to relate only to the Western breeding stock.

B. BASIC DYNAMICS

The population dynamics are based on the standard age- and sex-structured model, which has formed the basis for the evaluation of *Strike Limit Algorithms* for eastern North Pacific gray whales, i.e.:

$$\begin{aligned} N_{t+1,0}^{m/f,i,j} &= 0.5B_{t+1}^{i,j} && a = 0 \\ N_{t+1,a}^{m/f,i,j} &= ((N_{t,a-1}^{m/f,i,j} - C_{t,a-1}^{m/f,i,j})S_{a-1} + I_{t,a-1}^{m/f,i,j})\tilde{S}_t^{i,j} && 1 \le a \le x\text{-}1 \\ N_{t+1,x}^{m/f,i,j} &= ((N_{t,x}^{m/f,i,j} - C_{t,x}^{m/f,i,j})S_x + (N_{t,x-1}^{m/f,i,j} - C_{t,x-1}^{m/f,i,j})S_{x-1} + I_{t,\mathrm{x}}^{m/f,i,j} + I_{t,\mathrm{x}-1}^{m/f,i,j})\tilde{S}_t^{i,j} && a = x \end{aligned} \quad \text{(B.1)}$$

where:

$N_{t,a}^{m/f,i,f}$ is the number of males/females of age a in feeding aggregation j of breeding stock i at the start of year t;

$C_{t,a}^{m/f,i,f}$ is the number of anthropogenic removals of males/females of age a in feeding aggregation j of breeding stock i during year t (whaling is assumed to take place in a pulse at the start of each year);

[1]The term 'dispersal' is used here in the sense of 'effective dispersal', and refers to permanent movement of individuals among feeding aggregations. Such individuals become part of the feeding aggregation to which they move and contribute to future reproduction.
[2]Mixing is defined here as two feeding aggregations that overlap at some time on the feeding grounds, but do not interbreed.
[3]Bycatch is understood to include mortality or 'serious' injury from entanglement or entrapment in fishing gear (or debris) and ship strikes.

S_a is the annual survival rate of animals of age a in the absence of catastrophic mortality events (assumed to be the same for males and females):

$$S_a = \begin{cases} S_0 & \text{if } a = 0 \\ S_{1+} & \text{if } 1 \le a \end{cases} \quad \text{(B.2)}$$

S_0 is the calf survival rate;

S_{1+} is the survival rate for animals aged 1 and older;

$\tilde{S}_t^{i,j}$ is the amount of catastrophic mortality (represented in the form of a survival rate) for feeding aggregation j of breeding stock i during year t (catastrophic events are assumed to occur at the end of the year after mortality due to anthropogenic removals and non-catastrophic natural causes, and dispersal; in general $\tilde{S}_t^{i,j}$ =1, i.e. there is no catastrophic mortality);

$B_{t+1}^{i,j}$ is the number of births to feeding aggregation j of breeding stock i during year t+1;

$I_{t,a}^{s,m/f}$ is the net dispersal of female/male animals of age a into feeding aggregation j of breeding stock i during year t; and

x is the maximum (lumped) age-class (all animals in this and the x-1 class are assumed to be recruited and to have reached the age of first parturition). x is taken to be 15.

C. DENSITY-DEPENDENCE

Density-dependence is assumed to be a function of numbers of animals aged 1 and older by feeding ground relative to the carrying capacity by feeding ground. The density-dependence component for feeding aggregation j of breeding stock i is the sum of the density-dependence components by feeding aggregation weighted by the proportion of animals from feeding aggregation j of breeding stock i that are found on each feeding ground, i.e.:

$$F(i,j,t) = \sum_A \psi^{A,i,j} \left(X^{A,i,j} (N_t^{1+,A} / K^{1+,A})^z \right) / \sum_A \psi^{A,i,j} X^{A,i,j} \quad \text{(C.1)}$$

where

z is the degree of compensation;

$\psi^{A,i,j}$ indicates whether sub-area A impacts density-dependence for feeding aggregation j of breeding stock i;

N_t^{1+A} is the number of 1+ animals on feeding ground A at the start of year t:

$$N_t^{1+,A} = \sum_i \sum_j X^{A,i,j} \sum_{a=1}^{x} (N_{t,a}^{m,i,j} + N_{t,a}^{f,i,j}) \quad \text{(C.2)}$$

K_t^{1+A} is the carrying capacity for feeding ground A:

$$K^{1+,A} = \sum_i \sum_j X^{A,i,j} \sum_{a=1}^{x} (N_{-\infty,a}^{m,i,j} + N_{-\infty,a}^{f,i,j}) \quad \text{(C.3)}$$

$X^{A,i,j}$ is the proportion of animals in feeding aggregation j of breeding stock i that are found in feeding ground A[4] (see Table 1).

The number of births at the start of year t for feeding aggregation j of breeding stock i, $B_t^{i,j}$, is given by:

$$B_t^{i,j} = b_t^{i,j} N_t^{f,i,j} \quad \text{(C.4)}$$

where $N_t^{f,i,j}$ is the number of mature females in feeding aggregation j of breeding stock i at the start of year t:

$$N_t^{f,i,j} = \sum_{a=a_m}^{x} N_{t,a}^{f,i,j} \quad \text{(C.5)}$$

a_m is the age-at-maturity (the convention of referring to the mature population is used here, although this actually refers to females that have reached the age of first parturition);

$b_t^{i,j}$ is the probability of birth/calf survival for mature females in feeding aggregation j of breeding stock i during year t:

$$b_t^{i,j} = \max(0, b_K \{1 + A^{i,j} (1 - F(I,j,t))\}) \quad \text{(C.6)}$$

b_K is the average number of live births per year per mature female at carrying capacity; and

$A^{i,j}$ is the resilience parameter for feeding aggregation j of breeding stock i.

[4]It is usually the case that $\Sigma X^{A,i,j} = 1$. However, for gray whales, this is not necessarily the case because removals can take place in the various feeding grounds at different times. What is then important is the relative values of the $X^{A,i,j}$ among feeding aggregations for a given feeding ground.

Table 1

The mixing matrices for stock structure hypotheses 3a, 3e, 5a and 6b. The γs denote the estimable parameters of the catch mixing matrix and the χs denote values that are varied in the tests of sensitivity. Note that the 'CA-3' sub-area is included so that the surveys (= encompasses all methods for obtaining abundance estimates) cover all of the PCFG, Sakhalin and north feeding aggregations while the BCNC-3 sub-area is included so that the surveys for the BCNC sub-area pertain only to the PCFG feeding aggregation.

Breeding stock	Sub-area															
Feeding aggregation	VSC	KWJ	EJPJ	OS	SI	EKK	BSCS	SEA (J-N)	SEA(D-M)	BCNC (J-N)	BCNC (D-M)	BCNC-3	CA (J-N)	CA (D-M)	CA-3	M
(a) Hypothesis 3a (no extant Western breeding stock)																
Eastern WFG	-	-	1	1	1	1	-	-	1	-	γ_4	-	-	1	1	1
North	-	-	γ_1	-	-	-	1	1	1	1	1	-	1	1	1	1
PCFG	-	-	-	-	-	-	χ_1	γ_2	1	γ_3	γ_5	1	γ_6	1	1	1
(b) Hypothesis 3e (extant Western breeding stock)																
Western	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Eastern WFG	-	-	γ_7	1	1	1	-	-	1	-	γ_4	-	-	1	1	1
North	-	-	-	-	-	-	1	1	1	1	1	-	1	1	1	1
PCFG	-	-	-	-	-	-	χ_1	γ_2	1	γ_3	γ_6	1	γ_6	1	1	1
(c) Hypothesis 5a (with Western breeding stock in SI)																
Western	1	1	1	1	γ_8	-	-	-	-	-	-	-	-	-	-	-
Eastern WFG	-	-	γ_7	1	1	1	-	-	1	-	γ_4	-	-	1	1	1
North	-	-	-	-	-	-	1	1	1	1	1	-	1	1	1	1
PCFG	-	-	-	-	-	-	χ_1	γ_2	1	γ_3	γ_5	1	γ_6	1	1	1
(d) Hypothesis 6b (no WFG feeding aggregation)																
Western	1	1	1	1	1	1	-	-	1	-	γ_4	-	-	1	1	1
Eastern North	-	-	-	-	-	-	1	1	1	1	1	-	1	1	1	1
PCFG	-	-	-	-	-	-	χ_1	γ_2	1	γ_3	γ_5	1	γ_6	1	1	1

D. IMMIGRATION (DISPERSAL)

The numbers dispersing into feeding aggregation *j* of breeding stock *i*, include contributions from pulse migration as well as diffusive dispersal:

$$I_{t,a}^{s,j,i} = \sum_k \delta^{k,j,i} \tilde{N}_{t,a}^{s,i,k} \left(\frac{N_t^{f,i,k}}{N_{-\infty}^{f,i,k}}\right)^{\lambda} - \sum_k \delta^{j,k,i} \tilde{N}_{t,a}^{s,i,j} \left(\frac{N_t^{f,i,j}}{N_{-\infty}^{f,i,j}}\right)^{\lambda} + \sum_{k \neq j} \Omega_y^{k,j,i} \frac{\tilde{N}_{t,a}^{s,i,k}}{\sum_{a=1}^{x} (\tilde{N}_{t,a}^{m,i,k} + \tilde{N}_{t,a}^{f,i,k})} - \sum_{k \neq j} \Omega_y^{j,k,i} \frac{\tilde{N}_{t,a}^{s,i,j}}{\sum_{a=1}^{x} (\tilde{N}_{t,a}^{m,i,j} + \tilde{N}_{t,a}^{f,i,j})} \quad \text{(D.1)}$$

where

$\delta^{k,j,i}$ is the rate of dispersal from feeding aggregation *k* to feeding aggregation *j* of breeding stock *i*;

λ is a factor to allow for density-dependence in the dispersal rate (set to 2);

$\Omega_y^{k,j,i}$ is the number of animals that disperse during year *y* from feeding aggregation *k* to feeding aggregation *j* of breeding stock in a pulse; and

$$\tilde{N}_{t,a}^{s,i,k} = (N_{t,a}^{s,i,k} - C_{t,a}^{s,i,k}) S_a$$

E. ANTHROPOGENIC REMOVALS

The catch by feeding aggregation is generally determined by apportioning the catches by fleet[5], taking account of mixing (i.e. exposure to harvesting) matrices, according to:

$$C_{t,a}^{m/f,i,j} = \sum_k C_t^{m/f,k} \frac{\alpha_a^k X^{A_k,i,j} N_{t,a}^{m/f,i,j}}{\sum_{i,j,a} \alpha_a^k X^{A_k,i,j} N_{t,a}^{m/f,i,j}} \quad \text{(E.1)}$$

where

$C_t^{m/f,k}$ is the catch of males/females caught by fleet *k* during year *t*;

A_k is the sub-area in which fleet *k* operates; and

α_a^k is the relative vulnerability of animals of age *a* to harvest by the fleets that operate in sub-area *k*.

The incidental catches (bycatch as defined above) by feeding ground are computed using the equation:

[5]A fleet is the combination of a fishery sector (commercial/aboriginal) and the feeding ground in which the catch is taken.

$$C_t^{\mathrm{I},A} = \lambda^A E_t^A \sum_{i,j,a,m/f} \tilde{\alpha}_a X^{A,i,j} N_{t,a}^{m/f,i,j} \tag{E.2}$$

where

$C_t^{\mathrm{I}/s,A}$ is the incidental catch of animals of sex s in feeding ground A during year t;

E_t^A is a measure of the effort in feeding ground A during year t;

λ^A is the catchability coefficient for bycatch; and

$\tilde{\alpha}_a$ is 1 for ages 0 to 5 and 0 for all other ages (IWC, 2016).

The incidental catches are allocated to feeding aggregation, sex and age using the formula:

$$C_{t,a}^{I,m/f,i,j} = \sum_A C_t^{I,A} \frac{\tilde{\alpha}_a X^{A,i,j} N_{t,a}^{m/f,i,j}}{\sum_{i,j,m/f,a} \tilde{\alpha}_a X^{A,i,j} N_{t,a}^{m/f,i,j}} \tag{E.3}$$

F. INITIALISING THE PARAMETER VECTOR

The numbers at age in the pristine population are given by:

$$\begin{aligned} N_{-\infty,a}^{m/f,i,j} &= 0.5\, N_{-\infty,0}^{i,j} \prod_{a'=0}^{a-1} S_{a'} && \text{if } a < x \\ N_{-\infty,x}^{m/f,i,j} &= 0.5\, N_{-\infty,0}^{i,j} \prod_{a'=0}^{x-1} S_{a'} / (1 - S_x) && \text{if } a = x \end{aligned} \tag{F.1}$$

The value for $N_{-\infty,0}^{i,j}$ is determined from the value for the pre-exploitation size of the 1+ component of feeding aggregation j of breeding stock i using the equation:

$$N_{-\infty,0}^{m,i,j} = K^{1+,i,j} \Big/ \left(\sum_{a=1}^{x-1} \left(\prod_{a'=0}^{a-1} S_{a'} \right) + \frac{1}{1 - S_x} \prod_{a'=0}^{x-1} S_{a'} \right) \tag{F.2}$$

where $K^{1+,i,j}$ is the carrying capacity (in terms of the 1+ population size) for feeding aggregation j of breeding stock i:

$$K^{1+,i,j} = \sum_{a=1}^{x} (N_{-\infty,a}^{m,i,j} + N_{-\infty,a}^{f,i,j}) \tag{F.3}$$

$N_{-\infty,a}^{m/f,i,j}$ is the number of animals of age a that would be in feeding aggregation j of breeding stock i in the pristine population.

The model is based on the assumption that the age-structure at the start of year τ is stable rather than that the population was at its pre-exploitation equilibrium size at some much earlier year. The determination of the age-structure at the start of year τ involves specifying the effective 'rate of increase', γ, that applies to each age-class. There are two components contributing to γ, one relating to the overall population rate of increase (γ^+) and the other to the exploitation rate due to all forms of anthropogenic removal. Under the assumption of knife-edge recruitment to the fishery at age a_r, only the γ^+ component (assumed to be zero following Punt and Butterworth, 2002) applies to ages a of a_r or less. The number of animals of age a at the start of year τ relative to the number of calves at that time, $N_{t,a}^*$, is therefore given by the equation:

$$N_{\tau,a}^* = \begin{cases} 1 & \text{if } a = 0 \\ N_{\tau,a-1}^*\, S_{a-1} & \text{if } a \le a_r \\ N_{\tau,a-1}^*\, S_{a-1} (1-\gamma) & \text{if } a_r < a < x \\ N_{\tau,x-1}^*\, S_{x-1} (1-\gamma) / (1 - S_x (1-\gamma)) & \text{if } a = x \end{cases} \tag{F.4}$$

where B_τ is the number of calves in year τ and is derived directly from equations C.1 and C.6.

$$B_\tau = \left(1 - \left[1 / (N_\tau^f b_K) - 1 \right] / A \right)^{1/z} \frac{K^{1+}}{N_\tau^{1+,*}} \tag{F.5}$$

The effective rate of increase, γ, is selected so that if the population dynamics model is projected from year τ to a year Ψ, the size of the 1+ component of the population in a reference year Ψ equals a value, P_ψ.

G. CONDITIONING

The parameters of the model are: (a) the carrying capacity of each stock; (b) the population (expressed relative to carrying capacity) for each stock at the start of 1930; (c) MSYR by stock; (d) annual survival under 'normal' conditions; (e) maturity as a function of age; (f) the impact of the mortality event in the eastern Pacific in 1999 and 2000; (g) selectivity; (h) the rate of dispersal between the North and PCFG feeding aggregations; (i) the parameters of the mixing matrices; (j) the catchability coefficients that determine bycatch by sub-area; and (k) the extent of additional variation for each abundance index. Some of these parameters are pre-specified:

(1) MSYR (except for trials 14-20);

(2) annual survival under 'normal' conditions (=$e^{-0.05}$);

(3) maturity as a function of age (a logistic function of age, with an age-at-50%-first-parturition of 8 years and a minimum age-at-first parturition of 3 years); and

(4) selectivity (knife-edged at age 1).

Under the assumption that the estimates of abundance for a feeding ground (see Table 2) are log-normally distributed, the negative of the logarithm of the likelihood function is given by:

$$-\ell nL = \ell n\sqrt{\mathrm{Det}[V]} + 0.5\sum_{k}(\ell \mathrm{n}\,\underline{N}^{A,obs} - \ell \mathrm{n}\,\underline{N}^{A})[V^{-1}](\ell \mathrm{n}\,\underline{N}^{A,obs} - \ell \mathrm{n}\,\underline{N}^{A})^{T} \qquad \text{(G.1)}$$

where

$N_t^{A,\mathrm{obs}}$ is the survey estimate of abundance for sub-area A during year t; and

V is the sum of the variance-covariance matrix for the abundance estimates plus an additional variance term (assumed to be independent of year).

The data on the proportion of each stock (see Table 3) in each feeding ground is modelled under the assumption that the proportions are normally distributed, i.e.:

$$-\ell nL = \sum_{i}\sum_{A}\sum_{t}\frac{1}{2(\tau_t^{i,A})^2}(p_t^{i,A} - p_t^{i,A,\mathrm{obs}})^2 \qquad \text{(G.2)}$$

where

$p_t^{i,A}$ is the model-estimate of the proportion of the animals in feeding ground A that are from feeding aggregation i of the Eastern breeding stock;

$p_t^{i,A,\mathrm{obs}}$ is the observed proportion of animals in in feeding ground A that are from feeding aggregation i of the Eastern breeding stock; and

$\tau_t^{i,A}$ is the standard error of $p_t^{i,A,\mathrm{obs}}$.

The (non-zero) bycatches by sub-area (see Table 4) are assumed to be log-normally distributed, and the model is fitted to the average bycatch by sub-area over a pre-specified set of years, i.e.:

$$-\ell \mathrm{n}L = \sum_{A}\frac{1}{2\sigma_{BC}^2}\left(\ell \mathrm{n}C^{I,A,\mathrm{obs}} - \ell \mathrm{n}\hat{\bar{C}}^{I,A}\right)^2 \qquad \text{(G.3)}$$

where

$C^{I,A,\mathrm{obs}}$ is the observed average annual bycatch from feeding ground A over the pre-specified period;

$\hat{\bar{C}}^{I,A}$ is the average over this period of the model-estimate of the bycatch from feeding ground A; and

σ_{BC} is the standard error of the logarithms of the observed bycatches.

A penalty is imposed on the average number of animals moving permanently from the 'north' feeding aggregation into the 'PCFG' feeding aggregation between 2001 and 2008, i.e.:

$$-\ell nL = \frac{1}{2\sigma_I^2}\left(\tilde{I} - \frac{\delta^{\mathrm{m/f,north,West}}}{8}\sum_{t=2001}^{2008}\sum_{s=m/f}\sum_{a=1}^{x}\tilde{N}_{t,a}^{s,\mathrm{East,north}}\right)^2 \qquad \text{(G.4)}$$

where

$\tilde{I}$ is the pre-specified average number of immigrants into the PCFG feeding aggregation from the 'North' feeding aggregation; and

σ_I is a weighting factor.

Table 2a
Indices of 1+ abundance for the Sakhalin sub-area based on Bayesian population dynamics model (J.G. Cooke, pers. commn).

Year	Estimate	CV
1995	68.9	0.0567
1996	71.1	0.0513
1997	76.3	0.0367
1998	78.7	0.0338
1999	87.2	0.0240
2000	87.7	0.0235
2001	92.3	0.0190
2002	97.2	0.0172
2003	104.8	0.0170
2004	114.6	0.0175
2005	120.2	0.0191
2006	126.2	0.0181
2007	128.0	0.0192
2008	128.8	0.0215
2009	131.1	0.0232
2010	137.2	0.0238
2011	141.1	0.0240
2012	152.0	0.0282
2013	155.6	0.0333
2014	164.3	0.0390

Table 2b
Estimates of absolute abundance (with associated standard errors) for the eastern North Pacific stock of gray whales based on shore counts (source: 1967/78-2006/07: Laake *et al.*, 2012; 2006/07-2010/11: Durban *et al.*, In press).

Year	Estimate	CV	Year	Estimate	CV
1967/68	13,426	0.094	1985/86	22,921	0.081
1968/69	14,548	0.080	1987/88	26,916	0.058
1969/70	14,553	0.083	1992/93	15,762	0.067
1970/71	12,771	0.081	1993/94	20,103	0.055
1971/72	11,079	0.092	1995/96	20,944	0.061
1972/73	17,365	0.079	1997/98	21,135	0.068
1973/74	17,375	0.082	2000/01	16,369	0.061
1974/75	15,290	0.084	2001/02	16,033	0.069
1975/76	17,564	0.086	2006/07	19,126	0.071
1976/77	18,377	0.080	2006/07	20,750	0.060
1977/78	19,538	0.088	2007/08	17,820	0.054
1978/79	15,384	0.080	2009/10	21,210	0.046
1979/80	19,763	0.083	2010/11	20,990	0.044
1984/85	23,499	0.089			

Table 2c
Estimates of absolute abundance (with associated CVs) for the PCFG feeding aggregation based on mark-recapture analysis (source: J. Laake, pers. commn).

Year	Estimate	CV	Year	Estimate	CV
1998	126	0.086	2006	200	0.106
1999	147	0.102	2007	193	0.133
2000	149	0.101	2008	207	0.088
2001	181	0.077	2009	206	0.098
2002	198	0.064	2010	194	0.094
2003	210	0.086	2011	197	0.080
2004	218	0.078	2012	209	0.073
2005	218	0.120			

Table 3
Data on mixing proportions (definite and likely matches/non-matches only) to be used when conditioning the models.

Area	Year	Stock concerned	Estimate (assumed SD)
EJPJ	2007[d]	WFG	1 (0.1)
EJPJ	2012[d]	Western	1 (0.1)
EJPJ	2015[d]	WFG	1 (0.1)
EJPJ	2005[l]	Western	1 (0.1)
EJPJ	2007[l]	Western	1 (0.1)
SI	2012	Western	0.40[a] (0.1)
SEA (Jun.-Nov.)	2012	PCFG	0.559 (0.15)
BCNC (Jun.-Nov.)	2012	PCFG	0.951 (0.05)
BCNC (Dec.-May)	2012	WFG	0.002 (0.05)
BCNC (Dec.-May)	2012	PCFG	0.339 (0.15)
CA (Jun.-Nov.)	2012	PCFG	0.472 (0.15)

[a]Stock structure hypothesis 5a only (changed in sensitivity analysis).
[d]Definite; [l]Likely.

Table 4
Scenarios regarding bycatch.

Sub-area	Years	Numbers dead	Dead and serious injury	Numbers dead x 4	Numbers dead x 8
VSC	1990-2014	1/25	??	4/25	8/25
EJPJ	1990-2014	4/25	??	16/25	32/25
SI	1997-2014	1.5/18	??	6/18	12/18
BSCS					
SEA (Jun.-Nov.)					
SEA (Dec.-May)					
BCNC (Jun.-Nov.)					
BCNC (Dec.-May)					
CA (Jun.-Nov.)					
CA (Dec.-May)					

H. QUANTIFYING UNCERTAINTY USING BOOTSTRAP

A bootstrap procedure is used to quantify uncertainty for a given model specification. Each bootstrap replicate involves:

(1) generating pseudo time-series of abundance estimates based on the assumption that the abundance estimates are log-normally distributed with means and variance-covariance matrices given by the observed abundance estimates and the reported variance-covariance matrices;

(2) generating pseudo mixing proportions from beta distributions with means and CVs given by the observed means and CVs;

(3) generating pseudo bycatch rates by feeding ground from log-normal distributions with means of $C^{l,A,\text{obs}}$ and a log standard error of σ_{BC}; and

(4) generating a pseudo immigration rate from the 'North' into the PCFG feeding aggregation based on a normal distribution (truncated at zero) with mean $\tilde{I}$ and standard error σ_I.

I. GENERATION OF DATA

The actual historical estimates of absolute abundance (and their associated CVs) provided to the *Strike Limit Algorithms* are listed in Table 2. The future estimates of abundance for sub-areas BCNC-3 and CA-3 (say sub-area *K*) are generated using the formula:

$$\hat{P} = PYw / P^* \beta^2 Yw \tag{F.1}$$

where:

Y is a lognormal random variable $Y=e^{\varepsilon}$ where $\varepsilon \sim N(0;\sigma_\varepsilon^2)$ and $\sigma_\varepsilon^2 = \ell n(1+\alpha^2)$;

w is a Poisson random variable with $E(w) = \text{var}(w) = \mu = (P / P^*) / \beta^2$, *Y* and *w* are independent;

P is the current total (1+) population size in survey area *K*:

$$P = P_t^K = \sum_i \sum_j \sum_g \sum_{a\geq 1} N_{t,a}^{g,i,j} \tag{F.2}$$

*P** is the reference population level, and is equal to the total (1+) population size in the survey area prior to the commencement of exploitation in the feeding ground for which an abundance estimate is to be generated. For consistency with the first-stage screening trials for a single stock (IWC, 1991; 1993), the ratio $\alpha^2 : \beta^2 = 0.12 : 0.025$, so that $CV^2(\hat{P}) = \tau\,(0.12 + 0.025\,P^*/P)$. If $\overline{CV}$ is the target CV then $\tau = \overline{CV^2}\,/(0.12 + 0.025 P_{\text{ref}}/P^*)$ where P_{ref} is the population size in a reference year.

An estimate of the *CV* is generated for each estimate of abundance:

$$CV(\hat{P})^2_{\text{est}} = \sigma^2 \chi^2 / n \tag{F.3}$$

where $\sigma^2 = \ell n(1+\alpha^2+\beta^2 P^*/\hat{P})$, and χ is a random number from a Chi-square distribution with *n* degrees of freedom (where n=10 as used for NP minke trials; IWC, 2004).

J. TRIALS

The factors included in the trials are listed in Table 5 and the trials in Table 6.

Table 5
Factors considered in the model scenarios. The **bolded** values are the base-levels.

Factor	Levels
Model fitting related	
Stock hypothesis	**3a, 3e, 5a**
Proportion of 'Western' stock in Sakhalin sub-area	**0** (stock hypotheses 3a, 3e), **0.33** (stock hypothesis 5a), 0.70
$MSYR_{1+}$ (western)	As for WFG
$MSYR_{1+}$ (north)	**4.5%**, 5.5%, Estimated (common); estimate (separately)
$MSYR_{1+}$ (WFG)	**4.5%**, 5.5%, Estimated (common); estimate (separately)
$MSYR_{1+}$ (PCFG)	2%, **4.5%**, Estimated (common); estimate (separately)
Matches	Definite; Definite+Likely (Table 2)
Immigration into the PCFG	**0, 2,** 4
Bycatches and ship strikes	Numbers dead, M/SI, numbers dead x 4; x numbers dead x 10
Pulse migrations into the PCFG	10, **20,** 30
Bycatch off Sakhalin	**1.5,** 3
Projection-related	
Northern need in final year (from 150 in 2014)	**340**, 530
Struck and lost rate	25%, **50%**, 75%
Future effort	**Constant,** Increase by 100% over 100 years
Probability of mismatching a north whale, p_1	**0.01**
Probability of mismatching a PCFG, p_2	0.05 (trials)
PCFG harvest month	**Migratory**

K. MANAGEMENT OPTIONS

The strike limits for the BSCS feeding ground are based on the *Gray Whale SLA* (IWC, 2005), while the strike limits for the BCNC feeding ground are based on 'research with variant' (*SLA* variant 1) option (IWC, 2013). The steps below show how the proposed Makah Management plan operates. Variant 1 would have steps (1), (3), and (4) but not (2). Variant 2 would have (2) (3) and (4). Furthermore, variant 1 has hunting from December-May.

(1) Compute the ABL (Allowable Bycatch Limit of PCFG whales)
  (a) Strike an animal.
  (b) If the animal is struck-and lost in December-April[6]:
  (c) if the total number of struck and lost animals is 3, stop the hunt.
  (d) if the total number of struck animals equals the need of 7 stop the hunt.
  (e) go to step (2).

(2) If the animal is struck-and lost in May:
  (a) add one to the number of whales counted towards the ABL.
  (b) if the ABL is reached; stop the hunt.
  (c) if the total number of struck and lost animals is 3, stop the hunt.
  (d) if the total number of struck animals equals the need of 7; stop the hunt.
  (e) go to step (2).

(3) If the animal is landed and is matched against the catalogue[7]:
  (a) add one to the number of whales counted towards the ABL.
  (b) if the ABL is reached; stop the hunt.
  (c) if the total number of landed whales equals 5; stop the hunt.
  (d) if the total number of struck animals equals the need of 7; stop the hunt.
  (e) if the number of landed whales for the current five-year block equals 20; stop the hunt.
  (f) go to step (2).

(4) If the animal is landed and does not match any whale in the catalogue:
  (a) if the total number of landed whales equals 5; stop the hunt.
  (b) if the total number of struck animals equals the need of 7; stop the hunt.
  (c) if the number of landed whales for the current five-year block equals 20; stop the hunt.
  (d) go to step (2).

Removals due to bycatch are based on the scenarios regarding future trends in effort. Table 5 lists the factors considered in the projections.

[6]Whether a whale is struck and lost is determined from a Bernoulli trial with probability 0.5 (base-case).
[7]PCFG whales are mismatched as north stock whales with probability p_2 while north stock whales are matched to the catalogue with probability p_1.

Table 6
The model specifications.

Trial	Description/stock hypothesis	PCFG in BSCS	$MSYR_{1+}$ North	$MSYR_{1+}$ PCFG	$MSYR_{1+}$ WFG	% Western in Sakhalin	PCFG immigration
1A	Reference 3a	No	4.5%	4.5%	4.5%	0	2
1B	Reference 3e	No	4.5%	4.5%	4.5%	0	2
1C	Reference 5a	No	4.5%	4.5%	4.5%	0.33	2
2A	Lower MSYR PCFG 3a	No	**4.5%**	**2%**	**4.5%**	0	2
2B	Lower MSYR PCFG 3e	No	**4.5%**	**2%**	**4.5%**	0	2
2C	Lower MSYR PCFG 5a	No	**4.5%**	**2%**	**4.5%**	0.33	2
3A	Higher MSYR WFG and North 3a	No	**5.5%**	**5.5%**	**4.5%**	0	2
3B	Higher MSYR WFG and North 3e	No	**5.5%**	**5.5%**	**4.5%**	0	2
3C	Higher MSYR WFG and North 5a	No	**5.5%**	**5.5%**	**4.5%**	0.4	2
4C	Higher Western breeding stock in Sakhalin 5a	No	4.5%	4.5%	4.5%	**0.7**	2
5A	Alternative matches 3a	No	4.5%	4.5%	4.5%	0	2
5B	Alternative matches 3e	No	4.5%	4.5%	4.5%	0	2
5C	Alternative matches 5a	No	4.5%	4.5%	4.5%	0.33	2
6A	Lower PCFG Immigration 3a	No	4.5%	4.5%	4.5%	0	**0**
6B	Lower PCFG Immigration 3e	No	4.5%	4.5%	4.5%	0	**0**
6C	Lower PCFG Immigration 5a	No	4.5%	4.5%	4.5%	0.33	**0**
7A	Higher PCFG Immigration 3a	No	4.5%	4.5%	4.5%	0	**4**
7B	Higher PCFG Immigration 3e	No	4.5%	4.5%	4.5%	0	**4**
7C	Higher PCFG Immigration 5a	No	4.5%	4.5%	4.5%	0.33	**4**
8A	Lower Pulse into PCFG 3a	No	4.5%	4.5%	4.5%	0	2
8B	Lower Pulse into PCFG 3e	No	4.5%	4.5%	4.5%	0	2
8C	Lower Pulse into PCFG 5a	No	4.5%	4.5%	4.5%	0.33	2
9A	Higher pulse into PCFG 3a	No	4.5%	4.5%	4.5%	0	2
9B	Higher pulse into PCFG 3e	No	4.5%	4.5%	4.5%	0	2
9C	Higher pulse into PCFG 5a	No	4.5%	4.5%	4.5%	0.33	2
10A	Bycatch x 4 3a	No	4.5%	4.5%	4.5%	0	2
10B	Bycatch x 4 3e	No	4.5%	4.5%	4.5%	0	2
10C	Bycatch x 4 5a	No	4.5%	4.5%	4.5%	0.33	2
11A	Bycatch x 10 3a	No	4.5%	4.5%	4.5%	0	2
11B	Bycatch x 10 3e	No	4.5%	4.5%	4.5%	0	2
11C	Bycatch x 10 5a	No	4.5%	4.5%	4.5%	0.33	2
12A	Bycatch = 3 in SI 3a	No	4.5%	4.5%	4.5%	0	2
12B	Bycatch = 3 in SI 3e	No	4.5%	4.5%	4.5%	0	2
12C	Bycatch = 3 in SI 5a	No	4.5%	4.5%	4.5%	0.33	2
13A	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0	2
13B	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0	2
13C	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0.33	2
14A	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0	2
14B	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0	2
14C	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0.33	2
15A	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Estimated**	**Estimated**	**Estimated**	0	2
15B	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Estimated**	**Estimated**	**Estimated**	0	2
15C	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Estimated**	**Estimated**	**Estimated**	0.33	2
16A	Lower PCFG immigration and higher bycatch 3a	No	4.5%	4.5%	4.5%	0	**0**
16B	Lower PCFG immigration and higher bycatch 3e	No	4.5%	4.5%	4.5%	0	**0**
16C	Lower PCFG immigration and higher bycatch 5a	No	4.5%	4.5%	4.5%	0.33	**0**
17A	MSYR estimated and lower pulse 3a	No	**Estimated**	**Estimated**	**Estimated**	0	2
17B	MSYR estimated and lower pulse 3e	No	**Estimated**	**Estimated**	**Estimated**	0	2
17C	MSYR estimated and lower pulse 5a	No	**Estimated**	**Estimated**	**Estimated**	0.33	2
18A	MSYR estimated and higher pulse 3a	No	**Estimated**	**Estimated**	**Estimated**	0	2
18B	MSYR estimated and higher pulse 3e	No	**Estimated**	**Estimated**	**Estimated**	0	2
18C	MSYR estimated and higher pulse 5a	No	**Estimated**	**Estimated**	**Estimated**	0.33	2
19A	MSYR estimated and higher immigration 3a	No	**Estimated**	**Estimated**	**Estimated**	0	**4**
19B	MSYR estimated and higher immigration 3e	No	**Estimated**	**Estimated**	**Estimated**	0	**4**
19C	MSYR estimated and higher immigration 5a	No	**Estimated**	**Estimated**	**Estimated**	0.33	**4**
20A	MSYR estimated and much higher immigration 3a	No	**Estimated**	**Estimated**	**Estimated**	0	**8**
20B	MSYR estimated and much higher immigration 3e	No	**Estimated**	**Estimated**	**Estimated**	0	**8**
20C	MSYR estimated and much higher immigration 5a	No	**Estimated**	**Estimated**	**Estimated**	0.33	**8**

L. OUTPUT STATISTICS

The population-size statistics are produced for each breeding stock/feeding aggregation, while the removal-related statistics are for each sub-area.

L.1 Risk

D1. Final depletion: P_T/K.

D2. Lowest depletion: min $(P_t/)$: t=0,1,…,T.

D3. Plots of $\{P_{t[x]}$: t=0,1,…,T where $P_{t[x]}$ is the xth percentile of the distribution of P_i. Results are presented for x=5 and x=50.

L.2 Removal-related

R1. Plots of strikes by year for simulations 1-100.

R2. Plots of landed whales by year for simulations 1-100.

R3. Plots of incidental catches by year for simulations 1-100.

R4. A table for the proportion of catch of WFG whales by sub-area (20 and 100 years).

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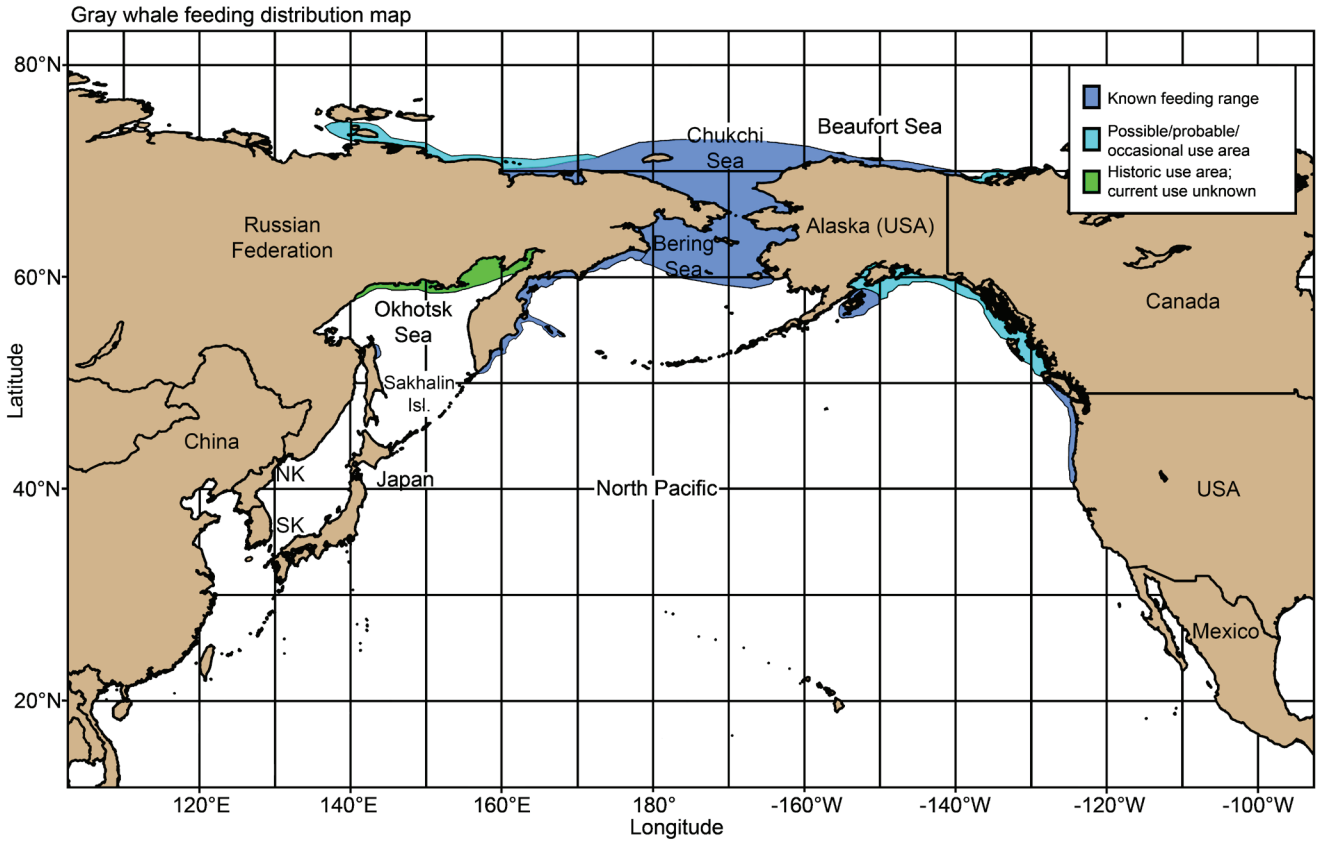
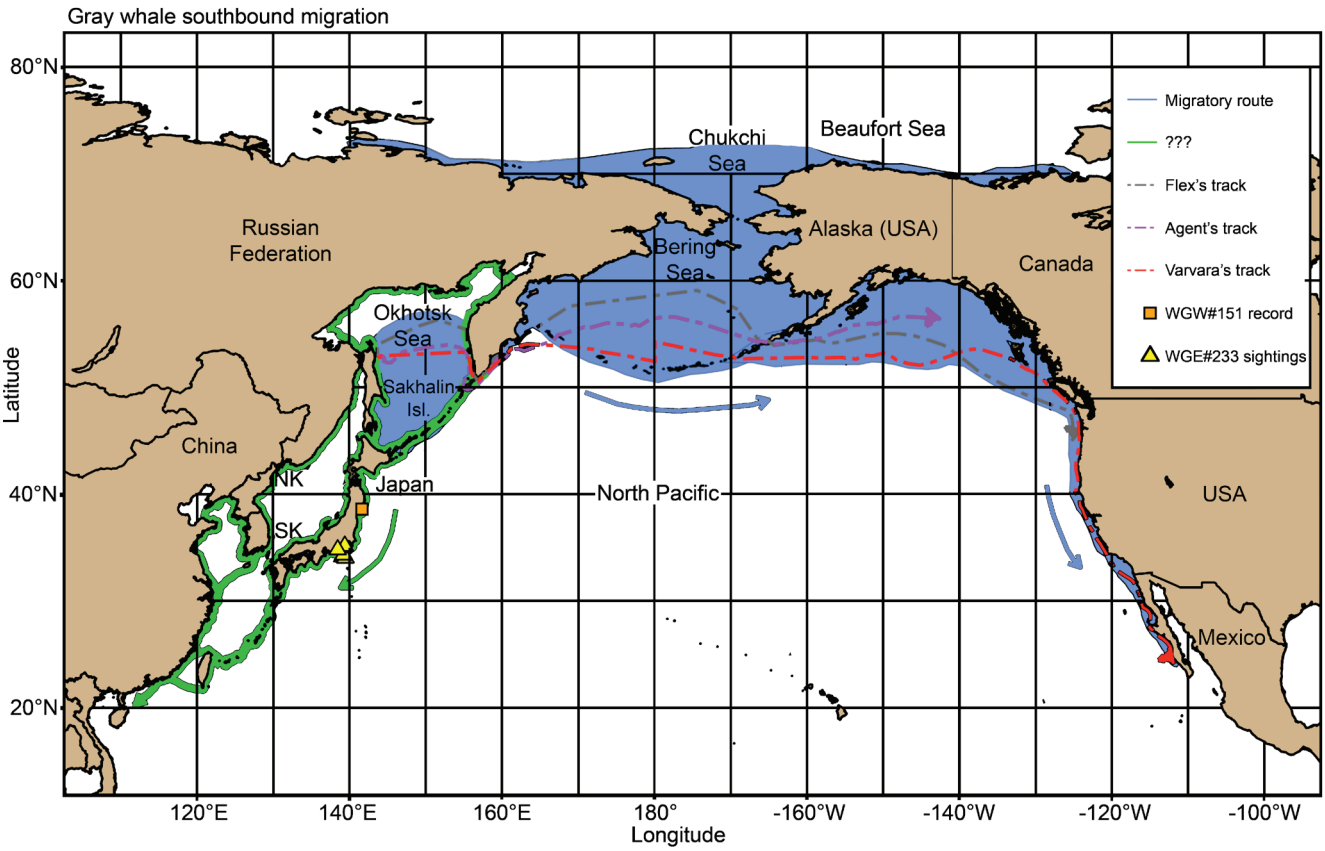
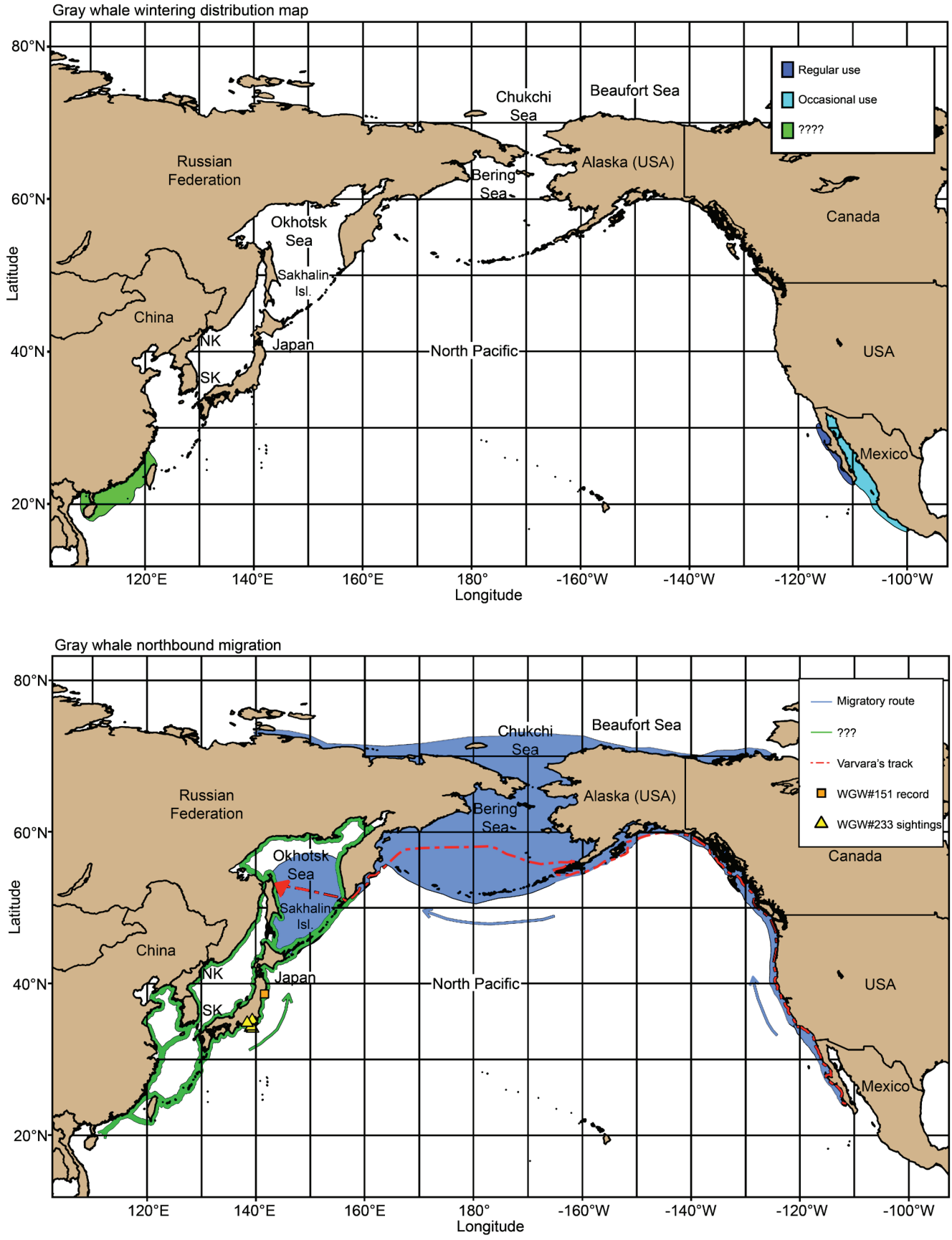
Annex G

Schematic Summarising Present Knowledge of the Distribution of Gray Whales in the North Pacific on a Seasonal Basis







This four-panel map is a schematic summarising present knowledge of the distribution of gray whales in the North Pacific on a seasonal basis: the summer feeding period (a), the period of southward migration (and breeding) in late autumn (b), the winter calving, early calf rearing and fasting season (c), and the period of northward migration in spring (d). The maps also include all known reports of gray whales in the western North Pacific since 1995 (for details see Annex E).

Report of the Scientific Committee

Bled, Slovenia, 24 April-6 May 2018

**This report is presented as it was at SC/67b.
There may be further editorial changes (e.g. updated references, tables, figures)
made before publication.**

International Whaling Commission
Bled, Slovenia, 2018

Report of the Scientific Committee
Bled, Slovenia, 24 April - 6 May 2018

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The meeting (SC/67b) was held at the Rikli Balance Hotel, Bled, Slovenia, from 24 April-06 May 2018 and was chaired by Caterina Fortuna. The next meeting of the Commission (IWC/67) will take place 4-14 September 2018. The list of participants is given as Annex A (about one-third of the Contracting Governments were represented by delegates).

1. INTRODUCTORY ITEMS

1.1 Chair's welcome and opening remarks

Fortuna welcomed the participants to the meeting. Although the meeting was not officially hosted by the Slovenian Government, she thanked it for welcoming them back and noted how pleased the Scientific Committee was to be once again in such a beautiful place. She thanked the IWC Secretariat staff for their hard work during the intersessional period, particularly Mark Tandy for organising the meeting under time pressure Stella Duff and Andrea Cooke for their assistance with meeting documents and Greg Donovan for all his support intersessionally. She thanked Sava Hotels for providing the meeting facilities and her Slovenian colleagues for helping meeting arrangements run smoothly. Fortuna also thanked the vice-Chair Robert Suydam, the Convenors (including those of intersessional groups) and Committee members for all their hard work since the last meeting.

Rebecca Lent, the new IWC Executive Secretary, welcomed participants to the meeting She noted this was her first IWC meeting, but already knew of its excellent global reputation and looked forward to attending many sessions. She noted her pleasure at joining the IWC at such an exciting time, with a busy year of meetings and several new initiatives. Two new coordinators have joined the Secretariat as part of the IWC work programmes endorsed by the Commission in 2016: Marguerite Tarzia as bycatch coordinator; and Karen Stockin as strandings coordinator. They will lead the Commission's work in these areas and will provide valuable input into the Scientific Committee's work.

Lent noted that the external "The IWC review – final report" (https://archive.iwc.int/?r=6890) undertaken as part of the IWC's Governance Review has recently become available and she noted that the Commission would welcome comments on it from the Scientific Committee, and that in particular, the Commission's Operational Effectiveness Working Group will take into consideration the comments from the Scientific Committee in making its recommendations to the Finance and Administration Committee; that Committee will then make recommendations to the Commission, which will determine the next steps in the governance review. Budget Management has become more challenging in recent years and there is much work to do to make sure the workplan of the Commission and all its subsidiary bodies is affordable going forward and into the long term. Finally, she thanked Scientific Committee members for their scientific input over the next two weeks and wished everyone a successful meeting.

The Committee was saddened to learn of the death of four scientists connected with the Scientific Committee:

(1) Greg Kaufman, a member of the Committee since 2006 and an active member of the sub-committee on whale watching and the Whale watching Working Group of the Conservation Committee;

(2) Doug Coughran, who although he did not attend Scientific Committee meetings, was a participant in numerous IWC workshops on entanglement and stranding response and was a charter member of both the IWC's entanglement and stranding expert (advisory) groups;

(3) Dale Rice, who although he has not attended IWC meetings in recent years, first represented the USA on the Scientific Committee as far back as 1960; and

(4) John Reynolds, who although not a member of the Scientific Committee, was a mentor to many Committee members.

The Committee paused in silence and respect for these scientists who had contributed directly and indirectly to the Committee's work and to whale conservation and management. Short obituaries can be found in Annex AA.

1.2 Appointment of rapporteurs

Donovan was appointed rapporteur with assistance from various members of the Committee as appropriate. Chairs of sub-committees and Working Groups appointed rapporteurs for their individual meetings.

1.3 Meeting procedures and time schedule

The Committee agreed to the meeting procedures and time schedule outlined by the Chair.

1.4 Establishment of sub-committees and Working Groups

The following pre-meetings were held:

(1) the Standing Working Group on Environmental Concerns held a pre-meeting on 'Cumulative Effects' from 22-23 April; and
(2) the sub-committee on Whale Watching held a pre-meeting on the IWC's 'Five Year Strategic Plan for Whale Watching' from 22-23 April.

Several sub-committees and Working Groups were established. Their reports were either made Annexes (see below) or subsumed into this report.

Annex D – Sub-Committee on the Revised Management Procedure;

Annex E – Standing Working Group on an Aboriginal Whaling Management Procedure;

Annex F – Sub-Committee on In-Depth Assessments;

Annex G – Sub-Committee on Other Northern Hemisphere Whale Stocks

Annex H – Sub-Committee on Other Southern Hemisphere Whale Stocks;

Annex I – Working Group on Stock Definition and DNA testing;

Annex J – Sub-Committee on Non-Deliberate Human-Induced Mortality of Cetaceans;

Annex K – Sub-Committee on Environmental Concerns;

Annex L – Standing Working Group on Ecosystem Modelling;

Annex M – Sub-Committee on Small Cetaceans;

Annex N – Sub-Committee on Whale Watching;

Annex O – Sub-Committee on Conservation Management Plans;

Annex P – Revised 'Annex P';

Annex Q – Standing Working Group on Abundance Estimates, Stock Status and International Cruises;

Annex R – *Ad hoc* working Group on Sanctuaries;

Annex S – *Ad hoc* Working Group on Photo-ID;

Annex T – Ad hoc Group on Global databases and repositories

Annex U – Statements on Special Permit discussions

Annex V – IWC-SORP – Southern Ocean Research Partnership

Annex W – Updated Rules of Procedure

Annex X – Comments on the 'Governance Review'

Annex Y – Intersessional groups

Annex Z – Minority Statements on the Agenda

1.5 Computing arrangements
Donovan outlined the computing and printing facilities available for delegate use.

2. ADOPTION OF AGENDA

The adopted Agenda is given as Annex B. Statements on the Agenda are given as Annex Z.

3. REVIEW OF AVAILABLE DATA, DOCUMENTS AND REPORTS

3.1 Documents submitted
The documents available are listed in Annex C. As agreed at the 2012 Annual Meeting, primary papers were only available at the meeting in electronic format (IWC, 2013a, pp 78-79).

3.2 National Progress Reports on research
The National Progress Reports have their origin in Article VIII, Paragraph 3 of the Convention. All member nations are urged by the Commission to provide Progress Reports to the Scientific Committee following the most recent guidelines developed by the Scientific Committee and adopted by the Commission. The report is intended to provide (1) a concise summary of information available in member countries and (2) advice on where to find more detailed information if required. In addition, the IWC holds several specialist databases (including, catches, sightings, ship strikes, images – see Item 23).

As agreed at the 2013 Annual Meeting (IWC, 2014), all National Progress Reports were submitted electronically through the IWC National Progress Reports data portal. Encouragingly, 18 countries (Argentina, Australia, Brazil, Croatia, Denmark, France, Germany, Iceland, Italy, Japan, Korea, Mexico, New Zealand, Netherlands, Norway, Spain, UK and USA) submitted reports this year compared to 12 last year. Information was provided on bycatch, entanglement, ship strikes, direct and indirect takes, sampling, sightings and tracking studies.

Nearly all the recommendations identified by the Committee in 2017 (IWC, 2018c) have been implemented although further guidance is required on the appropriate level of aggregation for some records (e.g. strandings) to simplify and accelerate data entry without losing valuable resolution.

Although data entry this year was hampered due to problems with the IWC server, this generic issue has already been resolved by the IWC Secretariat. Several suggestions for improvements, including the removal of default values, can be See Annex T for full details.

Attention: C, CG, S, SC

Despite the technical issues of the portal, the eighteen Progress Reports submitted to SC67b was an improvement on the twelve submitted to SC67a. Nevertheless, this represents a small proportion of IWC member nations. The Committee ***reiterates*** *that National Progress Reports are required under the Convention and they represent a useful tool and* ***recommends*** *that Contracting Governments to submit them annually through the IWC data portal (http://portal.iwc.int).*

National Progress Reports include records of reported bycatch and ship strikes. The Committee ***agrees*** *that the data collected in these reports are not intended to replace in-depth studies and they should be considered and used with great caution. However, it also* ***agrees*** *the reports have value because much of these data would not otherwise be available and the reporting process can assist in supporting national compilation of cetacean data.*

To address in part several of the issues and challenges described above the Committee ***agrees*** *to:*

(1) develop a strategy with the Scientific Committee Chair and Secretariat to raise awareness of National Progress Reports and promote reporting by member nations;
(2) produce a short summary explaining the utility of National Progress Reports and suggest including this text in the circular to member nations calling for data submission;
(3) request the Secretariat to issue the first call for data submission in February and repeat the call a few weeks prior to the start of the SC meeting;
(4) develop text acknowledging the likely limitations of the reported data (subsequently this text will be included in all reports and data downloads;
(5) further explore approaches (using R markdown) to produce PDF- formatted national reports.
This work will be conducted by the GDR Steering Group intersessionally (see Annex Y).

3.3 Data collection, storage and manipulation

3.3.1 Catch data and other statistical material

Table 1 lists data received by the Secretariat since the 2017 meeting.

Table 1
List of data and programs received by the IWC Secretariat since the 2017 meeting.

Date	From	IWC ref.	Details
18/05/2017	St Vincent&G: J. Cruickshank-Howard	E128 Cat2016	Information from St Vincent and the Grenadines aboriginal hunt 2016-17
3-10 7/2017	S. Kromann and Y. Ivashchenko	E127 C	Individual catch data for Taiyo Gyogyo, Japan in 1943-44. Copy of data held at NMML Seattle
16/08/2017	Y. Ivashchenko	E127	Extra details of N. Pacific sei whale catches by the USSR 1963-71
16/02/2018	Japan: K. Matsuoka	CD103	2017 POWER sightings cruise data (except photographs)
16/02/2018	Japan: K. Matsuoka	CD104	2017 ICR North Pacific dedicated sighting survey data.
04/04/2018	Canada: S. Reinhart	E130 Cat2017	Details of the Canadian bowhead harvest for the 2015-7 seasons and some information on the 2018 quota
11/04/2018	Japan: K. Matsuoka	E131	Data from the 2017-18 NEWREP-A dedicated sighting survey
18/04/2018	Iceland: G. Vikingsson	E130 Cat2017	Individual records of minke whales caught by Iceland 2017 [there was no fin whale catch]
18/04/2018	Norway: N. Øien	E130 Cat2017	Individual minke records from the Norwegian 2017 commercial catch. Access restricted (specified 14-11-00).
19/04/2018	USA: R. Suydam	E130 Cat2017	Individual records from USA Alaska aboriginal bowhead hunt 2017
20/04/2018	Japan: H.Morita	E130 Cat2017	Individual data for Japan's catch in 2017 in the N. Pacific (JARPN II) & 2017/8 in the Antarctic. (pdf format)

3.3.2 Progress of data coding projects and computing tasks

On behalf of Allison, Donovan reported that the 2017 catches and Japan coastal records in 1943-44 (data from NMML Seattle) have been added to the database. The changes agreed at the 2017 meeting, in particular to split out the catches taken *en route* to and from the Antarctic whaling grounds, have been implemented. Work on computing tasks with respect to work on the AWMP, RMP and in-depth assessments is reported under the relevant agenda items.

4. COOPERATION WITH OTHER ORGANISATIONS

Attention: C-A

*The Committee **stresses** the value of cooperation with other organisations when addressing the range of issues affecting cetacean conservation and management. In addition to the summaries below, co-operation is also discussed where relevant elsewhere in the agenda.*

4.1 African States Bordering the Atlantic Ocean (ATLAFCO)

There was no meeting of the Ministerial Conference of ATLAFCO during the intersessional period.

4.2 Arctic Council

4.2.1 PAME (Protection of the Arctic Marine Environment)

The PAME II-2017 meeting was held in Helsinki, Finland from 18-20 September 2017. No IWC observer attended the meeting. The Committee agrees that if possible an IWC observer should attend the next meeting of PAME.

4.3 Convention on Biological Diversity (CBD)

There was no meeting of the Conference of Parties during the intersessional period. The next meeting will take place 10-22 November 2018. The Committee agrees that if possible an IWC observer should attend the next meeting of CBD.

4.4 Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)

The 36th Meeting of the CCAMLR Scientific Committee was held 16 - 20 Oct 2017 October 2016 in Hobart, Australia. Although no IWC observer attended the meeting, co-operation with CCAMLR remains an important component of the IWC's work and is discussed further under Item 16.1.

4.5 Convention on the Conservation of Migratory Species (CMS)

4.5.1 Scientific Council

The Second Meeting of the Sessional Committee of the Scientific Council was held 10- 13 July 2017 in Bonn, Germany. No IWC observer attended the meeting.

4.5.2 Conference of Parties

The Conference of Parties met 23-28 October 2017 in Manila, Philippines. No IWC observer attended the meeting.

4.5.3 Agreement on Small Cetaceans of the Baltic and North Seas (ASCOBANS)

The report of the observer to ASCOBANS is given as SC/67b/COMM01E. The following key activities have occurred since the last IWC Scientific Committee meeting:

(1) first Joint Meeting of the 13th Meeting of the Jastarnia Group (Baltic Sea harbour porpoises) and the 6th Meeting of the North Sea Group;
(2) best-practice workshop on 'Fostering Inter-regional Cooperation on Underwater Noise Monitoring and Impact Assessments in waters around Europe, within the context of the European Marine Strategy Framework Directive';
(3) 23rd Meeting of the Advisory Committee; and
(4) 14th Meeting of the Jastarnia Group.

The key ongoing ASCOBANS activities are:

(1) work on the three harbour porpoise Action Plans (Baltic, Belt and North Seas)- in place since February 2018;
(2) web-accessed database on marine mammal stranding and necropsy in preparation (ZSL/IOZ leading), 2018-2020;
(3) preparation of an action plan for common dolphins; and
(4) implementing a change in the national reporting cycle from annual (on all topics) to a four-year cycle (selected topics each year) - the intention is that all the key ASCOBANS working groups and meetings align their agendas to home in on these issues in the respective years of reporting (e.g. covering 2017 in 2018).

The Action Points at the last Advisory Committee meeting included:

(1) preparing a discussion on prey depletion and changes in prey quality on the agenda of the 24th Meeting of the Advisory Committee;
(2) co-organisation of a workshop with ACCOBAMS on strandings and marine debris (the report has been made to the Scientific Committee);
(3) future focuses will include the white-beaked dolphin and the white-sided dolphin.
(4) a draft Action Plan for the Common Dolphin is due to be presented at the 24th Advisory Committee Meeting.

The Committee thanked Simmonds for his report and **agrees** that he should represent the Committee as an observer at the next ASCOBANS meeting.

4.5.4 Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS)

MEETING OF PARTIES

There was no Meeting of the Parties (MoP) to ACCOBAMS during the intersessional period. Donovan will represent the Committee as an observer at the next ACCOBAMS MoP.

SCIENTIFIC COMMITTEE

There was no meeting of the ACCOBAMS Scientific Committee during the intersessional period. Donovan will represent the Committee at the next ACCOBAMS Scientific Committee meeting.

4.6 Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES)

No relevant meetings of CITES have taken place during the intersessional period.

4.7 Food and Agriculture Organisation of the United Nations (FAO)

There was no meeting of The Committee on Fisheries (COFI) during the intersessional period. The next meeting will take place in Rome, Italy 9-13 July 2018.

4.8 Inter-American Tropical Tuna Commission (IATTC)

The 92nd meeting of the Inter-American Tropical Tuna Commission (IATTC) was held in Mexico City, Mexico 24-28 July 2017. No observer attended IATTC meetings in the intersessional period.

4.8.1 Agreement on the International Dolphin Conservation Program (AIDCP)

No observer attended IADCP meetings in the intersessional period.

4.9 International Committee on Marine Mammal Protected Areas (ICMMPA)

There was no meeting of ICMMPA task force during the intersessional period. The 5th International Conference will be held from 8- 12 April 2019 in Greece. It will evaluate progress in meeting the ICMMPA's long-standing goal of bringing the MMPA community closer together. A primary goal is to focus on the challenges ahead towards achieving effective place-based protection and management for marine mammals. It will build on previous initiatives to advance our understanding of science, management, and effective biodiversity conservation in protected areas. It will also provide updates on plans for the worldwide Important Marine Mammal Area (IMMA) initiative (*marinemammalhabitat.org*). Rojas-Bracho will represent the Committee at this meeting.

4.10 International Council for the Exploration of the Sea (ICES)

The report of the IWC observer documenting the 2017 activities of ICES is given as SC/67b/COMM01A. The ICES Working Group on Marine Mammal Ecology (WGMME) reported on recent information on status of, and threats to, marine mammal populations and briefly reviewed current knowledge of effects of plastics and underwater noise. Criteria for assessment of abundance trends in offshore cetaceans in the context of the Marine Strategy Framework Directive (MSFD) were reviewed, modifying the proposed indicator (previously based solely on the rate of decline) to make specific reference to baseline values. The group also considered the outcomes of the 2016 SCANS III survey[1]. All three SCANS surveys have arisen from individual projects. WGMME recommended that the surveys be co-organised and coordinated by Member States as part of their routine monitoring and that the frequency is increased to once every six years to match the MSFD reporting cycle.

A Workshop on Predator-prey Interactions between Grey Seals and other marine mammals (WKPIGS) focused on predatory behaviour of grey seals towards other grey seals, harbour seals and harbour porpoises in European waters. The workshop aimed to consolidate pathological indicators of grey seal predation events, collate data on the prevalence and distribution and discuss methods to aid in detection of predation events and potential population level consequences of reported incidences. Cases of predation on harbour porpoises peaked in spring months. Reported incidence has increased over the last decade although it is not known if this represents a true increase in prevalence, an increase in seal numbers or an increase in effort/reporting.

Highlights from the 2017 ICES Working Group on Bycatch of Protected Species (WGBYC) included: review of ongoing bycatch mitigation research projects; presentations on interdisciplinary bycatch monitoring programs in the US Northwest Atlantic northeast region; collaborations with other ICES working groups; positive advancements on WGBYC database development working jointly with the ICES Data Centre; and progress on summarising bycatch for the Baltic Sea and Bay of Biscay/Iberia fisheries overviews.

Four cetacean species were reported as bycatch from the 2015 member state reports (common dolphins, white-beaked dolphin, bottlenose dolphin, and harbour porpoise). The WGBYC continues to highlight the inconsistent submission and content of annual reports provided by some member states and the shortcomings to accurately reflect the full magnitude of cetacean bycatch in European fisheries. WGBYC is preparing for the transition away from regular member state reports as the primary source of data on bycatch of cetaceans over to data coming through the ICES regional database.

[1] https://synergy.st-andrews.ac.uk/scans3/

The 2017 ICES Annual Science Conference (ASC) had no sessions devoted entirely to marine mammals. Nevertheless, some sessions had marine mammals included as an integral part - the most relevant sessions were: 'microbes to mammals: metabarcoding of the marine pelagic assemblage' and 'from iconic to overlooked species: how (electronic) tags improve our understanding of marine ecosystems and their inhabitants'.

More information is available from the ICES website *www.ices.dk.*

The Committee thanked Haug for his report and **agrees** that he should represent the Committee as an observer at the next ICES meeting.

4.11 International Maritime Organisation (IMO)

The report of the observer is given as SC/67b/COMM01D. At IWC66, the Commission endorsed recommendations of the IWC Conservation and Scientific Committees for continued engagement with the IMO, including submission of a paper to the IMO Marine Environment Protection Committee (MEPC) providing an update of recent information related to the extent and impacts of underwater noise from shipping. This paper was written by an intersessional group appointed at SC67a and submitted to the IMO MEPC 72 meeting 9-13 April 2018 (MEPC 72/Inf.9).

The ship strike section of the IWC website now contains a list of the measures that have been put in place globally through IMO or national regulations, to reduce ship strike risks to whales. These include Traffic Separation Schemes, Areas to be Avoided, Recommended Routes, voluntary and mandatory speed restrictions. New measures relevant to ship strikes include three recommendatory areas to be avoided (ATBA) encompassing King Island, Nunivak Island, and St. Lawrence Island in the Bering Sea proposed by the United States (NCSR 5/3/8). The proposal noted that King Island is a biologically important site to the gray whale, while St. Lawrence Island's ATBA would provide protection to bowhead whales, gray whales, and humpback whales. These areas were recommended for adoption (with a reduced size for the St. Lawrence ATBA) by the IMO Navigation, Communications and Search and Rescue sub-committee NCSR 5 in February 2018.

Members of the IWC Scientific Committee have attended IMO meetings in order to discuss how best to provide information on populations of marine mammals relevant to the marine mammal avoidance provisions of the IMO Polar Code. This is discussed further under Item 14.3.

The Committee thanked Ferris and Leaper for their report and **agrees** that they should represent the Committee at the next IMO meeting.

4.12 International Union for the Conservation of Nature (IUCN)

The report of the observers to IUCN is given as SC/67b/COMM01G. The IUCN Marine Mammal Protected Areas Task Force (*https://www.marinemammalhabitat.org*) held its 3rd regional workshop in Malaysia in March 2018 to identify, describe and map candidate areas for inclusion in the Important Marine Mammal Area (IMMA) e-Atlas (*marinemammalhabitat.org/imma-eatlas*). The 46 candidate IMMAs proposed by the workshop are currently undergoing independent review.

Cetaceans entries on the Red List are in the process of being updated. The first batch of updates covering 19 taxa was published on *redlist.org* in December 2017 and is summarised at *iucn-csg.org/index.php/page/3*. Most of the remaining mysticete species assessments and some subpopulation assessments, as well as around 10 more new assessments of small and medium-sized odontocetes, have been submitted for publication in the next Red List update in June 2018. Most of the remaining taxa are in the pipeline for publication in late 2018.

IUCN continues to convene the Western Gray Whale Advisory Panel (WGWAP), which provides advice to Sakhalin Energy Investment Company (SEIC) and other parties, especially on the mitigation of industrial and other impacts on the gray whales that feed each summer off Sakhalin Island, Russia. Details of the Panel's recent work are given in Annex O, Appendix 3.

Regular news items on activities by members of the IUCN SSC Cetacean Specialist Group are posted on the CSG website, *www.iucn-csg.org*.

4.13 North Atlantic Marine Mammal Commission (NAMMCO)

Scientific Committee

The report of the IWC observer at the 24th meeting of the NAMMCO Scientific Committee (NAMMCO-SC) is given as SC/67b/COMM01B. The NAMMCO-SC discussed a current joint project, 'Exploring marine mammal consumption relative to fisheries removal in the Nordic and the Barents Seas'. Preliminary results suggest that marine mammal consume around 15 million tons ± 50% of prey per year, predominantly targeting low and mid trophic level species (zooplankton and small pelagic fish). Fisheries remove around 4.3 million tons per year, targeting mid and top trophic levels (small pelagic fish and larger demersal and pelagic fish).

The NAMMCO By-Catch Working Group (BYCWG) met in May 2017. Methods used for collection of data and by-catch estimation were reviewed, and both the WG and the SC recommended methodological improvements to be implemented both in the data collection and the analysis before the bycatch estimates could be endorsed. Greenland is an atypical case because marine mammals that are caught, either directly or indirectly, are assumed to be reported as direct

catch (with large whales being the exception where bycatch is reported as such). The primary concern is to ensure that any bycatch is included in the total number of removals to be used in population assessments.

The NAMMCO SC noted and appreciated that the IWC *Implementation Reviews* for North Atlantic fin whales and North Atlantic common minke whales are completed. The NAMMCO SC provided advice on sustainable catch levels fro these species in Icelandic waters (from 2018-2025) based upon application of the RMP. The NAMMCO SC also recommended that the *SLAs* that are developed in the IWC SC be used for advice for large whales in Greenland and provided advice on strike limits for West Greenland humpback whales for the 2019-24.

The NAMMCO SC received the results from an updated global review of monodontids and provided updated assessments and advice for white whales and narwhals in Greenland and Canada. It also received a new abundance estimate for bottlenose whales from the Faroese component of the 2007 T-NASS survey that was analysed together with data on deep diving species from the SCANS-II and CODA surveys. Sightings were mainly from the Faroese survey block.

Increased research on harbour porpoises in Norway is being driven by the concerns regarding bycatch. Bycaught harbour porpoises were collected in 2016 and 2017 by Norway for biological sampling, and a food-web model is being developed for the Vestfjord area close to Lofoten to study the role of the species in this area. An abundance estimate is now available from the SCANS-III survey which was extended from 62°N to include Vestfjorden, an area with high bycatch. Preliminary investigations using this new abundance estimate suggest that bycatch levels are within PBR.

NAMMCO's whale sighting surveys in the Northeast Atlantic in 2015 (NASS2015) included an intensive survey with the purpose of estimating the abundance of pilot whales around the Faroe Isles, an aerial survey of the coastal waters in East Greenland and a ship-based survey around Jan Mayen following methods developed for the Norwegian minke whale surveys. The next NASS survey should be in 2022-23. The NAMMCO SC strongly recommended that an attempt be made to conduct again a trans-Atlantic coordinated survey and charged the NAMMCO Secretariat to explore what are the present plans and how much flexibility they encompass.

Council
The report of the IWC observer at the 26th Annual Council meeting of NAMMCO held in Tromsø, Norway 7-8 March 2018 is given as SC/67b/COMM01C. Relevant items discussed at the Council meeting include the following:

(1) A newly established working group on bycatch, entanglements and live strandings has started its work and will gather information on the matter from other organisations and develop recommendations for NAMMCO. The focus is animal welfare associated to non-hunting related activities, and how NAMMCO can best contribute to addressing significant adverse impacts of by-catch, entanglement and live strandings on marine mammals; and

(2) The report of the Global Review of Monodontids (white whales and narwhals) reviewed the conservation status, threats, and data gaps for all stocks globally. The last review was in 1999.

The Committee thanked Moronuki for his report.

4.14 North Pacific Marine Science Organisation (PICES)
The report of the IWC observer at 2017 annual meeting of PICES is given as SC/67b/COMM01F.

The marine birds and mammals section (S-MBM) focussed on 'seasonal and climatic influences on prey consumption by marine birds, mammals and predatory fishes' Presentations were made on (1) significance of seasonal changes in prey consumption on energy budgets and ecosystem dynamics; (2) effects of changes in water temperature and other climatic variables on food requirements; (3) relationships between dietary shifts and population trends; (4) limits of plasticity in prey selection; and (5) how prey consumption of birds, mammals and predatory fishes is affected by the recent extreme climatic events. Overall, the collection of presented studies in this session contributed to the efforts of the S-MBM to estimate prey consumption of birds and mammals. They provided new methods to estimate prey consumption of marine mammals and gave insights into the existing databases of diets and population estimates that can be used to further this effort.

For 2018, the S-MBM will focus on 'diets, consumption and abundance of marine birds and mammals in the North Pacific'. Since the 2016 workshop, work on the agreed upon databases to estimate prey consumption has been initiated and will continue to be added to over the coming 12 months in anticipation of the 2018 workshop, when invited experts will review the compiled information. This process should result in near-complete databases of diets, abundances and energy requirements of marine birds and mammals in the North Pacific.

The 2018 annual meeting of the PICES will be held in Yokohama, Japan 25 October-4 November 2018. The Committee thanked Tamura for attending on its behalf and **agrees** that he should represent the Committee as an observer at the next PICES meeting.

4.15 Protocol on Specially Protected Areas and Wildlife (SPAW) of the Cartagena Convention for the Wider Caribbean
No observer attended SPAW meetings in the intersessional period.

4.16 Pacific Region Environment Programme (SPREP)
No observer attended SPREP meetings in the intersessional period.

5. GENERAL ASSESSMENT ISSUES WITH A FOCUS ON THOSE RELATED TO THE REVISED MANAGEMENT PROCEDURE (RMP)

Several assessment topics apply not only to the Revised Management Procedure (RMP), but to the work of the Scientific Committee as whole. This item focuses on general assessment issues, such as: (1) the relationship between $MSYR_{mat}$ and $MSYR_{1+}$; (2) implications of RMP and AWMP simulation trials for consideration of 'status'; and (3) matters of relevance to special permits that involve RMP considerations including effects of catches upon stocks.

5.1 Evaluate the energetics-based model and the relationship between $MSYR_{1+}$ and $MSYR_{mat}$

MSYR is a key parameter in the *Implementation Simulation Trials* used to evaluate the conservation and catch performance of alternative RMP variants for specific species and regions. In recent years, the Committee has been reviewing progress on an individual based energetics model (IBEM) to provide insights into the relationship between $MSYR_{1+}$ and $MSYR_{mat}$. Two papers on the IBEM were reviewed by the Committee in SC/67b.

SC/67b/EM07 outlined enhancements to the IBEM since the last meeting. This included the ability to explicitly model the effects of feeding while on migration, which can have effects on the yield curve as well as MSYR and MSYL. The Committee discussed (Annex D, Item 2.1) several ways in which this model can potentially enhance understanding of the relationship between biological processes and MSYR.

SC/67/RMP01 reported on trials using the IBEM within the standard RMP testing framework. The results were consistent with the behaviour of the RMP *CLA* observed in less complex population models and will also provide a point of comparison for the emulator model for the IBEM currently under development. The Committee has previously agreed that a fully-developed emulator model could form the basis for future *Implementation Simulation Trials*.

Attention: SC

*The Committee **agrees** that work continue to develop an emulator model; assess whether it is possible to represent the trajectories from the IBEM using an emulator model; compare the yield curves from the IBEM with those from the emulator model; and develop guidelines for how to use an emulator model as the basis for a multi-stock, multi-area population dynamics model and how such a model could be conditioned given available data.*

5.2 Implications of ISTs for consideration of species' and populations' status

Last year, the Committee recommended that a set of *Implementation Simulation Trials* should be summarised using three statistics to provide information on status (IWC, 2018d). The Committee was advised that intersessional tasks toward that goal could not be completed prior to SC/67b due to computing workloads.

Attention: SC

*The Committee **agrees** that Allison should modify the control programs used for* Implementation Simulation Trials *to report the three measures of status agreed last year (IWC, 2018d). The RMP sub-committee, in conjunction with the Working Group on ASI, will review outcomes of the analyses at SC/68a. Punt and Donovan will develop draft updates to the Guidelines for* Implementations *and* Implementation Reviews *to reflect decisions on evaluation status of stocks for consideration at SC68a.*

5.3 General consideration of how to evaluate the effect of special permit catches on stocks and levels of information needed to show improved management performance

5.3.1 General issues

The Committee developed general guidelines on the levels of information needed to show improved management improvement, for proposals that identify this as an objective (Annex D; appendix 2). The guidelines are intended to assist proponents in proposal preparation and to facilitate the review process. It was stressed that these were guidelines not requirements. Proponents might request the establishment of an Advisory Group to provide comment on intersessional work, but this is not mandatory. An Advisory Group may most benefit nations which have not previously developed proposals or may be lacking analysts familiar with the modelling approaches commonly applied at the IWC.

Attention: SC

*The Committee **agrees** that the general guidelines on the levels of information needed to show improved management improvement, for proposals that identify this as an objective (Annex D; appendix 2), should be included as an Appendix to the Scientific Committee handbook.*

5.3.2 Specific issues

SC/67b/RMP03 provided draft specifications for RMP/IST type simulations to evaluate management procedures based on modified *CLA*s that use information on recruitment inferred from age data from Antarctic minke whales. This work originally arose from discussions of NEWREP-A and Recommendation 1 of the Panel Review of that proposal (and see Item 19). The Committee noted that SC/67b/RMP03 was a work-in-progress, and that several features of the operating models would need to be extended before final conclusions could be drawn. The author of SC/67b/RMP03 plans to continue this work and received several suggestions from the Committee to carry those efforts forward (Annex D, Item 2.3).

5.4 Work plan 2019-20

Details of work to be undertaken both before and during the 2019 Annual Meeting are given in Table 2.

Table 2

Work plan for general assessment matters with a focus on the RMP

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Item 5.1: Conduct work to evaluate the energetics-based model and hence the relationship between MSYR1+ and MSYRmat	(a) Continue to assess whether it is possible to represent the trajectories from the IBEM using the emulator model (Annex Y); (b) Compare the yield curves from the IBEM with those from the emulator model (Annex Y); and (c) Develop guidelines for how to use an emulator model as the basis for a multi-stock, multi-area population dynamics model and how such a model could be conditioned given available data (Annex Y).	Continue to work to evaluate the energetics-based model and hence the relationship between $MSYR_{1+}$ and $MSYR_{mat}$	Conduct follow-up analyses	Continue to work to evaluate the energetics-based model and hence the relationship between MSYR1+ and MSYRmat
Item 5.2: Implications of ISTs, for consideration of status	(a) Modify the control programs used for *Implementation Simulation Trials* to report the three measures of status (Allison) (b) Draft updates to the Guidelines for *Implementations* and *Implementation Reviews* to reflect decisions on evaluation status of stocks (Punt and Donovan)	Review the results of the projections Review the draft guidelines		
Item 5.3: levels of information needed to show improved management performance		Review progress implementing the suggested changes to the specifications of the model in SC/67b/RMP03 and any results.		

6. RMP – *IMPLEMENTATION*-RELATED MATTERS (RMP)

This agenda item includes the details of ongoing *Implementation Reviews* and preparation for new *Implementation Reviews*. For discussions related to the stock structure and abundance of these stocks, see also Items 11 and 12.

6.1 Completion of the *Implementation Review* of western North Pacific Bryde's whales

6.1.1 Report of the intersessional Workshop

The second intersessional Workshop on western North Pacific Bryde's whales was held in Tokyo from 14-16 February 2018 (SC/67b/Rep02). The objective was to facilitate completion of the *Implementation Review*. Much of the Workshop focussed on completing the final trial specifications, especially confirming the mixing matrices, updating the abundance estimates for the new sub-areas and confirming future sighting survey plans and whaling options. The Workshop reviewed preliminary conditioning results and agreed that they were satisfactory. It developed a workplan to try to ensure completion of the *Review* at SC/67b.

The Committee noted that the intersessional workshop had led to considerable progress towards completing the *Implementation Review*. It thanked Donovan for chairing the meeting, the Government of Japan for providing excellent facilities and all the participants for their contributions to the development of trial specifications and workplan.

The code and specifications for *Implementation Simulation Trials* were updated following the intersessional Workshop.

Attention: SC

*The Committee **agrees** to the updated trial specifications for the* Implementation Review *of western North Pacific Bryde's whales. These specifications are provided in Annex D, Appendix 3. It also **agrees** that conditioning has been achieved satisfactorily.*

6.1.2 Conclusions and recommendations

Once the trial specifications and conditioning had been agreed, the next step was to conduct projections under alternative RMP variants and survey plans. There was insufficient time during the meeting to complete all of the required projections and to check the associated calculations. Consequently, the remaining work will be completed intersessionally and reviewed and summarised by a Steering Group (Annex Y). This will occur well before SC/68a so that Japan has sufficient time to consider the results (e.g. with regard to its preferred survey options), prior to final conclusions being drawn. The Committee expects that this work can be completed before the end of 2018, but if complications arise conducting the projections, an extra day should be added to the 'First Intersessional Workshop for the western North Pacific minke whales' (see Item 6.2) to address outstanding issues.

Attention: SC

*The Committee **agrees** that the* Implementation Review *of western North Pacific Bryde's whales will be completed at SC/68a. Outstanding tasks will be completed intersessionally and the results reviewed and summarised by a Steering Group (Annex Y). This will occur well prior to SC/68a, and if complications arise then an extra day should be added to the First Intersessional Workshop for the western North Pacific minke whales (see Item 6.2) to address those issues.*

6.2 Start of the *Implementation Review* of western North Pacific common minke whales

6.2.1 Report of the intersessional Workshop

Donovan summarised the report of the preparatory Workshop for the Western North Pacific common minke whale *Implementation Review* (SC/67b/Rep05). Last year, the Committee recognised that the most difficult aspect of the last *Implementation Review* had been selecting, modelling and assigning plausibility to stock structure hypotheses. The objective of this Workshop was to begin to review work undertaken since the last *Implementation Review* and to develop, if necessary and possible, consensus advice on further analyses that will assist in the forthcoming *Implementation Review*. Stock structure discussions on common minke whales are detailed in Annex I, item 4.2.

This past lack of agreement with respect to the plausibility of existing stock structure hypotheses has, in part, revolved around how genetic analyses can be used to assign whales as part of the 'J' versus 'O' stocks. While some whales assign strongly to one of the two groups based on genetic data, the assignment of others is dependent on the assignment probability deemed sufficient to assign stock affinity. At the intersessional workshop (SC/67b/Rep05), the results of new stock structure-related analyses were reviewed by an advisory panel, and two recommendations were made with regard to additional genetic analyses needed to better understand stock structure. One of the recommended analyses involved evaluating the consistency of individual assignment probabilities when additional loci were genotyped. Progress with respect to that recommendation is discussed below.

The Workshop was also provided with an update to SC/67a/SCSP/13 that used information on the trend over time in the J:O stock ratio for common minke whale bycatches around Japan to draw various inferences, in particular about the value of the MSYR. The Workshop agreed that J:O stock ratios in bycatch will require attention when formulating stock distribution assumptions for the process of conditioning *IST*s in the coming *Implementation Review* and made some recommendations on how this could be achieved.

The Committee noted that the intersessional Workshop was held in an excellent spirit of co-operation among the participants and led to identification of additional data sets and analyses that should be taken forward. The Committee thanked Donovan for chairing the meeting, the Government of Japan for providing excellent facilities and all the participants for their contributions to progress the *Implementation Review*.

6.2.2 Progress since the intersessional Workshop

SC67b/SDDNA06 presented the results of the recommended analysis from the Workshop (see Item 6.2.1) and the Committee confirmed that the workshop's recommendation for this analysis had been properly completed.

Attention: SC

The Committee reviewed new results of genetic analyses that were recommended at the intersessional workshop (SC/67b/Rep05) to better evaluate the use of genetic data to assign stock affinity in North Pacific common minke whales. The Committee:

(1) ***agrees*** *that future analyses should incorporate a range of assignment thresholds to encompass uncertainty;*
(2) ***supports*** *the additional genetic analyses described in Annex I Appendix 5 relating to the second recommendation of the intersessional workshop and agrees that they should be performed prior to the next intersessional workshop; and*
(3) ***encourages*** *the inclusion of non-genetic biological data to inform stock structure where possible.*

SC/67b/RMP/02 aimed at suggesting a plausible range for $MSYR_{1+}$ for the western North Pacific common minke whales, and the relative plausibility of two stock structure hypotheses. The Committee thanked Kitakado for the updated analysis, which implemented some of the recommendations from the intersessional Workshop. Details of this paper and associated discussion can be found in Appendix D, Item 3.2.2. The Committee also discussed the analysis of genetic data conducted since the intersessional workshop (Annex I, Item 4.5).

Attention: SC, CG-A

The Committee ***agrees*** *that:*

(a) it is necessary to update the mixing matrices in the trial specifications to be more consistent with observed genetic and bycatch data, also taking into account sensitivity to alternative methods of genetic assignment to stock;
(b) whether it is possible to use the bycatch data to assign plausibility ranks to $MSYR_{1+}$ values and stock structure hypotheses depends on assumptions regarding trends in fishing effort spatially and temporally; and
(c) trials would need to consider different assumptions regarding the use of J:O bycatch ratios, including that these data do not provide information on $MSYR_{1+}$ and the plausibility of stock structure hypotheses because of possible differential distributional changes by stock.

The Committee therefore ***agrees*** *that scientists from Japan and Korea should provide data on the amount, location and timing (seasonal and annual) of fishing effort and bycatch to the First Intersessional Workshop (see item 6.2.3).*

6.2.3 Preparation for the First Intersessional Workshop

The Committee began preparations for the First Intersessional Workshop on the *Implementation Review* of western North Pacific common minke whales. It re-established the Steering Group (Annex Y) to organise this Workshop.

In accordance with the Committee's *'Requirements and Guidelines for Implementations and Implementation Reviews'* (IWC, 2012b), the primary objectives of the First Intersessional Workshop will be to: (a) consider plausible hypotheses and eliminate any hypotheses that are inconsistent with the data); (b) examine more detailed information in expected whaling operations, including options or suggested modifications to the pattern of those operations; (c) review the small geographical areas ('sub-areas') that will be used in specifying the stock structure hypotheses and operational pattern; and (d) specify the data and methods for conditioning the trials that will be carried out before the next annual meeting. An initial annotated agenda for the Workshop, highlighting the associated data and analysis requirements can be found in Annex D, appendix 5.

6.3 Workplan 2019-20

Details of work to be undertaken both before and during the 2019 Annual Meeting are given in Table 3.

Table 3

Work plan for RMP (*Implementation*-related matters)

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Item 6.1: Western North Pacific Bryde's whales	Finalise the projections and the application of the criteria for evaluating which RMP variants are acceptable, borderline, and unacceptable	Complete the *Implementation Review*		
Item 6.2: Western North Pacific minke whales	(a) conduct the First Intersessional Workshop; (b) code the resulting trials and condition the trials	Conduct the work required for the First Annual Meeting	Conduct the Second Intersessional Workshop	Conduct the work required for the Second Annual Meeting

7. ABORIGINAL SUBSISTENCE WHALING MANAGEMENT PROCEDURE (AWMP)

This item continues to be discussed as a result of Resolution 1994-4 of the Commission (IWC, 1995), which has been strengthened by Resolution 2014-1 (IWC, 2016a). The report of the Standing Working Group (SWG) on the development of an aboriginal whaling management procedure (AWMP) is given as Annex E. The Committee's deliberations, as reported below, are largely a summary of that Annex, and the interested reader is referred to it for a more detailed discussion. The primary issues at this year's meeting comprised: (1) finalising the development of *SLA*s (*Strike Limit Algorithms*) for Greenlandic hunts, with a focus on fin and common minke whales; (2) finalising the work on the scientific components of the AWS (Aboriginal Subsistence Whaling Management Scheme); (4) completion of the *Implementation Review* for Bering-Chukchi-Beaufort Seas stock of bowhead whales; and (3) providing management advice for aboriginal hunts (see Item 8).

Considerable progress on items (1) and (2) was made because of intense intersessional work including two workshops in Copenhagen in October 2017 and March 2018, as well as a small technical meeting in December 2018 at OSPAR headquarters in London.

7.1. *SLA* development for the Greenland hunts

7.1.1 Fin whales

SC/67b/Rep06 incorporated the discussions of the two intersessional Workshops and the small working group meeting. Considerable progress was made in relation to (a) updated abundance estimates; (b) finalisation of the trial structure; (c) review and approval of conditioning; and (d) initial consideration of new *Strike Limit Algorithms* (*SLA*s) and results.

The Committee thanked Donovan, the Workshop chair and the participants for the excellent progress made.

The final trial specifications for the West Greenland fin whales are provided in Annex E (Appendix 2).

Table 4 below summarises the main factors considered in the *Evaluation Trials.* The most influential involve different stock structure hypotheses, different productivity rates (MSYR) and different 'need' envelopes (need envelopes incorporate scenarios where need remains constant at the present level for 100 years (termed A), where it increases linearly to twice the present level over the 100-year simulation period (termed B) and where it increases linearly to three times the present level over the 100-year period (termed C).

Table 4

Summary of the key factors considered in the fin whale trials

Factor
Stock structure hypotheses
Mixing matrices
MSYR rate
Survey bias
Need envelope

7.1.1.1 CANDIDATE *SLA*S

The Committee received two papers with candidate *SLA*s, SC/67b/AWMP13 and SC/67b/AWMP15. The general properties of the three *SLA*s presented in SC/67b/AWMP13 involve taking an inverse variance weighted average of the last three estimates as an estimate of abundance and calculating the strike limit as a growth rate fraction of a lower percentile of the abundance (conditional on a trend modifier), a snap to need feature and a protection level. The three variants relate to how they are 'tuned' (the trade-off balance between conservation and need).

The three *SLA*s presented in SC/67b/AWMP15 are based on a weighted-average interim *SLA* which uses all abundance estimates, but where the earlier ones are down-weighted. An adjustment to the multiplier of the abundance estimate in the interim *SLA* is applied which depends on the trend of the abundance indices. The three variants relate to how they are 'tuned' (the trade-off balance between conservation and need).

7.1.1.2 REVIEW FINAL RESULTS AND PERFORMANCE

In total, seven potential *SLA*s (which include the 'Interim' *SLA* – a modified version of the *Interim SLA* used to provide advice previously by the Committee until the final *SLA*s had been developed) were considered. The full range of conservation and need statistics were reviewed for the *Evaluation Trials*[2], noting that the initial focus is on meeting the Commission's conservation objectives. Those candidate *SLA*s that meet these are then evaluated on their ability to meet need satisfaction. In summary, conservation performance is deemed satisfactory if either the population is not at MSYL but it is increasing towards it or the population is above MSYL (in which case it may be increasing or decreasing towards MSYL). These concepts are captured in the 'D1' and 'D10' statistics (defined fully in Annex E, table 2) and can be visualised in bivariate plots given in Annex E.

The Committee agreed that the proposed *SLA*s had performed satisfactorily on the joint conservation statistics for the A and B (but not for the C) need envelopes for all trials. The focus was then to evaluate the need satisfaction performance over 20 and 100 years and consider stability in catch levels. This performance was captured by examining three statistics:

[2] The Committee also examines the results of *Robustness Trials* to ensure that the *SLA* does not exhibit unusual behaviour in more extreme trials.

N9(20) the average need satisfaction over the first 20 years, N9(100) the average need satisfaction over the 100 years and N12 the mean down step statistic (these are also defined fully in Annex E, table 2). They can be visualised in 'Zeh' plots (e.g. see Annex E).

Given the present incorporation into the trial structure of two widely different stock structure hypotheses ('influx' and 'partial'- see Annex E, appendix 2) to explain the variability of the abundance estimates, the need satisfaction over 20 years was given more weight in the evaluation as it is likely that future *Implementation Reviews* may be able to remove one or other scenario.

After an examination of the full range of results, there was no obvious 'winner' between two of the *SLA*s (one from each developer). Depending on the trials considered, and which statistic was examined, they performed slightly differently but their performance overall was equivalent.

Following an approach originally adopted during the development of the *Bowhead SLA*, it was decided that an *SLA* which sets the strike limit to the average of the values obtained by the two *SLA*s[3] would be preferable, providing performance was as good or better than either individual *SLA*; no 'snap to need' for the averaged *SLA* has been applied. The results of the 'combined *SLA'* are summarised in Annex E, appendix 3[4].

7.1.1.3 CONCLUSIONS AND RECOMMENDATIONS

The management advice developed using this *SLA* is given under Item 8. 6.

Attention: C-A, SC

The Committee ***draws attention*** *to the extensive work undertaken over recent years to develop an* SLA *for the West Greenland hunt for fin whales. In concluding this work, the Committee:*

(1) ***agrees*** *that the combined* SLA *(which sets the strike limit to the average of the values obtained by the two best* SLAs *considered) performed satisfactorily in terms of conservation performance and was to be preferred over the individual SLAs in terms of need satisfaction;*
(2) ***recommends*** *that this* 'WG-Fin SLA' *be used to provide management advice to the Commission on the subsistence hunt for West Greenland fin whales (provided the need request falls within need scenarios A and B);*
(3) ***expresses*** *its great thanks to the developers, Brandão and Witting for the vast amount of work put into the development process and to Allison and Punt for their extensive work developing the operating models and running the trials; and*
(4) ***agrees*** *that one focus of the next* Implementation Review *will be to examine further stock structure in relation to the two hypotheses being considered at present, and especially the 'influx' model which was developed in the context of low abundance estimates in some years, rather than being based upon genetic information.*

7.1.2 Common minke whales (Greenland)

SC/67b/Rep06 incorporated the discussions of the two intersessional Workshops and a small working group meeting. Considerable progress was made in relation to (a) updated abundance estimates; (b) finalisation of the trial structure; (c) conditioning; and (d) initial consideration of new *Strike Limit Algorithms* (*SLA*s) and results.

The Committee thanked Donovan, the Workshop chair and the participants for the excellent progress made.

The final trial specifications for the West Greenland common minke whales are provided in Annex E (appendix 4).

Table 5 below summarises the main factors considered in the *Evaluation Trials* for common minke whales. The most influential involve different stock structure hypotheses, different productivity rates (MSYR) and different 'need' envelopes (see discussion under Item 7.1.1), where it increases linearly to twice the present level over the 100-year simulation period (termed B) and where it increases linearly to three times the present level over the 100-year period (termed C).

Considerable work was undertaken to finalise the list of trials, to ensure that the mixing matrices were correctly specified and to complete and agree conditioning. The final trial specifications are provided in Annex E, Appendix 4.

Table 5

Summary of the key factors considered in the common minke whale trials

Factor
Stock structure hypotheses
Mixing matrices
MSYR rate
Survey bias
Need envelope

[3] tuned to a D10 of 0.8 for the influx trial F34-1B

[4] Final validation and archiving of results will be undertaken by Allison in Cambridge.

7.1.2.1 CANDIDATE *SLAS*

SC/67b/AWMP14 developed a candidate *SLA* for common minke whales off West Greenland similar to that used for fin whales in SC/67b/AWMP13. It operates on an inverse variance weighed average of the last three abundance estimates. The strike limit is calculated as a growth rate fraction of a lower percentile of the abundance measure, conditional on a 'snap to need' feature, and a protection level. It does not include a trend modifier.

It was tuned to have a 5th percentile of D10 of 0.80 for need envelope A for the most difficult *Evaluation Trial* (trial M04-1A – see Annex E, appendix 4), where there are two sub-stocks in the western North Atlantic in which the mixing between the Central and the Western stock, and mixing between the putative western sub-stocks, is minimal, and where the MSYR is 1%).

7.1.2.2 CONSIDERATION OF RESULTS

Conditioning of the *Evaluation Trials* was completed satisfactorily and a summary of the results of the is provided in Annex E (appendix 5[5]). Annex E, fig. 3 provides the bivariate plot.

In determining satisfactory conservation and need performance when evaluating *SLA*s, the Committee considers the full range of results across all the *Evaluation Trials*, not simply the worst-case scenarios. Conservation performance was satisfactory for all but the most extreme trial (trial M04-1A) where it was slightly below for the lower 5th percentile. This trial had low MSYR and two W-stocks; it had been originally considered in the context of investigating potential problems for the hunt to simulate possible local depletion in the hunting area rather than for conservation reasons. Genetic stock structure in the entire North Atlantic is subtle such that even an hypothesis of almost complete panmixia is not rejected by most of the analyses and thus differentiation among 'C' and 'W' is very low. This is even more true for substructure within the W stock (if, indeed, there is any). Given that trials are conservative in so far as they overrate isolation among stocks, and the very subtle differentiation among stocks and sub-stocks in the North Atlantic, a single trial (which implements two fully separate W sub-stocks, for which there is little evidence) not meeting the D1/D10 criteria is not of conservation concern.

The SWG (Annex E, item 2.2.3) had noted that given the unforeseen situation with Secretariat computing, there had been insufficient time for it to consider the results of the *Robustness Trials* during its meeting. Such trials are not needed to determine an *SLA* but are examined to ensure that the selected *SLA* has no unforeseen properties in extreme trials. These were subsequently run prior to the plenary discussions and the results showed no unexpected properties.

7.1.2.3 CONCLUSIONS AND RECOMMENDATIONS

The management advice developed using the *WG-common minke SLA* is provided under Item 8.5.

Attention: C-A, SC

The Committee ***draws attention*** *to the extensive work undertaken over recent years to develop an* SLA *for the West Greenland hunt for common minke whales. In concluding this work, the Committee:*

(1) ***agrees*** *that the tested* SLA *which performed satisfactorily in terms of conservation performance;*
(2) ***agrees*** *that this 'WG-Common minke SLA' be used to provide management advice to the Commission on the subsistence hunt for West Greenland common minke whales provided the need request falls within need scenario A (i.e. does not exceed 164 annually);*
(3) ***expresses*** *its great thanks to the developers, Brandão and Witting for the vast amount of work put into the development process and to Allison and Punt for their extensive work developing the operating models and running the trials; and*
(4) ***agrees*** *that one focus of the next* Implementation Review *will be to examine further stock structure in relation to the two hypotheses being considered at present, should be consideration of the results of analyses of genetic data using additional samples from Canada (as well as the additional samples that will become available from West Greenland and Iceland); and*
(5) ***agree****s to establish an intersessional advisory group (Annex Y) to facilitate issues relating to samples.*

7.1.3 North Pacific gray whales (Makah whaling)

7.1.3.1 MANAGEMENT PLAN PROPOSED BY THE U.S. FOR MAKAH WHALING

The Makah Indian Tribe has requested that the U.S. National Marine Fisheries Service (NMFS) authorise a tribal hunt for Eastern North Pacific (ENP) gray whales in the coastal portion of its 'usual and accustomed fishing area' in Washington State. The Tribe intends to hunt gray whales from the ENP population, which currently numbers approximately 27,000 animals (Durban *et al.*, 2017). However, at certain times of the year there is a possibility that the hunt may take animals from the PCFG (Pacific Coast Feeding Group) and/or the WNFG (Western North Pacific Feeding Group). In an updated management plan – known as the Makah Management Plan (the Committee had approved an earlier plan for this hunt in 2012 (IWC, 2013), NMFS has taken measures to restrict the number of PCFG whales that are struck or landed in a given 10-year period and to avoid, to the extent possible, striking or killing a WNFG gray whale. The Government of the USA requested the Committee to test this plan to ensure that it meets IWC conservation objectives.

[5] Final validation and archiving of results will be undertaken by Allison in Cambridge.

This task was begun at the Fifth Rangewide Workshop on the Status of North Pacific Gray Whales (SC/67b/Rep07) from 28-31 March 2018. The major focus of the Workshop related to finalising the specifications for modelling, to enable results to be available for SC67b including incorporation of the Makah Management Plan (SC/67b/Rep07, Annex E, appendix 1) into the modelling framework. The factors taken into account in the trials are given in Table 6.

Table 6

Summary of the main factors considered in the Makah gray whale trials

Factor	
Model fitting related	Projection-related
Stock hypothesis	Additional catch off Sakhalin
MSYR	Catastrophic events
Mixing rate	Northern need in final year
Immigration into the PCFG	Struck and lost rate
Bycatches and ship strikes	Future effort
Pulse migrations into the PCFG	Factors related to obtaining and matching photographs

At the present meeting, the focus was on the conservation performance of the Makah Management Plan. Performance was evaluated in the same manner as described for the evaluation of the *SLA*s for West Greenland fin and common minke whales (see Items 6.1 and 6.2). The results can be found in Annex E (appendix 6). The only scenarios under which the plan might not perform adequately were considered to have low plausibility (e.g. a bycatch mortality of ~ 20 PCFG whales per year). Annex E, fig. 4 shows the bivariate plot.

7.1.3.2 CONCLUSIONS AND RECOMMENDATIONS

The management advice relating to the Makah Management Plan is provided under Item 8.2.

Attention: C-A, SC

The Committee reviewed a US Management Plan for a Makah hunt of gray whales off Washington State (the Committee had evaluated a previous plan in 2011 - IWC, 2011; 2012), using the modelling framework developed for its rangewide review of gray whales (SC/67b/Rep07). In conclusion, the Committee:

(1) ***agrees*** *that the performance of the Management Plan was adequate to meet the Commission's conservation objectives for the Pacific Coast Feeding Group, Western Feeding Group and Northern Feeding Group gray whales;*
(2) ***notes*** *that the proposed management plan is dependent on photo-identification studies to estimate PCFG abundance and the mixing proportions of PCFG whales available to the hunt (and to bycatch in its range);*
(3) ***stresses*** *that its conclusions are dependent on the assumption that these studies will continue in the future; and*
(4) ***expresses*** *its* ***great thanks*** *to Punt, Brandon and Allison for their excellent work in developing and validating the testing framework and running the trials.*

7.1.4 Conclusions on AWMP work

The Chair of the SWG on the AWMP, Donovan, noted that this meeting represented the end of a long journey – with the adoption of the two new *SLA*s, the SWG and the Committee has completed the development tasks it had been assigned by the Commission, originally in Resolution 1994-1. It was an immense task but a great pleasure to work with such dedicated and talented people. He thanked all of the scientists who have made such a wonderful contribution to this work over the years and especially Geof Givens, Kjartan Magnússon (sadly no longer with us), Eva Dereksdóttir, Lars Witting, Anabela Brandão, Doug Butterworth, Cherry Allison and André Punt – the SWG has, in his view, achieved ground-breaking work over the last two decades in a spirit of great collaboration and co-operation, even when there were disagreements, as inevitably there were. He also thanked the hunters and their representatives who had made major contributions in terms of not only data provision but also advice on the AWS (see Item 7.2). The Committee **concurred** that this was an excellent example of what the Scientific Committee could achieve with international collaboration. Finally, they **thanked** Donovan for his dedicated, good humoured and impartial leading of such a major piece of complex work over such a long period - this work has been central to the Committee's role in providing the best scientific advice to the Commission on aboriginal subsistence whaling hunts, bringing together conservation needs and the needs of the hunters.

7.2 Aboriginal Whaling Scheme (AWS)

7.2.1 Introduction

The Scientific Committee's Aboriginal Whaling Management Procedure (AWMP) applies stock-specific *Strike Limit Algorithms* (*SLA*s) to provide advice on aboriginal subsistence whaling (ASW) strike/catch limits.

ASW management (as part of an AWS, the aboriginal whaling scheme) incorporates several components, several of which have a scientific component:

(1) *Strike Limit Algorithms* (case-specific) used to provide advice on safe catch/strike limits;

(2) operational rules (generic to the extent possible) including carryover provisions, block quotas and interim relief allocations;
(3) Guidelines for *Implementation Reviews*; and
(4) Guidelines for data and analysis (e.g. guidelines for surveys, other data needs).

Considerable work on updating the AWS since the version presented (but not accepted by) to the Commission in 2002 (IWC, 2003) was undertaken by an intersessional correspondence group (SC/67b/AWMP 21) and at the intersessional workshops (SC/67b/Rep04).

7.2.2 Carryover request from the Governments of USA and Denmark/Greenland
The Governments of USA and Denmark/Greenland (SC/67b/Rep06, Annex F, appendix) had requested advice at the March intersessional Workshop on the conservation implications of carryover provisions allowed for a carryover provision that allowed use of unused strikes from the previous three blocks, provided that the number used in any year did not exceed 50% of the annual strike limit.

This request was tested on the two *SLA*s available for stocks hunted by the USA and Greenland at the time of the Workshop i.e. the *Bowhead SLA* (applicable to the Bering-Chukchi-Beaufort Seas stock) and the *WG-Humpback SLA* (applicable to West Greenland).

Three types of options were examined:

(1) baseline case - all strikes taken annually (i.e. no need for carryover);
(2) 'frontload' case - strikes taken as quickly as possible within block (+50% limit annually until the block limit is reached); and
(3) Two alternative scenarios where carryover strikes are accrued for one or three blocks, followed by a period of carryover usage subject to the +50% limit.

The three-block scenario considered in (3) served as a direct test of the provision described in the request of USA and Denmark/Greenland.

Attention: CG-A

The Committee received a request from the USA and Denmark/Greenland (SC/67b/Rep06, Annex F, appendix) on the conservation implications of carryover provisions that
'…allow for the carry forward of unused strikes from the previous three blocks, subject to the limitation that the number of such carryover strikes used in any year does not exceed 50% of the annual strike limit'.
The Committee reviewed the request using its simulation frameworks and the two SLA*s available for stocks hunted by the USA and Greenland available at the time of the Workshop i.e. the* Bowhead SLA *(applicable to the Bering-Chukchi-Beaufort Seas stock) and the* WG-Humpback SLA *(applicable to West Greenland) and*

(1) ***agrees*** *that a carryover provision for up to 3-blocks meets Commission's conservation objectives; and*
(2) ***reiterates*** *its previous advice, applicable for all* SLA*s, that interannual variation of 50% within a block with the same allowance from the last year of one block to the first year of the next is acceptable; and*
(3) ***agrees*** *to evaluate the above request for the other Greenland* SLA*s at the 2019 Committee meeting.*

7.2.3 Review proposed updates to the AWS
The proposed update to the previous AWS is provided in Annex E, appendix 8. It has sections on carryover, block quotas, interim relief allocation (and see Annex E, appendix 7), *Implementation Reviews* and guidelines for surveys and data.

7.2.4 Conclusions and recommendations

Attention: C-R

The Committee has been working for some years to update the scientific components of an Aboriginal Whaling Scheme. It has completed this work and ***recommends*** *the AWS provided in Annex E, appendix 8 to the Commission. It has sections on carryover, block quotas, interim relief allocation (and see Annex E, appendix 7), Implementation Reviews and guidelines for surveys and data. It* ***notes*** *that the Commission's AWS may include additional, non-scientific provisions.*

7.3 *Implementation Review* of BCB bowhead whales
According to the Committee's guidelines, the primary objectives of an *Implementation Review* are to:

(1) review the available information (including biological data, abundance estimates and data relevant to stock structure issues) to ascertain whether the present situation is as expected (i.e. within the space tested during the development of a *Strike Limit Algorithm* (*SLA*)) and determine whether new simulation trials are required to ensure that the *SLA* still meets the Commission's objectives; and
(2) to review information required for the *SLA*, i.e. catch data and, when available at the time of the *Review*, new abundance estimates (note that this can also occur outside an *Implementation Review* at an Annual Meeting).

The *Bowhead SLA* was adopted in 2002 (IWC, 2003, p.158) and there was an extensive *Implementation Review* completed in 2007 (IWC, 2008a, p.124) with a major focus on stock structure including three intersessional workshops. That included consideration of additional trials investigating management implications of assuming additional population structure even though these were considered of low plausibility. The Committee concluded that the *Bowhead SLA* remained the best tool to provide management advice. The next *Implementation Review* was completed in 2012 (IWC, 2013b, p.147); that concluded that there was no need to develop additional trials to those evaluated during the previous *Implementation Review* (IWC, 2008c).

The primary review was undertaken by the SWG on the AWMP (Annex E, Item 4) but the review benefitted from discussions within two other groups, SD-DNA (Annex I, Item X) and ASI (Annex Q, Item Y).

7.3.1 Stock structure: review new information

A full discussion of the work on stock structure can be found in Annex E (item 4.1) and Annex I. New information considered included genetic analyses (SC/67b/SDDNA 01) and telemetry results (SC/67b/AWMP04). SC67b/SDDNA01provided information on genetic analyses using samples from the BCB, Canadian and Okhotsk Sea stocks of bowhead whales. Within the BCB stock, no significant differences were identified in temporal or spatial comparisons, and age-related structure was not detected in comparisons between groups of large (old) versus small (young) whales. While comparisons of the BCB stock with the Okhotsk Sea stock revealed significant differences, there were only small, and in most cases statistically insignificant, differences between BCB and Canadian stocks. While this pattern could be related to historical connectivity between the two stocks, it could also, or additionally, be driven by some degree of contemporary gene flow.

Attention: SC

With respect to stock structure, considering the multiple lines of evidence, the Committee:

(1) ***agrees*** *that BCB bowheads comprise a single population, with no signs of substructure;*
(2) ***agrees*** *that there was no need to consider any new SLA trials regarding stock structure, since the trials conducted in 2002 and 2007 already covered all plausible stock structure hypotheses;*
(3) ***welcomes*** *the telemetry information provided, thanks the hunters involved for their skill and assistance;*
(4) ***encourages*** *additional telemetry efforts; and*
(5) ***agrees*** *with the suggestions for future genetic studies in the Arctic provided under Item 11.*

7.3.2 Abundance estimates: review new information

A new abundance estimate (SC/67b/AWMP) has been accepted for the year 2011 from a long-term photo-id capture-recapture study (27,133, CV=0.217; 95% CI from 17,809 to 41,337) that it has been agreed is suitable for providing management advice and for use in the *SLA* (Annex Q). The previously accepted, completely independent, 2011 abundance estimate from the ice-based survey (Givens *et al.*, 2016) is also acceptable for use in the *SLA* and has already been used in that regard (16,820, CV=0.052; 95% CI 15,176 to 18,643).

There are thus two independent estimates for the same year considered suitable for use in the *SLA* and this is considered under Item 8.3.

The Committee also discussed plans for future surveys (SC/67b/AWMP 12 and AWMP 16) in Annex Q (item 3.1.1.1). These plans are in accord with the AWS Guidelines that 'plans for undertaking a survey/census should be submitted to the Scientific Committee in advance of their being carried out, although prior approval by the Committee is not required.

7.3.3 Biological parameters: review new information

New and extensive information on biological parameters was received as discussed Annex E (item 4.3). These covered such matters: length at sexual maturity and pregnancy rate from hunted animals (SC/67b/AWMP 07); the potential use of samples from baleen plates to examine hormone cycles and pregnancy; and information on calves from aerial surveys (SC/67b/AWMP03).

Attention: SC

With respect to biological parameter information, the Committee:
(1) ***welcomes*** *the extensive information presented;*
(2) ***encourages*** *the continued collection of such data from the hunt;*
(3) ***encourages*** *the work on the baleen plate analyses to examine hormone levels and pregnancy;*
(4) ***encourages*** *continued aerial surveys under the ASAMM surveys and any future collaboration involving life history data from the harvest; and*
(5) ***agrees*** *that the information presented does not suggest the need to consider any new SLA trials regarding stock structure.*

7.3.4 Removals: review new information

The Committee received updated information about the 2017 harvest (SC/67b/AWMP 05) and long-term removals (SC/67b/AWMP 06). In 2017, 57 bowhead whales were struck resulting in 50 animals landed. The total landed for the hunt in 2017 was higher than the average over the past 10 years (2007-2016 mean of landed =41.7; SD=6.7). Efficiency (number landed / number struck) in 2017 was 88%, which was also higher than the average for the past 10 years (mean of efficiency=75.2%; SD=6.5%).

The Committee also received SC/67b/AWMP06 that provided a summary of bowhead whale catches in Alaska between 1974 and 2016. The authors pointed to the excellent cooperation and contribution of the whale hunters from the 11 villages that are members of the Alaska Eskimo Whaling Commission (AEWC). This information is discussed in Annex E (item 4.4).

From 2013 to 2017, four bowhead whales (2 females and 2 males) were harvested near Chukotka, mainly in Anadyr Bay (SC/67b/AWMP20). The average length was 14.5m (minimum 13.0m, maximum 17.0m). Although the portion of the annual strike limit allocated to Russia under their bilateral agreement with the USA is 5 animals, the actual annual take is usually only 1-2 whales per year, and this has been the case since at least 2004.

The Committee thanked the authors of the provision of this information, noting that catch and strike data are used in the *SLA* calculations (see Item 8.3).

7.3.5 Other anthropogenic threats and health: review new information

The Committee received extensive information related to threats and health ranging from entanglement, predation and health (body condition, pathology and parasite loads). The discussion of this can be found in Annex E (item 4.5).

Attention: SC

With respect to threats and health to the BCB bowhead whales, the Committee:
(1) ***welcomes*** *the extensive information presented;*
(2) ***agrees*** *that whilst the present level of unintentional human induced mortality is too low to require new Implementation trials or incorporation into the SLA calculations, the situation should continue to be monitored and evaluated at the next Implementation Review;*
(3) ***agrees*** *that the health analyses give no cause for concern with respect to the continued application of the Bowhead SLA; and*
(4) ***encourages*** *that the excellent work on health-related issues continues.*

7.3.6 Conclusions and recommendations (and, if needed, workplan to complete Review)

Attention: SC

With respect to the Implementation review of BCB bowhead whales, the Committee ***concludes*** *that:*
(1) the Implementation Review has been satisfactorily completed; and
(2) the range of hypotheses and parameter space already tested in Bowhead SLA trials was sufficient and therefore the Bowhead SLA remains the best way to provide management advice for this stock;
In addition, it ***thanks*** *the US scientists for the extremely hard work that they have put into providing comprehensive papers to facilitate this review.*

8. STOCKS SUBJECT TO ABORIGINAL SUBSISTENCE WHALING (NEW INFORMATION AND MANAGEMENT ADVICE)

The Committee noted that the Commission will be setting new catch/strike limits for at its 2018 biennial meeting in Brazil. It had received written or verbal requests for limits to be considered for each hunt as discussed below.

Attention: C-A

A general request had been received from the USA and Denmark (SC/67b/Rep06, annex F, appendix) for advice on whether there would be a conservation issue if there was a one-time 7-year block followed by a return to 6-year blocks to address logistical issues related to the Commission.

The Committee ***agrees*** *there are no conservation issues associated with this suggestion (and see the block quota section of the ASW in Annex E, appendix 8).*

8.1 Eastern Canada/West Greenland bowhead whales

8.1.1 New abundance information

Last year, the Committee had recommended that Canadian scientists attend the Committee to present the results of their work on abundance. It was very pleased that Doniol-Valcroze from Department of Fisheries and Oceans Canada, and the primary author of the paper on the 2013 aerial survey abundance estimate, was present at the meeting.

The Committee accepted, for the provision of management advice and use in an *SLA* (see Annex Q for details), the fully corrected abundance estimate (Doniol-Valcroze *et al.*, 2015) from a 2013 aerial survey of 6,446 bowheads (CV=0.26, 95% CI 3,722-11,200). The survey covered the major summering area for the Eastern Canada/West Greenland (EC/WG) stock.

The Committee recalled that the *WG-Bowhead SLA* had been developed on the conservative assumption that the abundance estimates for the West Greenland area alone (1,274 whales in 2012 (CV=0.12)) represented the abundance of the whole stock, as it believed that it was not possible to assume that a non-member country would continue with regular surveys. Doniol-Valcroze advised the Committee that the present management strategy of Canada does involves obtaining regular abundance estimates. The Committee noted it would be pleased to receive such estimates from Canada being presented to the Committee in the future.

Attention: SC

The Committee greatly appreciated the presence of a Canadian scientist at its meeting. The Committee:
(1) ***welcomes*** *the provision of the abundance estimate for the Eastern Canada/West Greenland stock and (see Item 8.1.2) the regular provision of information on catch data by Canada;*
(2) ***welcomes*** *the attendance of Canadian scientists at its meetings;*
(3) ***agrees*** *that consideration of how to incorporate abundance estimates from Canada should be one focus of the next Implementation Review for this stock;*
(4) ***notes*** *the regular collaboration of Canadian and Greenlandic scientists on other matters such as genetic sampling (inter alia for mark-recapture abundance estimation); and*
(5) ***encourages*** *further collaboration between Canada, Greenland and the USA for the study of bowhead whales across their range and the presentation of these results at future Committee meetings.*

8.1.2 New catch information

SC/67B/AWMP/10 provided an update of recent Canadian takes made in the Inuit subsistence harvest of the EC-WG bowhead whale stock. In the eastern Canadian Arctic, the maximum allowed take is 7 bowhead whales per year according to domestic policy, with no carry-over of unused takes between years. Since 2015, 5 strikes were taken and 4 bowhead whales were successfully landed (1 in 2015, 2 in 2016 and 1 in 2017). Witting reported that West Greenland hunters struck no bowheads in 2017. There was one 14.7m whale that died from entanglement in crab gear.

The Committee notes that the reported number of strikes was within the parameter space that was tested for the *WG-Bowhead SLA*, and encourages the continued collection of genetic samples from harvested whales.

8.1.3 Management advice

Attention: C-A

SC/67b/AWMP19 reported Greenland's plans for requesting aboriginal whaling provisions at IWC67 and no changes were requested for bowhead whales. The Committee therefore:

(1) ***agrees*** *that the WG-Bowhead SLA remains the best available way to provide management advice for the Greenland hunt;*
(2) ***notes*** *that this SLA had been developed under the conservative assumption that the number of bowhead whales estimated off West Greenland represented the total abundance between West Greenland and Eastern Canada;*
(3) based on the agreed 2012 estimate of abundance for West Greenland (1,274, CV=0.12), the catch of one whale in Canada in 2017, and using the agreed WG-Bowhead SLA, ***agrees*** *that an annual strike limit of two whales will not harm the stock and meets the Commissions conservation objectives; and*
(4) although the Committee has not yet had time to examine the request from the US/Denmark (SC/67b/Rep06, annex F, appendix) for the WG-Bowhead SLA, ***reiterates*** *its advice, applicable for all SLAs, that interannual variation of 50% within a block with the same allowance from the last year of one block to the first year of the next, is acceptable.*

8.2 North Pacific gray whales

8.2.1 New information (including catch data)

The Committee received considerable new information on the hunt off Chukotka as discussed in Annex E (item 5.2). In 2017, a total of 119 gray whales were struck in 2017 (37 males and 82 females). No whales were struck and lost, and no stinky (inedible) gray whales were taken. Similar whaling methods were employed as in recent years and the overall efficiency of the hunt was almost same as in 2016.

In advance of the gray whale *Implementation Review* that is scheduled to begin in 2019, the Committee reviewed new information regarding the stock structure of gray whales in the North Pacific (SC67b/SDDNA02 and SC67b/SDDNA03) – for details see Annex I. The results were based on whole genome sequence data from three individuals (one sampled off Barrow, Alaska and two sampled off Sakhalin Island, Russia) and SNP genotype data generated from larger sample sets representing whales sampled off Sakhalin and in the Mexican lagoons.

Attention: SC

*In reviewing the results of new genetic analyses of gray whales in the North Pacific, the Committee **agrees** that the genetic and photographic data for this species be combined to better assess stock structure-related questions. Given the potential for genomic data to aid in better evaluating the stock structure hypotheses currently under consideration for North Pacific gray whales, the Committee **encourages** the continuation of work to produce additional genomic data from sampled gray whales.*

8.2.2 Management advice

Attention: C-A

The Russian Federation (SC/67b/AWMP/17) had requested advice on the following provision:

'For the seven years 2019, 2020, 2021, 2022, 2023, 2024 and 2025, the number of gray whales taken in accordance with this sub-paragraph shall not exceed 980 (i.e. 140 per annum on average) provided that the number of gray whales taken in any one of the years 2019, 2020, 2021, 2022, 2023, 2024 and 2025 shall not exceed 140.'

The Committee therefore:
*(1) **agrees** that the* Gray Whale SLA *remains the best available way to provide management advice for the gray whale hunts;*
*(2) **advises** that an average annual strike limit of 140 whales will not harm the stock and meets the Commission's conservation objectives;*
*(3) **notes** that its previous advice that the interannual variation of 50% within a block with the same allowance from the last year of one block to the first year of the next remains acceptable;*
*(4) **advises** that the Makah Management Plan (see Item 2.3) also is in accord with the Commission's management objectives.*

8.3 Bering-Chukchi-Beaufort Seas bowhead whales

8.3.1 New information

New information (on abundance and catches) was considered as part of the *Implementation Review* discussed under Item 7.3.

The USA had indicated that it was proposing no changes to the present catch/strike limits although it may suggest changes to its carryover request in light of the advice received by the Committee as discussed at the intersessional workshop (SC/67b/Rep06).

The Committee noted that there are now two independent estimates of abundance for this stock in 2011 (see Item 7.3.1). Recognising the need to formally consider the general question of how best to combine estimates in such cases as part of the workplan in the next biennium, the Committee noted that if they are combined as a weighted average by the inverse of their variances, there is little difference (it is slightly higher) between the combined estimate and that from the ice-based census estimate; the ice-based approach has been the method used for the other estimates used in the *SLA*. Therefore, the ice-based census estimate for 2011 (16,820, CV=0.052; 95% CI 15,176 to 18,643) is considered the most recent estimate of abundance for use in the *Bowhead SLA* this year.

8.3.2 Management advice

Attention: C-A

The USA indicated that it requested advice on the existing catch/strike limits. The Committee therefore:

*(1) **agrees** that the* Bowhead Whale SLA *remains the best available way to provide management advice for this stock;*
*(2) **advises** that a continuation of the present average annual strike limit of 67 whales will not harm the stock and meets the Commission's conservation objectives; and*
*(3) **advises** that provisions allowing for the carry forward of unused strikes from the previous three blocks, subject to the limitation that the number of such carryover strikes used in any year does not exceed 50% of the annual strike limit, has no conservation implications (see SC/67b/Rep04).*

8.4 Common minke whales off East Greenland

8.4.1 New information on catches

In the 2017 season, nine common minke whales (3 males and 6 females) were landed in East Greenland, and one was struck and lost. Genetic samples were obtained from 8 of the landed whales. One common minke whale died from entanglement in fishing gear.

8.4.1 New information on abundance

The Committee endorsed the 2015 aerial survey abundance estimate of 2,762 (CV=0.47; 95%CI 1,160-6,574). This is only a small part of the wider Western and Central stocks from which catches may occur.

8.4.2 Management advice

Attention: C-A

SC/67b/AWMP19 reported Greenland's plans for requesting aboriginal whaling provisions at IWC67. It requested advice on an annual take of 20 animals (it had previously been 12). It had also requested advice on any conservation implications of a 12-month hunting season for common minke whales.

The Committee therefore:

*(1) **notes** that in the past its advice for the East Greenland hunt had been based upon the fact that the catch was a small proportion of the number of animals in the Central Stock;*
*(2) **notes** the process to develop an* SLA *for common minke whales off West Greenland resulted in a simulation framework that produces a considerably more rigorous way to provide advice for this hunt than before, by taking into account stock structure issues;*
*(3) **notes** that the results of the simulation trials that incorporated a continuing catch of 20 whales from East Greenland gave rise to no conservation concerns;*
*(4) **notes** that the 2015 aerial survey abundance estimate of 2,762 (CV=0.47; 95%CI 1,160-6,574) is only a small part of the wider western and central stocks;*
*(5) **advises** that a continuation of the present average annual strike limit of 20 whales will not harm the stock and meets the Commission's conservation objectives;*
*(6) **advises** that changing the length of the season to 12 months had no conservation implications; and*
*(7) **agrees** that an* SLA *should be developed for this hunt in the future; and*
*(8) **encourages** the continued collection of samples fro collaborative genetic analyses (and see Item 7.1.2.3).*

8.5 Common minke whales off West Greenland

8.5.1 New information on catches

In the 2017 season, 129 common minke whales were landed in West Greenland and four were struck and lost. Of the landed whales, there were 95 females, 33 males and one of unknown sex. Genetic samples were obtained from 104 whales, and the Committee was pleased to note that samples were already part of the data used in the genetic analyses of common minke whales in the North Atlantic. The Committee **encourages** the continued collection of samples and the collaborative approach of the genetic analysis.

8.5.2 New information on abundance

The Committee endorsed the 2015 aerial survey abundance estimate of 5,095 (CV0.46; 95%CI 2,171-11,961) as discussed in Annex Q.

8.5.3 Management advice

Attention: C-A

SC/67b/AWMP19 reported Greenland's plans for requesting aboriginal whaling provisions at IWC67. It requested advice on annual strikes of 164 animals (i.e. no change). It had also requested advice on any conservation implications of a 12-month hunting season for common minke whales.
The Committee therefore:

*(1) **agrees** that the WG-Common minke SLA is the best available way to provide management advice for this stock under need scenario A;*
*(2) **advises** that a continuation of the present average annual strike limit of 164 whales will not harm the stock and meets the Commission's conservation objectives;*
*(3) although the Committee has not yet had time to examine the request from the US/Denmark (SC/67b/Rep06, annex F, appendix) for this SLA, **reiterates** its previous advice**,** applicable for all SLAs, that interannual variation of 50% within a block with the same allowance from the last year of one block to the first year of the next is acceptable;*
*(4) **advises** that changing the length of the season to 12 months had no conservation implications; and*
*(5) **encourages** the continued collection of samples for collaborative genetic analyses (and see Item 7.1.2.3).*

8.6 Fin whales off West Greenland

SC/67b/AWMP19 reported Greenland's plans for requesting aboriginal whaling provisions at IWC67. It requested advice on annual strikes of 19 animals (i.e. no change).

8.6.1 New information on the catch
A total of seven fin whales (5 females and 2 males) was landed, and one was struck and lost, off West Greenland during 2017. The Committee was pleased to note that genetic samples were obtained from five of these, and that the genetic samples are analysed together with the genetic samples from the hunt in Iceland.

8.6.2 New information on abundance
The Committee endorsed the 2015 aerial survey abundance estimate of 2,215 (CV=0.41; 95%CI 1,017-4,823) for use in providing management advice and in the *SLA* as discussed in Annex Q (Item Y).

8.6.3 Management advice

Attention: C-A

SC/67b/AWMP19 reported Greenland's plans for requesting aboriginal whaling provisions at IWC67. It requested advice on annual strikes of 19 animals (i.e. no change). It also requested advice on whether there were any conservation implications of removing length limits (while retaining the prohibitions relating to calves.
The Committee therefore:

(1) ***agrees*** *that the WG-Fin SLA is the best available way to provide management advice for this stock;*
(2) ***advises*** *that a continuation of the present average annual strike limit of 19 whales will not harm the stock and meets the Commission's conservation objectives; and*
(3) although the Committee has not yet had time to examine the request from the US/Denmark (SC/67b/Rep06, annex F, appendix) for this SLA, ***reiterates*** *its advice****,*** *applicable for all SLAs, that interannual variation of 50% within a block with the same allowance from the last year of one block to the first year of the next is acceptable;*
(4) ***advises*** *that removing the length limits had no conservation implications; and*
(5) ***encourages*** *the continued collection of samples for collaborative genetic analyses (and see Item 7.1.1.3).*

8.7 Humpback whales off West Greenland
8.7.1 New information on catches
A total of two (both female) humpback whales were landed and none were struck and lost in West Greenland during 2017. Genetic samples were obtained from all the landed whales. The importance of collecting genetic samples and photographs of the flukes from these whales is emphasised.

Five humpback whales were observed entangled in fishing gear in West Greenland in 2017. Of these, one died, two became free and one was successfully disentangled by a disentanglement team. The remaining animal was alive and still entangled when it was last sighted.

Inclusion of bycaught whales had been incorporated into the scenarios for the development of the *Humpback SLA*. If high levels continued, then this will need to be taken into account in any *Implementation Review*. The Committee noted the IWC efforts with respect to disentanglement and prevention and welcomed the news that the Greenland authorities requested IWC disentanglement training that took place in 2016 and that they successfully disentangled one humpback whale.

8.7.2 New information on abundance
The Committee endorsed the 2015 aerial survey abundance estimate of 993 (CV=0.46; 95%CI 434-2,272) as discussed in Annex Q (Item Y) for use in the provision of management advice and in the SLA.

8.7.3 Management advice

Attention: C-A

SC/67b/AWMP19 reported Greenland's plans for requesting aboriginal whaling provisions at IWC67. It requested advice on annual strikes of 10 animals (i.e. no change).
The Committee therefore:
(1) ***agrees*** *that the* WG-Humpback SLA *is the best available way to provide management advice for this stock;*
(2) ***advises*** *that a continuation of the present average annual strike limit of 10 whales will not harm the stock and meets the Commission's conservation objectives;*
(3) ***advises*** *that that provisions allowing for the carry forward of unused strikes from the previous three blocks, subject to the limitation that the number of such carryover strikes used in any year does not exceed 50% of the annual strike limit' has no conservation implications (see SC/67b/Rep04); and*
(4) ***encourages*** *the continued collection of samples and photographs for collaborative analyses.*

8.8 Humpback whales off St. Vincent and The Grenadines
The alternate Commissioner for St Vincent and the Grenadines advised that no change to the present limits were envisaged.

8.8.1 New information on catch
It was reported that one humpback whale was struck and landed in 2017 by St. Vincent and The Grenadines.

8.8.2 New information on abundance

Last year, the Committee had requested that the USA provide a new abundance estimate for the western North Atlantic based upon the available NOAA data. A progress report on this work was provided with a focus on information on abundance estimates generated by the MONAH study, conducted in 2004 and 2005 on Silver Bank (a breeding ground in the West Indies) and in the Gulf of Maine feeding ground. The best estimate around 12,300, similar to the Committee endorsed best estimate from the YONAH project from 1992/93, which was 10,400 (8,000, 13,600). The lack of strong population growth was unexpected given information on rates of increase from some other areas of the North Atlantic, and may reflect either a true rate of increase, unidentified sampling bias, and/or the idea that Silver Bank as a habitat has reached maximum capacity. It is not clear whether the MONAH estimate is representative of the entire population, nor the extent to which the full estimate can be applied to the southeastern Caribbean in the context of the St Vincent hunt. However, four animals from the Gulf of Maine have been linked to animals seen in the southeastern Caribbean (including one that was caught in the hunt).

The Committee also noted several endorsed recent abundance estimates of humpback whales in parts of the North Atlantic including: 993 (95% CI: 434-2,272) in West Greenland in 2015; 4,223 (95% CI: 1,845-9,666) in East Greenland in 2015; and 12,879 (95% CI 5,074; 26,455) in the Iceland-Faroes region in 2007.

It has now been nearly two decades since the IWC has done an In-Depth Assessment on North Atlantic humpback whales. The Committee **agrees** that it would be a valuable exercise to perform a North Atlantic Rangewide review of humpback whales, similar in scope to the Rangewide Review for North Pacific gray whales and taking into account recent work on stock structure including that of Stevick *et al.* (2018).

8.8.3 Management advice

Attention: C-A

The alternate Commissioner for St Vincent and the Grenadines advised that no change to the present limits were envisaged. The Committee therefore:

*(1) **notes** that is does not have an approved abundance estimate for western North Atlantic since that in 1992;*
*(2) **notes** that in accord with the advice provided in the AWS (see Annex E, Appendix 8), it therefore considered the available evidence to see if was sufficient to provide safe management advice;*
*(3) **advises** that, given the information above on recent abundance in the North Atlantic combined with the size of the requested catch/strikes (an average of four annually), continuation of the present limits will not harm the stock;*

*The Committee also **reiterates** its previous advice that:*

(1) the status and disposition of genetic samples collected from past harvested whales be determined and reported next year;
(2) photographs for photo-id (where possible) and genetic samples are collected from all whales landed in future hunts; and that
(3) the USA (NOAA, NMFS) provides an abundance estimate from the MONAH data as soon as possible for the Committee.

8.9 Workplan 2019-20

Table 7 summarises the work plan for work related to aboriginal subsistence whaling. The Committee also established an Intersessional Correspondence Group to work on ASW related issues (Annex Y).

Table 7

Work plan for matters related to aboriginal subsistence whaling

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
(1) Annual review of catch/strike limits		Carry out		Carry out
(2) *Implementation Review*		Gray whales based upon rangewide review		West Greenland humpback whales
(3) *SLA*s		Consider development of an *SLA* for the hunt of common minke whales off East Greenland based on operational models developed for the West Greenland hunt		Adopt *SLA* if it is decided one is necessary
(5) Interim relief allowance testing	Run trials for gray whale hunts	Review results	Run trials for West Greenland common minke whales and fin whales	Review results
(6) Carryover (US/Denmark request)	Run trials for remaining Greenland hunts (West Greenland common minke whales, bowhead whales and fin whales	Review results		

9. WHALE STOCKS NOT SUBJECT TO DIRECTED TAKES

9.1 In-depth Assessments

Donovan gave a presentation explaining a streamlined procedure hereby the Committee, via its sub-groups, can undertake Comprehensive Assessment (traditionally the first time an assessment is undertaken for a particular species/ocean basin) or an in-depth assessment (assessments subsequent to a comprehensive assessment). This can be found as SC/67B/GEN04 and is summarised in Fig. 1. The objective is to provide a consistent approach (including methods) that initially focusses on ensuring that sufficient data are available to undertake an assessment (the pre-assessment approach that will normally be undertaken at annual meetings) and then follows this with a concentrated effort (ideally two workshops and two annual meetings, with no new data) to complete the assessment. The objective is to provide Commission with robust information on present status. This involves identifying:

(1) if populations are recovering, recovered or if there is cause for concern;

(2) factors that may be or are affecting status so that conservation and management needs can be determined; and

(3) information gaps and ways to address these in order to reduce uncertainty at the next assessment.

9.1.1 Comprehensive Assessment of North Pacific humpback whales

Work towards a Comprehensive Assessment of North Pacific humpback whales began in 2016, and included an intersessional workshop held in April 2017 (IWC, 2018b). After the 2017 Committee meeting, an intersessional steering group continued preparing the input data and assessment model (IA/67b/IA03). The assessment model is a simplified age-aggregated model of the breeding and feeding grounds. The development of the input data (stock structure, abundance, catches, and life history parameters) continued during the year but given the slower than initially expected progress, particularly with respect to narrowing down the number of stock structure hypotheses, the steering group had agreed that it was premature to hold the anticipated workshop prior to SC67b.

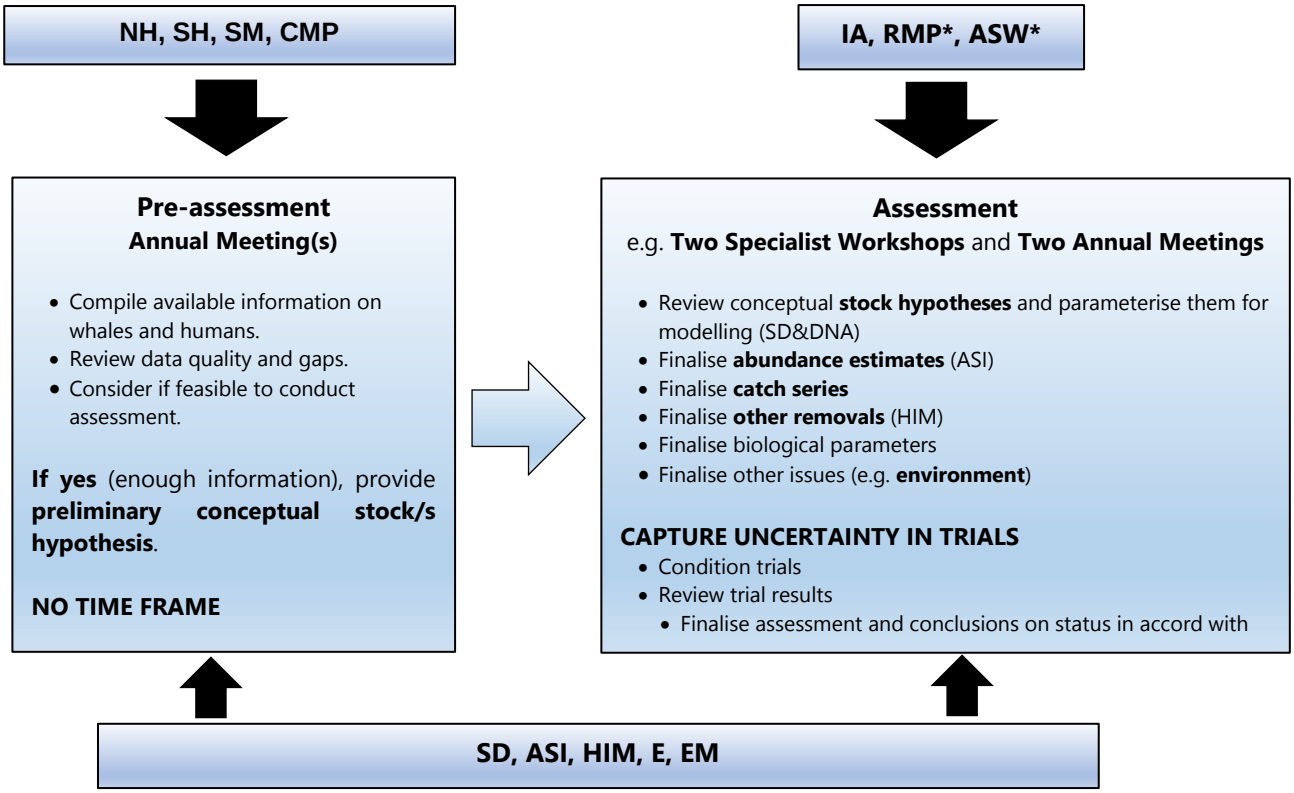

Fig. 1. Schematic of the approach to conduct assessments within the Scientific Committee. Acronyms refer to sub-groups. Normally the final assessment will take place in the sub-committee on in-depth assessments but for stocks subject to direct catches it may occur in the context of the RMP or AWMP sub-groups as appropriate.

Work continued at this meeting and the detailed discussions can be found in Annex F (item 4). The subdivisions of the North Pacific humpback whale feeding and breeding grounds in Annex F (fig. 1) are broadly consistent with existing data; identified uncertainties will be addressed in the assessment by evaluating four scenarios with different numbers of feeding and breeding grounds. This work will be greatly assisted by undertaking comparisons of humpback whale photographs from the Pacific obtained after the conclusion of the photographic component of the SPLASH (Structure of Populations, Levels of Abundance and Status of Humpback Whales) programme in 2005 (e.g. see Calambokidis *et al.*, 2008).

The general underlying structure of the assessment model has been developed but before the model can be run the input data (e.g. catches and abundance estimates) need to be updated and allocated for each stock structure hypotheses and mixing matrices developed and parameterised.

Attention: SC, G

*The Committee is undertaking a Comprehensive Assessment of North Pacific humpback whales. To complete this assessment the Committee **agrees** that:*

(1) a large-scale matching effort of post-2005 photo-identifications should be undertaken (see Annex F, item 4 for methods); and
(2) this matching effort will (a) help clarify the connections among the feeding/breeding areas within the North Pacific; and (b) assist in developing updated abundance estimates where appropriate.
*The Committee **stresses** that to obtain the most robust assessment and thus conservation advice, all available data should be included in the matching effort. Therefore, the Committee **strongly encourages** all catalogue holders to participate in this exercise, after the appropriate data sharing agreements are made.*

*The Committee also **welcomes** the provision of new abundance estimates (e.g. those from the IWC-POWER surveys and from local areas in Japan), noting that they will also need to be adjusted for the various stock structure hypotheses.*

*The Committee **agrees** that the next assessment workshop should take place at a time prior to SC68b when the intersessional Steering Group (Annex Y) decides sufficient progress has been made.*

9.1.2 Comprehensive Assessment of North Pacific sei whales
The Committee began what was called an in-depth assessment of North Pacific sei whales in 2015 (IWC, 2016c) but, in keeping with the discussion under Item 9.1 will now be termed a Comprehensive Assessment for consistency. Work has focussed since then on finalising the stock structure hypotheses (two have been agreed for use in the assessment - a single-stock hypothesis and a five-stock hypothesis), developing an appropriate population model and finalising the model inputs in accordance with these hypotheses (including catches, mark-recovery locations, abundance estimates, estimates of mixing between sub-areas, and life history parameters).

Considerable progress was made with this work intersessionally and at this meeting as discussed in Annex H, item 3.

Attention SC, G

*The Scientific Committee intends to complete the Comprehensive Assessment of North Pacific sei whales within the next biennial period. It notes the progress made at this meeting with respect to stock structure, abundance estimates, marking data, catch history, life history parameters and the assessment model. To complete this work, the Committee **agrees** to:*

(a) the work undertaken to finalise input data for the assessment (Annex F, appendices 2-7);
(b) support the modelling work identified in Annex F; and
(c) re-establish the intersessional steering group to oversee the assessment.

*In addition, the Committee **encourages** telemetry work in waters outside the 'pelagic' sub-area to assist in quantifying the movement patterns of animals.*

9.1.3 In-depth Assessment of Indo-Pacific Antarctic minke whales
An intersessional correspondence group under Murase completed its task to finalise a document synthesising the results of the 2001 - 2014 in-depth assessment of an eastern Indian stock (I-stock) and a western South Pacific stock (P-stock) of Antarctic minke whales distributed between 35°E and 145°W.

The Committee **commends** the authors for completing this paper and submitting it to the *Journal of Cetacean Research and Management.* As the paper has just entered the review process, the intersessional correspondence group (Annex X) has been re-established to see the paper through to publication.

9.1.4 Workplan 2019-20
The work plan for Comprehensive and in-depth assessments for the next biennium is provided in Table 8.

Table 8

Work plan for in-depth assessments

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting (SC/68b)
In-depth Assessment of Indo-Pacific Antarctic minke whales	Complete review of paper submitted for publication	-	-	-
Comprehensive Assessment of North Pacific sei whales	Re-establish the ISG (Annex Y) to further data preparation and development of the assessment model	Review progress of intersessional work and continue the assessment	Finalise preparation of assessment	Review progress of intersessional work and finalise the assessment
Comprehensive Assessment of North Pacific humpback whales	Re-establish the ISG (Annex Y) to further data preparation, development of the assessment model and hold a Workshop	Review progress of intersessional work and continue the assessment	Finalise /continue preparation of assessment	Review progress of intersessional work and continue/finalise the assessment

9.2 Evaluation for potential new Comprehensive or In-Depth Assessments

9.2.1 North Pacific blue whales

The Committee welcomed the report of an intersessional group that had been determining the data that are available on items required to carry out a Comprehensive Assessment of blue whales in the North Pacific. The status of the eastern North Pacific population is well known and a stock assessment was reviewed and accepted by the Committee in 2016 (Monnahan and Branch, 2015). However, information from the central and western North Pacific is sparser. Information presented at this meeting concerned stock structure, catch history, biological parameters, photo-identification, Discovery marks and sighting surveys. Details can be found in Annex G (item 6.1).

Several papers and datasets were discussed including: the use of blue whale sounds to identify stocks; morphological data; genetic data; sightings data (SC/67b/IA02; SC/67b/SCSP06; SC/67b/SCSP07; SC/67b/NH08).

Attention: SC

*The Committee **agrees** the following priorities to progress the pre-assessment:*

(1) obtain abundance estimates from the IWC-POWER surveys;
(2) obtain abundance estimates from the JARPN and JARPNII surveys;
(3) analyse and compare genetic samples from ENP, IWC-POWER and ICR biopsy samples to determine stock structure throughout the North Pacific;
(4) compare photo-identification data from POWER, JARPN/JARPNII and other ENP catalogues;
(5) Review new acoustic locations and information and conduct fine-scale analysis of song features for central Pacific blue whale calls, with particular focus on calls around Japan;
(6) Obtain better life history parameters (especially age at sexual maturity and calving interval) from the Cascadia Research Collective, the Mingan Island Cetacean Study Research Station and the CICIMAR-IPN photo-ID dataset;

*With respect to (3), the Committee **requests** the collection of about 20 biopsy samples if possible during the NEWREP-NP surveys in the western North Pacific to improve the power to evaluate stock structure and **encourages** genetic analysis of the existing Japanese samples.*

*With respect to (5), the Committee **requests** a reanalysis of recordings from the Northern Mariana Islands (Saipan and Tinian) collected by the Pacific Islands Fisheries Science Center to look for the presence or absence of the new song type recorded from Japan. It also **encourages** passive acoustic data collection during surveys (e.g. IWC-POWER, university/training cruises) from the region of high blue whale density southeast of the Kamchatka Peninsula to determine the song type produced by animals in that region.*

*The Committee **agrees** that the intersessional correspondence group continue to review data needed for an assessment of North Pacific blue whales be reappointed under Branch (Annex Y).*

9.2.2 Non-Antarctic Southern Hemisphere blue whales

9.2.2.1 SOUTHERN HEMISPHERE POPULATION STRUCTURE

The Committee is currently preparing for a Comprehensive Assessment of pygmy blue whales. For this reason, it continues to gather information on population structure (see Item 3.1, IWC, 2018a). This year, the web-based pygmy blue whale song library funded by the IWC will be launched (SC/67b/SH12). This will enable researchers to compare their acoustic recordings with validated song archetypes and greatly assist the determination of Southern Hemisphere blue whale distribution patterns and stock structure. Photo-ID and genetic evidence support the idea that each distinct pygmy blue whale song represents a geographically and genetically distinct population of pygmy blue whales around the Southern Hemisphere. A full description of the discussion of the use of songs in this pre-assessment is given in Annex H (item 3.1), including comparison with genetic and photo-identification data. The Committee also received information

from whale bones and notes that further analysis of blue whale bones from old whaling land stations will be helpful to establish the past distribution of these stocks.

Assessments require catches to be allocated to populations and in 2016 the Committee funded an examination of regional catches to assign them to each putative population (Item 5.1, IWC, 2017a). The results of this work are provided in SC/67b/SH23 and discussed in Annex H (item 3.1). Total pygmy blue whale catches were estimated at 12,184 with totals for each population of 1,228 (Northern Indian Ocean), 6,889 (South West Indian Ocean), 3,646 (South East Indian Ocean) and 421 (South West Pacific Ocean).

The Committee also discussed an intersessional effort to identify and standardise genetic markers used in Southern Hemisphere blue whale research (only four loci were common across all research laboratories) and received a progress report (SC/67b/PH04) on matching within the Southern Hemisphere Blue Whale Catalogue, which has been supported by funding from the Committee (Item 10.2.2, IWC, 2017a). This helps understanding of blue whale movements between regions, and allows estimation of regional abundance. The catalogue is currently being migrated to IWC servers (and see Item 23.2.3.2).

Attention: SC, G

In order to progress its work towards an assessment of pygmy blue whales, the Committee:

(1) ***agrees*** *that further work is needed to identify high and base case catch scenarios for pygmy blue whales;*
(2) ***encourages*** *deployment of more acoustic recorders in the southern Indian Ocean;*
(3) ***agrees*** *that further population modelling is needed to assess pygmy blue whale populations;*
(4) ***strongly encourages*** *blue whale research groups to publish the metadata associated with their sequences in order that levels of sample overlap can be established and datasets compared;*
(5) ***agrees*** *that the Southern Hemisphere Blue Whale Catalogue should be continued to help understand blue whale movements, with a priority focus on matching photographs within regions to measure regional abundance of pygmy blue whales.*

9.2.2.2 INDONESIA/AUSTRALIA BLUE WHALES

The Australian blue whale photo-ID catalogue data have now nearly all been uploaded and matched within the Southern Hemisphere Blue Whale Catalogue, at which point quality control analysis can begin. This will allow the potential for using these data for mark recapture abundance estimation to be assessed. The Scientific Committee was informed that mark-resighting data from the Perth Canyon (Australia) will be analysed intersessionally, to provide a new estimate of Australian blue whale abundance which assist in a future assessment of this population.

Attention: SC, G

The Committee ***encourages*** *analysis to provide an estimate of Australian blue whale abundance using mark-resighting data.*

9.2.2.3 MADAGASCAR BLUE WHALES

The Committee was informed that passive acoustic monitoring of blue whales in the Mozambique Channel detected both South West Indian Ocean (SWIO) and Antarctic blue whale song types, as well as fin and Antarctic minke whales (SC/67b/SH14). In addition, SC/67b/SH24 reported an unidentified blue whale song off Oman. A full discussion of the results of these papers can be found in Annex I (item 3.3.2).

This new information means that the blue whale catch allocations for the Indian Ocean, currently only ascribed to a single 'NIO' population in the Northern Indian Ocean, will need revision to take this new acoustic pattern into account.

Attention: SC, G

The Committee notes that the distribution and population isolation of blue whales is poorly understood in the northern and western Indian Ocean. The Committee therefore:

(1) ***strongly encourages*** *further acoustic work in the western Indian Ocean and Arabian sea to better understand the distribution, seasonality and overlap of blue whale calls;*
(2) ***strongly encourages*** *the collection and analysis of available tissue samples for analysis of genetic population structure in this region to assist with characterising these populations; and*
(3) ***agrees*** *that catch allocations of blue whales be revised to include the new blue whale song in the northwest Indian Ocean as a potential distinct 'stock'.*

9.2.2.4 NEW ZEALAND BLUE WHALES

Three papers were presented on blue whales off New Zealand (see Annex H, item 3.3.4 for a full discussion).

SC/67b/SH09 reported a recent study of blue whale movement and habitat use in the Taranaki region of New Zealand in which two animals were tagged. However, due to the small sample size and La Niña conditions, it is uncertain how representative these movements are for blue whales in New Zealand waters.

SC/67b/SH05 summarised a multi-disciplinary study included acoustics, genetics and photo-identification in the same area, and provided a conservative estimate of blue whale population abundance (see Annex Q, item 3.1.1.9), to consider if this estimate can be used in the upcoming regional assessments of pygmy blue whales. SC/67b/SH04 reported projects underway to assist regional conservation management, including a description of fine-scale habitat use during summer months in the South Taranaki Bight, and response to local acoustic disturbance.

Attention: SC, G

With respect to information on blue whales off New Zealand, the Committee:

*(1) **welcomes** the work being undertaken to understand abundance and connectivity, which will contribute towards the pygmy blue whale population assessments; and*
*(2) **agrees** that New Zealand photo-identifications should be combined with others within the Southern Hemisphere Blue Whale Catalogue to provide the fullest possible assessment of regional abundance and connectivity*

9.2.2.5 SOUTHEAST PACIFIC BLUE WHALES

The Committee received two papers relevant to blue whales off Chile and the full discussion can be found in Annex H (item 3.3.1). SC/67b/SH03 presented a morphometric analysis of Chilean blue whales which reinforces the argument that Chilean blue whales should be considered a separate sub-species from the Antarctic and pygmy forms. (Bedrinana-Romano *et al.*, 2018) reported distribution modelling of blue whales using Chilean Northern Patagonia waters. Preliminary delimitations of possible blue whale conservation areas in this region overlap with highly used vessel navigation routes and areas allocated for aquaculture. The Committee was also informed that predictions of southeast Pacific blue whale habitat following Redfern *et al.,* (2017) will be completed intersessionally.

Attention: SC, G

In view of the recent identification of movements of Chilean blue whales into the South Atlantic and ongoing questions about the distribution of this population, the Committee:

*(1) **encourages** further satellite tracking and surveys (including collection of photo-ID and genetic data) to assess the population limits, habitat use and abundance and sub-species identity of blue whales in Chile;*
*(2) **encourages** compilation of morphometric data available for northeast Pacific blue whales and comparison with Chilean data, to assess morphological differentiation of these whales in the eastern Pacific and evaluate sub-species identity; and*
*(3) **welcomes** plans for further photo-ID catalogue matching within this region to assist with regional abundance estimation.*

9.2.2.6 WORK PLAN

The work plan for all Southern Hemisphere blue whales is given in Table 9.

9.2.3 Antarctic blue whales (Areas III and IV)

Undertaking a regional population assessment of Antarctic blue whales is challenging due to the scarcity of whales and logistical challenges. The Committee received new information this year on sightings, abundance and genetic studies.

SC/67b/SH08 presents a preliminary estimate of abundance (the first using photo-ID data) and this is discussed in Annex Q (see item 3.1.19) where suggestions were made to refine the analyses. Reports from two 2017/18 NEWREP-A summer cruises included sightings of blue whales and information on biopsy sampling (SC/67b/SP08 and SC/67b/ASI07). An IWC-SORP Southern Ocean blue whale-focussed cruise is planned for January to March 2019 (140°E-175°W), which intends to describe krill swarms in relation to blue whale density and distribution (SC/67b/SH07).

With respect to genetic work, IWC-SORP funded work on blue whale bones to compare past and current genetic diversity levels is reported in SC/67b/SH02 and discussed in Annex I (item 4.4.2). The Committee was also updated about ongoing work to analyse a collection of 1,626 baleen plates (roughly 50:50 blue and fin whales) from the Japanese whaling in the 1940s and held at the Smithsonian Natural History Museum, USA. A pilot study has established that mitochondrial DNA can be sequenced from these plates. Further analyses including of stable isotope and hormone levels are planned for these samples.

Attention: SC, G

*The Committee **welcomes** the progress being made towards being able to undertake am in-depth assessment of Antarctic blue whales. The Committee:*

*(1) **encourages** further work to update the abundance estimate for Antarctic blue whales following Committee recommendations;*

*(2) **strongly encourages** continued opportunistic photo-ID data collection in the Antarctic to assist with developing estimates of population abundance for this subspecies; and*
*(3) **encourages** continued collection and analysis of bone and baleen from historical Antarctic commercial whaling samples and sites to evaluate loss of genetic diversity and shifts in population structure.*

9.2.3.1 WORK PLAN

The work plan for all Southern Hemisphere blue whales is given in Table 9.

Table 9.

Workplan for Southern Hemisphere Antarctic and pygmy blue whales

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Antarctic blue whales				
Catalogue matching	Catalogue matching of photo-IDs (Annex Y)	Report	Catalogue matching (opportunistically collected photos)	Report
Abundance estimation	Mark recapture modelling work to update SC/67b/SH08 Annex Y	Report		
Photo-ID outreach material	Create photo-ID information booklets for distribution via IAATO operators	Report		
SH non-Antarctic blue whales				
Population assessment	Improve catch separation model, explore alternative catch allocation models (Annex Y)	Report	Population assessment. Analyse minimum and extrapolated recovery status of all populations for which abundance is available	Report
Catalogue matching	Catalogue matching of photo-IDs within southeast and central east Pacific (Annex Y)	Report	Catalogue matching (opportunistic photos from citizen scientists and collaborators) if funds are available	Report
Blue whale song library	Finish implementation of blue whale song library (Annex Y)	Report		
Australian abundance estimate	Analyse Perth Canyon abundance using mark recapture data (Annex Y)	Report		

9.2.4 Southern Hemisphere fin whales

9.2.4.1 POPULATION STRUCTURE

As part of its pre-assessment work, the Committee is gathering information on Southern Hemisphere fin whales in order to: (1) clarify the subspecies status of these whales (currently two Southern Hemisphere subspecies are recognized, Committee on Taxonomy, 2017); and (2) measure population differentiation around the Southern Hemisphere to establish whether any distinct populations exist.

A summary of available data on Southern Hemisphere fin whale structure was presented in SC/67b/SH15 and is discussed in detail in Annex H (item 4.1). The only evidence for any structure comes from acoustics. A genetic study from the southeast Pacific (SC/67b/SH13) found high local diversity in Chile, with no significant differentiation from the other Southern Hemisphere datasets. The Committee noted however that genetic differentiation can be difficult to detect when diversity levels are high and genetic differentiation is low (see Annex H, item 4.1).

Attention: SC, G, S

Knowledge of population structure is essential to future efforts to assess Southern Hemisphere fin whales. To determine the differentiation and potential sub-species structure among fin whales the Committee:

*(1) **agrees** that analysis of concurrently collected acoustic recordings of fin whales, to assess song variation around the Southern Hemisphere, is a priority;*
*(2) **agrees** that a review of all Discovery mark data published on fin whales to assess population connectivity patterns should be carried out; and*

(3) ***requests*** *that the Secretariat provide a letter of support for a study examining the evidence for* B. physalus patachonica*, which requires access to the holotype for this species from the Bernardino Rivadavia Natural Sciences Museum in Buenos Aires.*

The Committee also ***encourages:***

(1) analysis of fin whale distribution and geographic aggregations using all available catches;
(2) strategic biopsy sampling and analysis to measure the genetic differentiation of fin whales around the Southern Hemisphere;
(3) further biopsy sampling and sequencing of multiple nuclear loci to establish Chilean fin whale differentiation patterns, with co-collection of photo-IDs and body length measurements to establish population identity;
(4) satellite telemetry to discern seasonal movements; and
(5) photo-identification to understand site fidelity and residency patterns and linkages between high- and low-latitude grounds.

9.2.4.2 DISTRIBUTION AND ABUNDANCE

The Committee welcomed a review of the available metadata on Southern Hemisphere fin whales (SC/67b/SH19), compiling data from dedicated and opportunistic surveys, moored acoustic recorders, sonobuoy surveys, photo-identifications, satellite tagging and biopsy sampling. The Committee also welcomed a summary of recent work by the Brazilian Antarctic Program to conduct dedicated fin whale research using sighting surveys, photo-ID, biopsy sampling and telemetry.

Reports from two 2017/18 NEWREP-A summer cruises included sightings of fin whales and information on biopsy sampling (SC/67b/SP08 and SC/67b/ASI07). A new abundance estimate for fin whales using sightings data from the third IDCR-SOWER circumpolar survey is expected to be available for review at next year's meeting.

SC/67b/14 provided information on the presence of fin whales in the Mozambique Channel and a new lower-latitude song. Details of the discussions can be found in Annex H (item 4.2).

The Committee was also informed that an analysis has suggested that Antarctic fin whales are sufficiently well marked to enable to use in photo-ID projects (SC/67b/PH01) and this is discussed in Annex S (item 4.1).

Attention: SC, G, CG-A

With respect to obtaining information on the distribution, movements and abundance of Southern Hemisphere fin whales for use in a future assessment, the Committee:

(1) ***encourages*** *a meta-analysis of the Antarctic Peninsula and Scotia Sea sightings data, to measure recent fin whale distribution, density and habitat use;*
(2) ***strongly encourages*** *continued work by the Brazilian Antarctic Program towards the understanding of fin whale population structure, movements and habitat use*
(3) ***agrees*** *that a new abundance estimate for fin whales from the IWC IDCR/SOWER programme should be presented for review at next year's meeting,*
(4) ***welcomes*** *news that fin whales can be used in photo-ID studies, and* ***encourages*** *further photo-ID data collection at high latitudes.*

9.2.4.3 WORK PLAN

The work plan for Southern Hemisphere fin whales is given in Table 10.

Table 10

Work plan for Southern Hemisphere fin whales

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Fin whale acoustic structure	Review fin whale call patterns across Southern Hemisphere, investigate call variation (Annex Y)	Report	Complete review of fin whale call patterns (Annex Y)	Report
Discovery marks	Review available Discovery mark data on fin whales (Pastene and Jackson)	Report		
Catch maps	Update fin whale catch model to include Soviet catch data (de la Mare)	Report		

9.2.5 North Atlantic sei whales

The Committee welcomed information on two separate habitat-based density modelling efforts, using visual survey data to produce seasonal abundance estimates for sei whales from the purported 'Nova Scotia' stock, ranging from Nova Scotia to the southeastern USA (SC/67b/NH07). There was also some consideration of passive acoustic and strandings data from the US eastern seaboard. No new data are available from around Iceland or Norway, partially due to difference in timing between surveys and species' arrival in regional waters. This information was discussed in Annex G (item 6.2). An intersessional correspondence group (Annex Y) will compile additional information this species in the North Atlantic and the Committee looks forward to a further update on reanalysis of historical data, particularly related to stock structure and strandings, next year.

9.2.6 North Atlantic right whales

Since 2016, the Committee has recommended a comprehensive update on North Atlantic right whales. SC/67b/NH05 summarised the information on the status of the North Atlantic right whale. This population has been slowly declining since 2010 and the abundance at the end of 2015 was estimated to be around 460 individuals (Pace *et al.*, 2017[6]). Of particular concern is the lower annual survival rate of females than males and poor recent calving (five in 2016/17 and none so far in the 2017/18 calving season). The observed number of dead whales in 2017 was 17 whales, several showing signs of death from fishing gear or blunt force trauma. These clearly represent minimum numbers and there was some discussion as to whether it was possible to scale minimum observed mortalities to an overall estimate but several confounding factors preventing this were identified (see Annex F, item 6.3 and Annex J, item 2.1.2).

Due to the increased 2017 Canadian interactions in the Gulf of St. Lawrence, on 19 April 2018 the Government of Canada implemented mitigation measures to reduce future interactions (DFO, 2018), including: closing a large part of the Gulf of St. Lawrence snow crab fishery on 30 June; creating a dynamic 15-day fishing closure; introducing a 10 knot speed restriction when any single right whale sighting in any area is detected; putting in place mandatory gear marking and reporting of any lost gear; minimising the allowable amount of floating line at surface; and using vessel monitoring systems that reports the boats position every 5 minutes.

A substantial increase in collaboration and data sharing between the US and Canada has occurred as a result of these mortalities.

Attention: C-A, CC

The Committee reiterates its serious concern over the status of the western North Atlantic stock of right whales as it is probably the only viable population of this species, for which entanglements and ship strikes have long been identified as key threats.

This year, the Committee:
(1) ***recognises*** *that entanglements have now replaced ship strikes as the primary cause of deaths (Kraus et al. 2016);*
(2) ***reiterates*** *its recommendation for the USA to submit a comprehensive update on the status of North Atlantic right whales (IWC, 2017:40) including an update of the Pace* et al. *abundance estimate, prior to the 2019 meeting;*
(3) ***stresses*** *that this update will allow time for explanations or additional analyses to be undertaken before the proposed 2019 Workshop on the Comparative Biology, Health, Status and Future of North Atlantic Right Whales: Insights from Comparative with other Balaenid Populations (including bowheads);*
(4) ***encourages*** *updates from the US Large Whale Take Reduction Team (ALWTRT) on progress of the Whale Safe Rope and Gear Marking Feasibility Subgroups; and*
(5) ***requests*** *that the Commission asks the IWC Executive Secretary to write to the U.S. National Marine Fisheries Service (NMFS) and the Canadian Department of Fisheries and Oceans, informing them of the Committee's serious concerns over the declining population trend of this species, and stressing that,* ***as a matter of absolute urgency****, every effort be made to reduce human induced mortality in the population to zero.*

9.2.7 North Pacific right whales

The Committee received a report of a dead right whale caught in a set net off Izu, Japan in 2018 (SC/67b/NH06) – the first in a set net since one in Korea in 2015 (Kim *et al.*, 2015).

The Committee welcomed information on a single sighting off Hokkaido (and a biopsy sample) from a Japanese national cruise (SC/67b/ASI10). It also welcomed information on North Pacific right whales from the visual, acoustic and biopsy sampling components of the 2017 IWC-POWER cruise in the eastern part of the Bering Sea. A total of 9 schools and 18 individuals (including 2 duplicate schools of 3 individuals) of right whales were sighted with photo-identification of 12 individuals and biopsy samples from 3 individuals. Discussion of these sightings can be found in Annex G (item 6.4).

In response to a recommendation made last year (IWC, 2018c), US and Japanese scientists presented the results of new genetic analyses of right whales in the North Pacific. Comparison of whales sampled in the eastern and western North Pacific revealed statistically significant differentiation based on mtDNA data, supporting presumed separation of the two stocks based on gaps in the spatial distribution of sightings (and also see discussion in Annex I, item 4.3).

[6] Any revised estimate from the Pace *et al.* 2017 paper will be reviewed by the ASI sub-committee during SC68a.

Attention: SC

*The results of new genetic analyses support the recognition of separate stocks of right whales in the eastern and western North Pacific. Given the importance of this work and the precarious situation of this species, especially in the eastern North Pacific, the Committee **encourages** the publication of this information as soon as possible.*

9.2.8 Workplan 2019-20
The Committee agreed to the two-year workplan in Table 11.

9. 3 New information and workplan for other northern stocks *(NH)*
9.3.1 North Pacific fin whales
The Committee received new information on studies of North Pacific fin whales. New sightings of fin whales were reported in the papers (SC/67b/ASI12, SC/67b/ASI10, SC/67b/SCSP06) during the POWER cruise in the Bering Sea and the two surveys in the western North Pacific (Areas 7, 8 & 9). Over 260 schools found, many individuals were photo-identified and biopsy samples were obtained from 28 whales.

9.3.2 Omura's whale
The Committee welcomed the new information on this species (SC/67b/NH09) from the west coast of Madagascar, supporting the current understanding that the population is resident and non-migratory with strong site fidelity. Likely threats to the Madagascar population include entanglement in local fisheries, impacts from oil and gas exploration, and most imminent the risk of coastal water contamination from a recently initiated mining operation for Rare Earth Elements. Future work should include a long-term latitudinal study that incorporates multiple methodologies to investigate all aspects of the species biology and conservation threats to the population.

Kim and colleagues reported on the first confirmed documentation of Omura's whale in the waters of South Korea. Two of six large baleen whales bycaught were confirmed by genetic analysis to be Omura's whale. This bycatch reinforces the concept that this coastal species is vulnerable to anthropogenic impacts, especially entanglement in fishing gear.

Attention: SC, G

The Committee notes that little information is available to assess the status of Omura's whale. The Committee:

*(1) **recognises** the significant contribution the research efforts off Madagascar have made to the understanding of this species and **encourages** this work to be continued and expanded into the future; and*
*(2) **encourages** identification of study sites that are suitable for long-term comparative study on Omura's whales in other parts of its range (e.g. New Caledonia, Komodo Islands, Indonesia, and the Bohol Sea, Philippines).*

Table 11

Workplan for other Northern Hemisphere stocks

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
North Pacific blue whales	Data collection and review with focus on catches and stock structure	Review especially stock structure	Develop proposal for stock structure	Agree stock structure hypotheses
North Atlantic sei whales	Review distribution, strandings, sightings and stock structure	Review new information for assessment	Develop proposal for stock structure	Agree stock structure hypotheses
North Atlantic right whales		Review status and mortality data		Review status and mortality data
North Pacific right whales		Review new information for assessment		Review new information for assessment
North Atlantic humpback whales		Consider information for new assessment		Develop plans for new assesssment
Gulf of Mexico Bryde's whale		Review new information on mortality		Review new information on mortality
All other stocks		Review new information		

9.3.3 North Atlantic Bryde's whales
SC/67b/ASI01 presented sightings collected during recent coastal surveys off Guinea, Sierra Leone and Liberia in March 2018. During this survey, two groups of five individual Bryde's whales were observed.

The Committee welcomed this information and **encourages** future surveys in this region.

9.3.4 North Atlantic blue whales

The Committee welcomed new information from the USA on blue whales in the North Atlantic including recent sightings, serious injuries or mortalities, seasonal occurrence based on acoustics. Lesage *et al.* (2018) provides an extensive summary of recent data collected in Canadian waters. This is discussed in Annex G (item 7.6) where it was noted that multiple new datasets (including from passive acoustic monitoring) have been recently collected and may provide more information on blue whale distribution in North Atlantic waters

Attention: SC, G

The Committee notes that there has been a recent increase in information available on North Atlantic blue whales. The Committee:

(1) ***draws attention to*** *the lack of data on interchange between blue whales in the eastern and western North Atlantic and* ***recommends*** *that U.S., Canadian and Icelandic colleagues conduct a new comparison of blue whale photo-identification catalogues and present this information at SC/68a; and*
(2) ***encourages*** *Canadian colleagues to generate a new population abundance estimate as soon as feasible, and looks forward to updates on new passive acoustic and visual sightings data SC/68a.*

9.3.5 North Atlantic humpback whales

The Committee received new information (NOAA, 2018b) on humpback mortalities along the US coast (vessel strikes and entanglements were noted as the primary causes of anthropogenic mortality). An 'Unusual Mortality Event' was declared by the USA for humpback whales in April 2017. This is discussed further in Annex G (item 7.7. New abundance estimates for parts of the North Atlantic are discussed in Annex Q (item 3.1.1.3) and presented in Item 12.1. Consideration of the need for a new in-depth assessment of North Pacific humpback whales is given in Annex E (item 5.8.2) and Item 8.7.3.

9.3.6 North Atlantic bowhead whales not subject to aboriginal subsistence whaling

No new information was available to the Committee.

9.3.7 North Pacific bowhead whales not subject to aboriginal subsistence whaling

No new information was available to the Committee.

9.3.8 North Pacific sperm whales

Three papers (SC/67b/ASI10,12 and SC/67b/SCSP06) provided new information of sperm whale occurrence and distribution was collected during 2017 in the western North Pacific, eastern Bering Sea. An intersessional correspondence group to examine possible ways to assess sperm whales has been reappointed (Annex Y)

9.3.9 Gulf of Mexico Bryde's whales

9.3.9.1 NEW INFORMATION

The Committee received an update on activities related to monitoring and new research plans for the critically endangered Gulf of Mexico sub-species of Bryde's whale. The Southeast Fisheries Science Center undertook a shipboard survey in the northern Gulf of Mexico in 2017, including known habitat of the Gulf of Mexico Bryde's whale. Passive acoustic data were collected in historic habitat of the central and western Gulf from June 2016 to June 2017. The In the USA, there is legislation that provides funds to restore and protect ecosystems of the Gulf of Mexico following the Deepwater Horizon oil spill (2010); this work will include research on the Gulf of Mexico Bryde's whale.

Attention: SC, G

The Committee ***agrees*** *that the NOAA scientists working with this sub-species should present results from shipboard and acoustic data analyses to the IWC at the 2019 Scientific Committee meeting and looks forward to receiving a report from the Workshop held in conjunction with the initiation of research associated with funds to restore and protect ecosystems of the Gulf of Mexico following the Deepwater Horizon oil spill.*

The Committee also ***encourages*** *U.S. and Mexican scientists to collaborate in efforts to determine whether any of these whales occur in Mexican waters (e.g. Bay of Campeche) where a major oil spill of three million barrels occurred in 1979. This should include consideration of the use o9f passive acoustics as well as visual surveys focusing on areas of habitat similar to that found in the core known range in the north-eastern Gulf. It was further noted that passive acoustic data or specimen records from the northern coast of Cuba would be useful to determine potential occurrence of this subspecies in that region.*

9.3.9.2 CONSERVATION ADVICE

Attention: CG-R, S

The small population size, known human related mortality, restricted range and low genetic diversity place the Gulf of Mexico sub-species of Bryde's whale (added to the Critically Endangered category of the IUCN Red List in 2017) at significant risk of extinction. The Committee ***reiterates*** *its previous* ***recommendations*** *that US authorities:*

(1) make full and immediate use of available legal and regulatory instruments to provide the greatest possible level of protection to these whales and their habitat;
ensure that seismic surveys and associated activities that degrade acoustic habitat are excluded from the region of the eastern Gulf of Mexico inhabited by these whales, including an appropriate geographic buffer against acoustic impacts from activities in the Central Planning Area and active leases in the Eastern Planning Area;
(2) characterise the degree of overlap between the whales' currently known preferred habitat and ship traffic, and immediately implement appropriate measures to reduce the risk of ship strikes (e.g. re-routing, speed restrictions);
(3) based on the known distribution of these whales and overlap with certain fisheries, improve understanding of potential for interaction with fishing gear, and expand and implement appropriate measures, such as area closures, to reduce the risk of entanglement throughout their range;
(4) develop and implement restoration projects (with funds from the Deepwater Horizon oil spill settlement) for these whales and their habitat as a priority and ensure that a robust monitoring and adaptive management plan is in place to evaluate the effectiveness of all restoration efforts;
(5) design and conduct research programmes (sighting surveys, acoustic monitoring, genetic mark-recapture, photoidentification if feasible, satellite tagging if feasible, health studies if feasible) to further investigate these whales' distribution, movements, habitat use, health, survival and fecundity - this should include efforts to better document the whales' total geographic range and to document causes of mortality through necropsies when carcasses are reported; and
(6) *ensure that information about core known habitat and movements in the Gulf of Mexico is transmitted to the U.S. Coast Guard, shipping industry trade organizations, and Gulf of Mexico port authorities (e.g. in Tampa, Florida) for their consideration to mitigate ship-strike risk.*

*In addition, the Committee **reiterates** its recommendation that the IWC Secretariat (i) communicate the above concerns and recommendations to range state authorities and (b) specifically explore in collaboration with the International Maritime Organization the feasibility of providing internationally recognized forms of protection to these whales (e.g. designation of an Area to be Avoided) that would reduce the risk of ship strike and help mitigate degradation of acoustic habitat by ship noise.*

9.3.10 Other stocks - Northern Indian Ocean sperm whales
No new information was available to the Committee.

9.3.11 Workplan 2019-20
The Committee agreed to the two-year workplan in Table 11.

9.4 New information and workplan for other Southern stocks
9.4.1 Southern Hemisphere humpback whales
9.4.2.1 BREEDING STOCK D
The assessment of the Breeding Stocks D (West Australia), E1 (East Australia) and Oceania was completed in 2014 (IWC, 2015a), but there were substantial associated problems in obtaining a reliable estimate of absolute abundance for Breeding Stock D. See Annex H (IWC, 2017a; 2018a) for a detailed discussion of these issues. Last year (IWC, 2018c), the Committee had agreed that efforts should focus on designing and implementing a new 'survey' (perhaps using new approaches such as drones), and recommended that prior to implementation, an assessment of the feasibility of such a 'survey', focusing in particular on the study conducted by du Fresne *et al.*, (2014), is conducted.

Attention: SC, G, CG-R

*The Committee **agrees** that obtaining a reliable estimate of absolute abundance for humpback whale Breeding Stock D (west Australia) is a priority for any future in-depth assessment. The Committee **reiterates** its recommendation that an evaluation of abundance survey feasibility be carried out for this population, focusing in particular on the study conducted by du Fresne et al. (2014), with a view to implementing a new survey of this population in the future.*

9.4.2.2 WORK PLAN
The work plan for Southern Hemisphere humpback whales is given in Table 12.

Table 12.
Work plan for Southern Hemisphere humpback whales

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Survey feasibility	Reanalyse pilot study to assess feasibility of future West Australia surveys (Kelly)	Receive report		

9.4.3 Southern Hemisphere right whales not the subject of CMPs

The Committee would like to progress regional population assessments for southern right whales (Item 10.8.1.5, IWC, 2017b) This requires a good understanding of population structure, abundance, trend and past exploitation levels. It was agreed that Australia should be the highest priority region for the next assessment (Item 9, IWC, 2018a).

9.4.3.1 SOUTH AFRICA

SC/67a/SH01 provided the results of the 2017 survey of southern right whales flown along the coast of South Africa, part of a long-term monitoring programme since 1979. Since 2015 there has been a marked decline in the presence of unaccompanied adults and cow-calf pairs for unknown reasons (see discussion in Annex S, item 5.1.3). Photo-ID analyses indicated an increasing occurrence of apparent 4- and 5-year calving intervals since 2014. SC/67b/SH22 applied a life history model to photo-ID data collected from 1979 to 2017. They showed that a model variant which allows the probability of a resting female remaining in the resting phase (rather than having a calf) to vary through time provided a better fit to the data than a time-invariant model. They calculate an annual population growth rate of 6.5% and measure first year survival at 0.852, with subsequent annual survival of 0.988.

Attention: SC, G, C-A, CG-A

*The Committee is **concerned** that the future of the exemplary long-term monitoring programme of right whales in South African waters remains uncertain. The Committee therefore **reiterates** that it:*

*(1) **strongly recommends** continuation of the survey;*
*(2) **requests** the Commission to urge South Africa to do all it can to ensure the long-term future of this vital monitoring programme; and*
*(3) **encourages** South African scientists to investigate the offshore movements and locations of southern right whales with future surveys.*

9.4.3.2 AUSTRALIA

The Committee was informed about the latest of a series of aerial surveys conducted in South and West Australia in 2017. The 2017 counts were the highest yet in the series and an exponential increase of ~6% per year remains a good description of the data. Funding has been obtained for the next three years of surveys. The Committee was also informed about: (a) a 26-year cliff-top study conducted at the Head of the Great Australian Bight (south Australia) on right whale population trends and identifications (Charlton *et al.*, In prep); and (b) an aerial survey in southeast Australia where small numbers of whales have been sighted (Watson *et al.*, 2015). Right whales in southeast Australia are genetically and geographically distinct from the large population in south/southwest Australia (e.g., Carroll *et al.*, In press).

The Committee was advised that the Australian Government has recently allocated funds towards a two-year project that will provide an abundance estimate for Australia's two southern right whale populations. It will investigate life history characteristics as well as connectivity between breeding areas on the eastern, southern and western coasts of Australia.

Attention: SC, G, CC, CG-A

*The Committee **recognises** the value of the Australian long-term right whale monitoring programmes to understand right whale population trends and dynamics, and **recommends** that this monitoring continues.*
*In regard to right whales in southeast Australia, the Committee **reiterates** concerns expressed in 2017 that abundance remains low despite this area having been a significant historic calving ground. The Committee therefore:*

(1) recommends an assessment of the likely effects of fish farms and other developments in hindering population recovery in this region; and
(2) encourages further work to estimate the abundance of the southeast Australia population.

9.4.3.3 NEW ZEALAND

The Committee welcomed information that surveys will be conducted in the Auckland Islands in 2020/21 to estimate abundance (updating the last estimate from 2009), to assess trend and population age structure, as well as changes in genetic diversity of right whales using this calving ground.

9.4.3.4 FEEDING GROUNDS

The Committee welcomed the results of a visual and acoustic survey of southern right whales off South Georgia/Islas (SC/67b/SH20). SC/67b/SH06 used genotypic markers to assess re-sight rates and sex ratios from biopsy samples (n=157) collected during 14 summer surveys in Antarctic Area IV. A preliminary abundance estimate was calculated using these data and further mark recapture analyses will be conducted intersessionally to provide an abundance estimate for review at next year's meeting. To further investigate linkages it was suggested that these high latitude data be compared the western Australia stock to investigate what population component is using this high latitude area.

Attention: SC

*The Committee **encourages** further mark recapture analysis of the genotype data of the 14-year dataset collected in the high latitudes of Area IV, to estimate the abundance of southern right whales in this feeding area and **agrees** that this will be considered at next year's meeting.*

9.4.3.5 PROGRESS TOWARDS POPULATION ASSESSMENT

This year, the Committee reviewed newly available information on population structuring of southern right whales around the Southern Hemisphere (Carroll *et al*., In press) which further confirms the genetic differentiation of regional calving grounds off Argentina, South Africa, New Zealand and Australia, showing limited migratory movements between these areas (see Annex H, item 5.1,).

The Committee was provided with updates on trends and distribution for calving grounds off South Africa and off south and southwest Australia. Recent published data on population size and trend for calving grounds across the Southern Hemisphere were summarised in Annex H (table 2); this will be reviewed at next year's meeting. Given the trends in abundance and calving rates reported this year (Items 9.4.3.1 and 9.4.3.2), integration of these analyses in a common modelling framework was suggested as a useful way to evaluate common patterns and changes in demography and investigate the relative importance of environmental drivers in determining these patterns.

Another important aspect of population assessment is to update the pre-modern catch series for southern right whales, to better reflect patterns of regional exploitation. The Committee was informed that substantial new data are available on offshore whaling patterns and extent, particularly from American and British voyage logbooks (see Annex H, item 5.2,), which are likely to increase regional catch estimates and provide revised estimates of the numbers of whales struck but lost at sea by the different fisheries.

Attention: SC, G

To better understand patterns of right whale population dynamics around the Southern Hemisphere, and further the work on updated assessments, the Committee:

*(1) **agrees** that analysis of three southern right whale calving grounds (Head of the Bight and southwest Australia, southwest Atlantic and south Africa) should be undertaken using the same life-history model, to estimate regional demographic parameters and investigate commonalities in the population dynamics of these populations; and*
*(2) **supports** the compilation of new data on pre-modern right whale catches, and the organisation of a workshop to investigate regional right whale catches and rates of whales struck but lost by fisheries, in order to proceed toward regional population assessments.*

9.4.3.6 WORK PLAN AND BUDGET REQUESTS FOR 2019-2020

The work plan for southern right whales not the subject of a CMP is given in Table 13.

Table 13.

Workplan for southern right whales that are not the subject of a CMP

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Southern right whales	Examine southern right whale demographic parameters across multiple calving grounds using a common modelling framework	Review progress		Complete comparison
Southern right whales	Plan right whale catch series workshop	Progress update	Organise catch series workshop	Workshop report

10. STOCKS THAT ARE OR HAVE BEEN SUGGESTED TO BE THE SUBJECT OF CONSERVATION MANAGEMENT PLANS (CMPs)

10.1 Stocks with existing CMPs

This item covers stocks (with a focus on progress with scientific work and information) that are either: (1) the subject of existing CMPs; or (2) are high priority candidates for a CMP. It also considers stocks that have previously been considered as potential CMPs, recognising that the Commission has stressed the need for Range States to support any IWC CMPs.

10.1.1 SE Pacific southern right whales

10.1.1.1 NEW INFORMATION

The Committee received information on advances with respect to sightings (SC/67b/CMP20) and acoustic monitoring (SC/67b/CMP08; SC/67b/CMP18) of the critically endangered population of SE Pacific southern right whales. This information is discussed in detail in Annex O (item 2.1.1). Four confirmed observations were made off Chile in 2017

(three opportunistic sightings and one entangled carcass) and there was another, as yet unconfirmed sighting involving adults and calves. Analysis to date of acoustic data collected off the southwestern tip of Isla de Chiloe in 2012 has provided valuable new information about call parameters and patterns.

10.1.1.2 PROGRESS WITH THE CMP

The Committee received information on progress in implementing priority actions of the CMP (SC/67b/CMP20) as discussed in Annex O (item 2.1.1.2).

This progress includes:

(1) deployment of Passive Acoustic Monitoring (PAM) devices along the coast of Chile and Peru (SC/67b/CMP18) in two locations that will also be used as the focus of educational and capacity-building activities in communities near the monitoring sites;
(2) additional capacity-building and awareness efforts (including posters, press releases and social media) including advice on how fishermen and the public can provide information to the national sighting network; and
(3) additional training towards increasing the capacity of range states to respond to entanglements.

Attention: SC, CC

*The Committee **reiterates** the importance of the CMP for the conservation of this critically endangered population of southern right whales in the southeastern Pacific, **welcomes** the progress being made in its implementation by Chile and Peru. It therefore:*

*(1) **commends** the scientific work and international co-operation being undertaken for the PAM project and looks forward to receiving the results of the acoustic studies such that future sighting surveys will be more informed and baseline information on the location of breeding grounds will be available; and*

*(2) **advises** that satellite imagery be explored as an additional means to inform the design of sighting surveys because it is likely that line-transect surveys would not successfully identify whales in some areas even if they were present.*

10.1.2 Southwestern Atlantic southern right whales

10.1.2.1 NEW INFORMATION

The Committee was pleased to receive a considerable amount of new information on the southwest Atlantic population of southern right whales; this is fully discussed in Annex O (item 2.1.2.1).

With respect to abundance, SC/67b/CMP/05 suggested that although the population has continued to increase, the rate may have been slowing, perhaps as a consequence of changes in distribution due to density-dependence processes (SC/67b/CMP02).

The Committee has for some time been focussing on the die off at Peninsula Valdes (e.g. IWC, 2011; 2015) and the excellent work of the Southern Right Whale Health Monitoring Program. New and updated information was presented this year on strandings and investigations related to health including examination of levels of stress hormones in baleen and kelp gull attacks (SC/67b/CMP04) and nutritional condition (SC/67b/CMP03). This work is ongoing.

Information was received on telemetry studies (one animal in 2016 and 8 in 2017) as part of an ongoing long-term study to understand the migratory routes and destinations of southern right whales wintering off the coast of Argentina (SC/67b/CMP17. Tracks reveal that these animals are found across a vast extent of the South Atlantic and each season visit multiple potential feeding areas.

The Committee also received the report of a land-based survey of whales near Miramar on the southwest coast of the Buenos Aires Province, Argentina, where there has been a recent expansion of right whales into the region where they have been seen from May to October with peaks in August and September (SC/67b/CMP21).

Attention: SC, G

*The Committee **reiterates** the importance of continued monitoring of the southwestern Atlantic population of southern right whales and research into threats that it may face. The Committee therefore:*

*(1) **commends** the work being undertaken on understanding the mortality events and **encourages** its continuation;*
*(2) **encourages** the researchers working on stress hormones in baleen to increase their sample size, consider suggestions for additional studies provided in Annex O (item 2.1.2.1) and present a full report to the Committee when it becomes available;*
*(3) **commends** the telemetry work, **encourages** its expansion and draws attention to additional analyses that could be addressed using the telemetry data suggested in Annex O (item 2.1.2.1).*

10.1.2.2 PROGRESS WITH THE CMP

The overall objective of the southern right whale CMP is to protect their habitat and minimise anthropogenic threats to maximise the likelihood that the population will recover to healthy levels and recolonise its historical range. The Committee was pleased to receive information on progress with the actions of the CMP from Argentina (SC/67b/CMP14),

including the work described under Item 10.1.2.2, and Brazil (Annex O, appendix 2). Work in Brazil includes long-term monitoring via sightings and strandings networks, mitigation of entanglements and the development of a management plan for whalewatching (see Annex O, item 2.1.2.2).

Attention: SC, CC

*The Committee **reiterates** the importance of the CMP for the conservation of the southwestern Atlantic population of southern right whales. The Committee therefore:*

*(1) **welcomes** the progress being made in the implementation of the CMP reported by Argentina and Brazil and supports its continuation;*
*(2) **encourages** the continued co-operation and collaboration amongst range states towards implementing the CMP and addressing mortality evens in this population; and*
*(3) recognising the report of a ship-struck southwestern Atlantic southern right whale in the range of the southeastern Pacific (Estrecho de Magallanes), **encourages** co-operation with those involved in the southeastern Pacific CMP to facilitate a regional assessment; and*
*(4) **encourages** the research work identified under Item 10.1.2.1.*

10.1.3 North Pacific gray whales

10.1.3.1 RANGEWIDE ASSESSMENT

Donovan summarised the report of the Fifth Rangewide Workshop on the Status of North Pacific Gray Whales (SC/67b/Rep07) held at the Granite Canyon Laboratory, California of the Southwest Fisheries Science Center from 28-31 March 2018. The primary tasks of the workshop were to (a) review the results of the modelling work identified at the fourth rangewide workshop (IWC, 2018a) and the 2017 Scientific Committee meeting (IWC, 2018b), (b) examine the new proposed Makah Management Plan (submitted by the USA – given as Annex E, Appendix 1) for gray whaling off Washington state and (c) to update as possible, and develop a workplan for, updating the scientific components of the Conservation Management Plan (CMP) for western gray whales.

A full discussion of the workshop can be found in Annex O (item 2.1.3.1). The Workshop finalised its work on (a) prioritising stock structure hypotheses, (b) finalising inputs for the modelling work especially related to bycatch; and (c) incorporating the Makah Management Plan (SC/67b/Rep07, Annex E, Appendix 1) into the modelling framework.

Two stock structure hypotheses (3a and 5a) were given priority whilst others were used in sensitivity tests. In summary, Hypothesis 3a assumes that whilst two breeding stocks (Western and Eastern) may once have existed, the Western breeding stock is extirpated. Whales show matrilineal fidelity to feeding grounds, and the Eastern breeding stock includes three feeding aggregations: Pacific Coast Feeding Group (PCFG), Northern Feeding Group (NFG), and the Western Feeding Group. Hypothesis 5a assumes that both breeding stocks are extant and that the Western breeding stock feeds off both coasts of Japan and Korea and in the northern Okhotsk Sea west of the Kamchatka Peninsula. Whales feeding off Sakhalin include both whales that are part of the extant Western breeding stock and remain in the western North Pacific year-round, and whales that are part of the Eastern breeding stock and migrate between Sakhalin and the eastern North Pacific.

In discussion of the report and intersessional progress, the Committee thanked Donovan, Punt and the participants for the progress made, approved the conditioning results developed after the workshop, noted the preliminary results from the modelling and agreed a strategy for obtaining conservation advice (see recommendation below under Item 10.3). The management implications of the results for the Makah Management Plan are found under Item 7.1.3.

10.1.3.2 REGIONAL STUDIES

The Committee was pleased to receive recent information from long-term studies in the breeding lagoons of Mexico (SC/67b/CMP09) as discussed in Annex O (item 2.1.3.1.1).

The Committee received several updates on work undertaken in the Russian Federation (see Annex O, item 2.1.3.2). It welcomed the annual update of activities from the IUCN Western Gray Whale Advisory Panel (see Annex O, appendix 3) which highlighted work to develop a monitoring and mitigation plan for a 2018 seismic survey being undertaken near the feeding grounds off Sakhalin Island, Russia and issues related to fishing gear. SC/67b/CMP07 updated findings from the long-term monitoring programme carried out by the Russian Gray Whale Project off Sakhalin Island, Russia. The research programme run in the same area by two oil companies was presented in SC/67b/ASI04 and discussed in Annex S (item 4.2).

The recent status of conservation and research on gray whales in Japan was reported in SC/67b/CMP12. During May 2017-April 2018, no anthropogenic mortalities were reported from the adjacent waters off Japan, while two opportunistic sightings of gray whales were made near Aogashima Island in May 2017 and February 2018.

Finally, SC/67b/CMP11 reported on the possible occurrence of a gray whale off the east coast of Korea; work is continuing to try to confirm the species identification; if confirmed it will be the first record in these waters in over 40 years.

Attention: CG-R, SC, G

*The Committee **reiterates** the importance of long-term monitoring of gray whales, **recommends** that range states support such work and **welcomes** the information provided this year. In particular, the Committee:*

*(1) **commends** the work in the breeding lagoons and urges its continuation;*
*(2) **encourages** an additional calf-count survey for Punta Banda to address apparent differences in numbers of calves observed in the lagoons with counts from California;*
*(3) **reiterates its concern** at the risk of whales becoming entangled in gear placed by the salmon trap-net fishery off Sakhalin Island, recognises that disentanglement training has occurred but **recommends** that measures to be taken to reduce risk;*
*(4) **encourages** continued genetic analyses to assist in stock structure discussions especially related to a western breeding stock;*
*(5) **welcomes** the continued provision of information from Japan and **encourages** researchers to continue to collect as much information on sightings as possible, including, if feasible, attempting to obtain biopsy samples; and*
*(6) **welcomes** the information from Korea and the willingness of researchers to investigate sightings from social media as a form of 'citizen science', which can be especially valuable for areas where occurrence is very rare animals in areas with little to no information on critically endangered species.*

10.1.3.3 PROGRESS WITH THE CMP

As noted above, one of the objectives of the fifth rangewide workshop was to progress work with updating the scientific components of the original IWC/IUCN CMP in the light of the results of the rangewide review. Although some work was undertaken, there was insufficient time at the workshop to complete this although a workplan to achieve it was suggested (see SC/67b/Rep07). The Committee concurred with this view and this is incorporated into the workplan below.

Another important component of the CMP effort is the need for a stakeholder workshop (tentatively forecast to occur in 2019) to finalise the CMP and develops a strategy for its implementation. The plan is for a workshop, co-sponsored by IWC, IUCN and the signatories to the Memorandum of Cooperation, to: (1) review and updating of the CMP; (2) establishing a stakeholder Steering Group to monitor CMP implementation, (3) arrange for a coordinator of the CMP and (4) establish a work plan and consider funding mechanisms to implement the actions of the plan.

Attention: C-A, CG-R, CC, SC

*The Committee **reiterates** the importance of the CMP for the conservation of western gray whales. The Committee therefore:*

*(1) **recognises** the tremendous work undertaken in the rangewide assessment and the value of the modelling framework developed;*
*(2) **agrees** that the next part of the process is to develop conservation-related questions and to use the framework to address these with a view to examining results at SC68a;*
*(3) **agrees** that a small group meeting (see Item 27) attended by at least the national co-ordinators of the Memorandum of Co-operation on gray whales, Reeves, Punt and Donovan be held to: (a) draft an update to the CMP; and (b) identify conservation-related questions to be addressed by the modelling framework and to present results at SC68a;*
*(4) **requests** those signatories to the Memorandum of Co-operation on western gray whales who have not yet named a national co-ordinator to do so promptly; and*
*(5) **supports** the holding of a stakeholder workshop in 2019 co-sponsored by the IWC, IUCN and the states that have signed the Memorandum of Co-operation and **welcomes** the valuable assistance of IUCN in organising the workshop.*

10.1.4 Franciscana

10.1.4.1 NEW INFORMATION

The Committee received valuable new information on franciscana at this meeting related to fisheries and bycatch from five localities in North Espírito Santo State, Brazil (SC/67b/SM30) – bycatches of Guiana dolphins was also reported. Additional information was presented assessing fisheries that operate in Fisheries Management Area (FMA) Ib for their compliance with Brazilian ordinance (IN) 12 (e.g. with respect to gill-net regulations and no-take zones) and risk of bycatch (SC/67b/SM05) – compliance was limited and enforcement poor. Both projects were funded by the IWC Small Cetacean Fund and the Government of Italy. This information is discussed in Annex O (item 2.1.4.1) and a related recommendation is given under Item 10.4.2.2.

10.1.4.2 PROGRESS WITH THE CMP

The overall objective of the CMP, submitted by Argentina, Brazil and Uruguay (IWC/66/CC11) and adopted in 2016, is to protect franciscana habitat and minimise anthropogenic threats, especially bycatch. It includes seven high priority actions, ranging from public awareness and capacity building through research to mitigation. Coordination with Uruguay to implement the CMP in this area will be initiated during a workshop that will take place in May 2018 with the main stakeholders (SC/67b/CMP16). The CMP is funded by the IWC CMP Voluntary Funds and the World Wildlife Fund.

Attention: *CG-R*

*The Committee **emphasises** the importance of the CMP for the conservation of franciscana in the waters of Argentina, Uruguay and Brazil. The Committee therefore:*

*(1) **stresses** the value of the actions included in the CMP towards future assessments of the status of franciscana, which is imperative for determining the effectiveness of conservation efforts;*
*(2) **recommends** that research be undertaken to estimate the abundance of franciscana dolphin off Buenos Aires province, Argentina; and*
*(3) **recommends** that additional research be undertaken to determine the effectiveness of management measures, such as that described in SC/67b/SM05 for other ports (e.g. Macaé, Tamoios (Cabo Frio) and Armação dos Búzios – the fishery in Tamoios coincides with a high diversity of marine megafauna).*

The Committee established an intersessional correspondence group that will help co-ordinate the presentation of CMP projects for this species across sub-committees at SC/68a (Annex Y).

10.2 Progress with identified priorities

10.2.1 Humpback whales in the northern Indian Ocean including the Arabian Sea

10.2.1.1 NEW INFORMATION

The Committee received several papers that improved knowledge of Arabian Sea humpback whales and a full discussion can be found in Annex O (item 2.2.1). It welcomed the information on the progress of work being undertaken by the Arabian Sea Whale Network (ASWN) formed in 2015 (SC/67b/CMP10). The ASWN is an informal collaboration of researchers, consultants and conservation and governmental organisations interested in the conservation of whales in the Northern Indian Ocean. A primary goal of the ASWN is to promote and foster research and collaboration in previously unsurveyed parts of the Arabian Sea humpback whales' suspected range, as well as in Oman where surveys have been conducted since 2000. Work has focused on collecting data on whale distribution and status (including through increased awareness and an observer programme – described in SC/67b/CMP15)), the introduction and implementation of a regional online data platform (SC/67b/PH03) and providing updates on research activities in Oman, India, Pakistan and Sri Lanka (SC/67b/INFO07). Two marine protected areas have been established in Pakistan (Astola Island and Indus Canyon).

Madhusudhana *et al.* (2018) reported on and compared humpback whale songs recorded off India, Oman, Reunion Island and Comoros Islands in the southwest Indian Ocean. The results highlighted (a) the distinct nature of the Arabian Sea population and (b) that SW Indian Ocean whales may move into the Arabian Sea more commonly than previously thought.

SC/67b/CMP13 reported on a humpback whale tagged off Oman that moved to the southern tip of India and back again - the first recorded movement of a whale across the Arabian Sea. Four additional satellite tags were deployed where the whales remained over the continental shelf of central and southern Oman.

Attention: G, SC

*The Committee **welcomes** the new information from the region on this critically endangered population and **commends** the researchers for their initiatives and collaborative efforts. In light of the information presented, the Committee:*

*(1) **encourages** the collection of genetic information which would be helpful for identifying stock structures within the area;*
*(2) **recommends** future use of unoccupied aerial systems to (i) measure whale health, (ii) develop long-term health metrics, (iii) compare body condition to stock C in the Southern Hemisphere, which is the presumed 'source' population for whales in the Arabian Sea and (iv) assess for evidence of anthropogenic threats;*
*(3) **commends** the use of fishing crew as observers and **advises** that the crew-based observer programme continue, recognising that it is not clear if the timing of the sightings reflects the seasonal distribution of whales or the seasonal nature of fishing effort and **encourages** future research to tease apart timing of the distributions using targeted surveys;*
*(4) **advises** that capacity building for local scientists be continued such that surveys can be deployed in suspected areas of humpback whale distribution and data can be gathered for future assessments;*
*(5) **advises** the continuation of monitoring songs of Arabian Sea humpback whales and that additional data sets be acquired comparison purposes, particularly from the southwest Indian Ocean, if they exist, to further (i) detect the movement of southwestern Indian Ocean animals in Boreal winter, (ii) document potential diffusion of southwestern Indian Ocean song, (iii) provide a long-term data set for the comparison of songs across Oman, Pakistan and India to assess continuity of whales in the Arabian Sea and (iv) evaluate the unprecedented temporal stasis of song in the Arabian Sea; and*
*(6) **agrees** that an intersessional correspondence group (Annex Y) be formed to review the methods used for the preliminary estimates of abundance, in order to increase their robustness by taking into account the non-random survey approach that violates some key assumptions of mark-recapture models.*

10.2.1.2 PROGRESS WITH INTERNATIONAL CO-OPERATION AND REGIONAL MEASURES SUCH AS CMPS

A Concerted Action for Arabian Sea humpback whales under the Convention on Migratory Species (CMS; SC/67b/INFO06) was drafted and passed with wide support from Arabian Sea range states at the CMS COP in October 2017. It is hoped that this Concerted Action can be implemented in conjunction with a CMP as a means to translate current research and conservation efforts and plans into concrete, government-supported conservation measures in Arabian Sea humpback whale range states.

Attention: *C-A, S*

*The Committee **reiterates** its serious concern about the status of the endangered Arabian Sea humpback whale population and the anthropogenic threats it faces. It therefore:*

*(1) **commends** efforts to develop the Concerted Action under the CMS, noting that it covers many of the elements required for a CMP;*
*(2) **stresses** the value of regional initiatives and **encourages** range states to explore future sources of collaboration; and*
*(3) **encourages** continued efforts between range states and Secretariats to work toward a joint CMS-IWC CMP.*

10.2.2 Mediterranean fin whales

The ACCOBAMS Meeting of Parties has endorsed the development of a CMP, ideally jointly with the IWC, for fin whales in the Mediterranean Sea. A small group will meet in the summer of 2018 to draft an outline for a CMP that can be presented at SC/68a. ACCOBAMS is also considering the development of CMPs for other species in the region.

10.2.3 South American River Dolphins

Advice was sought regarding the development of a CMP for South American river dolphins, which currently have several actions plans endorsed by various range states.

Attention: CG-A

*The Committee **advises** that the applicable range states work towards developing a draft CMP for presentation at SC/68a.*

10.3 Workplan 2019-20

The workplan on matters related to stocks that are or might be the subject of CMPs is given as Table 14.

Table 14

Summary of the work plan on conservation management plans.

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Southeast Pacific right whales	.	Review progress with scientific aspects of the CMP		Review progress with scientific aspects of the CMP
Southwestern Atlantic right whales		Review progress with scientific aspects of the CMP		Review progress with scientific aspects of the CMP
Gray whales	Hold workshop on scientific aspects of CMP and use of modelling framework.	Review results and provide advice on scientific aspects of CMP	Stakeholder workshop	Review scientific aspects of results of stakeholder workshop
Franciscana		Pre-assessment for in-depth review		Continue pre-assessment and develop plan for in-depth assessment
Humpback whales in Northern Indian Ocean	Intersessional email group (Annex Y) on abundance estimates	Review new information and progress towards CMP		Review new information and progress towards CMP
Mediterranean fin whales	Develop outline draft	Review draft and progress towards CMP		Review progress towards CMP
South American river dolphins		Review new information and progress towards CMP		Review new information and progress towards CMP

11. STOCK DEFINITION AND DNA TESTING

This agenda item merges two previously separate sub-groups, the Working Group on Stock Definition and the Working Group on DNA. During SC67b, the Stock Definition and DNA Testing Working Group assessed genetic methods used for species, stock and individual identification, including matters associated with the maintenance of DNA registers (see 11.1); continued to develop and update guidelines for preparation and analysis of genetic data within the IWC context (see 11.2); and provided the Committee with feedback and recommendations concerning stock structure related methods

and analyses (see 11.4), including those relevant to other sub-committees (see 11.3). The Report of the Working Group is given as Annex I.

11.1 DNA testing
This item has been considered since 2000 in response to a Commission Resolution (IWC, 2000).

11.1.1 Genetic methods for species, stocks and individual identification
The Committee received two papers relating to the use of genetic methods for species, stock and individual identification. The first paper (Carroll *et al.*, 2018) provided a review of how technological advances, particularly those associated with the development of high throughput sequencing (HTS) technology, can aid in genetic monitoring. Of particular interest to the Committee was discussion of targeted capture approaches that allow for microsatellite genotyping via HTS (e.g. De Barba *et al.*, 2017). Much of the past genetic work has relied on generating microsatellite datasets, including the work to maintain DNA registries of bycaught or direct catches (see Items 11.1.2 and 11.1.3). These 'legacy' datasets may include microsatellite genotypes for thousands of individuals. While technical challenges exist, microsatellite genotyping via HTS could 'bridge the gap' by maintaining the utility of these legacy datasets while also taking advantage of the newer HTS approaches.

The second paper (Baker *et al.*, In press) presented the results of a study confirming the potential to detect environmental DNA (eDNA) in seawater collected from the wake of killer whales. This is a new approach for detecting and identifying cetacean species, including those that may be elusive to study using other methods. Although eDNA has been more broadly used to detect the occurrence of species in an area (i.e. DNA barcoding), it could provide sequence data useful for stock-level identifications of cetaceans under certain circumstances (e.g., when a single animal is present). It was noted, however, that its utility in addressing questions requiring individual identification via multi-locus genotyping is, at least currently, limited for scenarios in which the water sample could contain DNA from multiple individuals.

Attention: SC

*The Committee **welcomes** the opportunity to review papers that take advantage of technological advances to improve the ability to detect and identify species, stocks, and individual cetaceans. It **encourages** the submission of similar papers in the future and recognises the relevance of these techniques to the Committee's work.*

11.1.2 'Amendments' of sequences deposited in GenBank
While *GenBank*[7] is an important scientific resource, it is an uncurated database of DNA sequences and thus contains sequences that are misidentified or have other annotation problems. While retaining the 'raw data' represented in *GenBank* is valuable, less-experienced users may be unaware that additional sequence validation may be needed when incorporating *GenBank* sequences into a study. The Committee has agreed (IWC, 2018c, p. 228) that its revised DNA quality guidelines will contain a section discussing the precautions that should be taken when including GenBank sequences in a study. This text has been drafted and will be incorporated into the revised guidelines (see Item 11.2).

11.1.3 Collection and archiving of tissue samples from catches and bycatches and
11.1.4 Reference databases and standards for diagnostic DNA registries
The Committee previously endorsed a new standard format for the updates of national DNA registers to assist with the review of such updates (IWC, 2012a, p. 53), and the new format has worked well in recent years. This year, the update of the DNA registers by Japan, Norway and Iceland were based again on this new format. Details are given in Annex I (appendices 2-4) for each country, covering the period up to and including 2017. Almost all samples in the three registries have been analysed for microsatellites, and work on unanalysed samples is continuing. Almost all samples in the registries of Japan and Iceland have also been analysed for mtDNA.

During last year's discussion of the Norwegian minke whale DNA register (IWC, 2018c, p. 228-229), the Committee was informed that mtDNA analysis on Norwegian samples had been discontinued and that microsatellite typing would eventually be replaced by SNP analysis. The Committee had expressed concern regarding the comparability of the DNA registers in the future. This year, the Committee noted that Norway had discontinued mtDNA typing of samples and substituted it with SNP genotyping.

Attention: CG-A

*The Committee **expresses appreciation** to Japan, Norway and Iceland for providing updates to their DNA registries using the standard format agreed in 2011 and providing the detailed information contained in their DNA registries.*

11.2 Guidelines and methods for genetic studies and DNA data quality
Two sets of guidelines have been developed for reference in the Committee's discussions of stock structure. The most recent version of the guidelines for genetic data analyses are in press with the Commission's *Journal of Cetacean*

[7] https://www.ncbi.nlm.nih.gov/genbank/

Research & Management. The DNA data quality guidelines address DNA validation and systematic quality control in genetic studies, and are currently available as a 'living document' on the IWC website[8]. In recent years, it has become common for the Committee to review papers using data derived from Next Generation Sequencing (NGS) approaches, including SNPs, to address stock structure questions (see Item 11.3).

Attention: SC

*The Committee **emphasises** the importance of keeping its guidelines related to genetic data quality and analyses up to date. It therefore:*

*(1) **reiterates** the need to update these guidelines to incorporate the discussion of data quality measures used for Next Generation Sequencing data; and*
*(2) **agrees** to continue the intersessional correspondence group (Annex Y) to review revised sections of the DNA data quality guidelines that apply to data generated from next generation sequencing platforms, including SNPs and whole genome sequencing, with the goal of posting an updated version of the guidelines on the website next year.*

11.3 Provide advice on stock structure to other sub-groups
The Working Group on Stock Definition and DNA also has the task of discussing high-priority stock related papers from other sub-committees and working groups to provide them with stock structure related feedback and recommendations. These discussions often refer to the genetic analysis guidelines and genetic data quality documents.

The discussions (see Annex I for details) are summarised under the relevant stock agenda items in this report. Two, more general issues arose from discussions of Southern Hemisphere stocks and North Atlantic common minke whales. These are considered below.

11.3.1. Southern Hemisphere whale stocks and use of samples
The Committee reviewed the results of genetic analyses of Southern Hemisphere whale stocks, including Southern Hemisphere blue, fin, right and sei whales. These results highlighted the value of existing collections of tissue samples to address stock structure questions.

Attention: SC

*In reviewing the results of stock structure analyses of Southern Hemisphere whale stocks, the Committee expresses **concern** regarding the depletion of tissue samples in existing collections (including those collected during the IWC SOWER surveys, although the Steering Group does take this into account when reviewing requests). Given recent advances in high throughput sequencing technology, the Committee **agrees** that an intersessional correspondence group (Annex Y) should be formed to provide recommendations on genomic approaches to maximise the utility of these samples for future studies.*

11.3.2. North Atlantic common minke whales
The Committee reviewed the results of genetic analyses pertaining to the stock structure of North Atlantic minke whales (SC/67b/Rep06). The analyses presented involved the use of a new approach to evaluate stock mixing proportions by (1) identifying a 'reference' year in which mixing of stocks was considered low based on a lack of heterogeneity in genetic characteristics estimated for each area, and (2) using principal component analysis of the genetic data to assign stock affinities in the non-reference years based on proximity to mean values in the reference year.

Attention: SC, C-A

The Committee reviewed the use of a new approach that used ordination analyses of genetic data to assign stock mixing proportions. Recognising that this new approach requires making certain assumptions about the data, the Committee:

*(1) **agrees** that the inference of mixing rates was informative for AWMP/RMP simulation trials in the absence of empirical data; and*
*(2) **encourages** the attempt to use genetic data to estimate mixing rates in the context of other IWC-related tasks.*

11.4 New statistical and genetic issues relating to stock definition
11.4.1. Simulation tools for spatial structuring
TOSSM was developed with the intent of testing the performance of genetic analytical methods in a management context using simulated genetic datasets (Martien *et al.*, 2009), and more recently the TOSSM dataset generation model has been used to create simulated datasets to allow the plausibility of different stock structure hypotheses to be tested (Archer *et al.*, 2010; Lang and Martien, 2012). The Working Group noted that while TOSSM has been particularly valuable in

[8] http://iwc.int/scientific-committee-handbook#ten

informing the interpretation of results of stock structure related analyses, it has not been broadly used within the IWC Scientific Committee for this purpose.

In recent years, a wide-range of software packages have become available for producing simulated datasets that can be used for statistical inference and/or validating statistical methods (Hoban, 2014, and see ; IWC, 2017c p.44), and in 2016 the Committee agreed to expand this item (formerly specific to TOSSM) to include a broader range of tools (IWC, 2016c p.44).

Attention: SC

*The Committee noted that while simulation-based approaches have been particularly valuable in informing the interpretation of results of stock structure-related analyses, they have not been broadly utilized within the Committee for this purpose. The Committee **agrees**:*

(1) to continue an intersessional review via an email correspondence group (Annex Y) of the available simulation tools and their potential utility to the Committee; and
(2) to consider bringing in invited expertise to present an overview of the applicability of such approaches in order to expedite progress on this agenda item.

11.4.2. Terminology
Defining and standardising the terminology used to discuss 'stock issues' remains a long-standing objective of the Working Group, in order to help the Committee report on these issues according to a common reference of terms (IWC, 2014 p.287-8). At SC67b, the status of the existing draft glossary on key terms related to stock definition was revisited.

Attention: SC

*The Committee **agrees** to establish an intersessional correspondence group (Annex Y) to revisit terminology with specific reference to the implications of inferred stock structure in other sub-committees, particularly those that deal with large whale assessments, and suggest revisions where appropriate for consideration at SC68a.*

11.4.3. Close-kin mark-recapture
An overview of the close-kin mark-recapture (CKMR) approach (Bravington *et al.*, 2016) was presented to the Committee last year (IWC, 2018c p.40). CKMR uses multi-locus genotyping to find close relatives among tissue samples from dead and/or live animals; the number of kin-pairs found, and their pattern in time and space, can be embedded in a statistical mark-recapture framework to infer absolute abundance, parameters like survival rate, and stock structure. No papers applying the CKMR approach were reviewed by Committee this year, although the value of integrating data from epigenetic aging (see 11.4.4) into CKMR was noted.

Attention: SC, G

*Given that close-kin mark-recapture has multiple applications that fall within the Committee's scope of work, the Committee **encourages** the submission of papers using this approach in the future.*

11.4.4. Epigenetic ageing
Information on estimated age of individuals can be used in many aspects of the Committee's work, including (1) discriminating between the parent and offspring among genetically identified parent-offspring pairs, which can inform both assessment of stock structure as well as genetic mark-recapture estimates of abundance (e.g. CKMR); and (2) integrating age information into the population modelling exercises integral to assessment work (e.g. on RMP implementation). Recently, epigenetic (DNA-methylation) ageing has been successfully used to estimate age in humpback whales (Polanowski *et al.*, 2014). This year, the Committee invited Jarman, the lead scientist on the humpback whale work, to give an overview presentation to the Committee. This session was organised as a special evening session in order to enable participation across sub-committees and Working Groups. He covered issues specific to age estimation in cetaceans, including how DNA methylation-based age estimation are likely to perform in cetaceans and what current and near-future prospects there are for this class of methods (see Annex I, item 5.5).

The Committee also reviewed the results of a study to evaluate the feasibility of using the DNA-methylation technique to estimate age in Antarctic minke whales (SC/67b/SDDNA04). This study was initiated in response to a recommendation made during the Expert Panel review of the NEWREP-A proposal (SC66A/REP06, p17). DNA-methylation rates were examined for seven methylation sites (CpG sites) within three genes, and regressions of each CpG methylation site against age determined by earplug were conducted. When all sites were incorporated, the assay predicted age from skin samples with a standard deviation of about 8.9 years. While some sites showed age-related effects, others did not show such correlation. Thus, using only those loci that appear to have an age-related effect might reveal a stronger relationship between methylation rates and age.

During the discussion (Annex I, item 5.5) it was noted that the humpback whale age assay, which used the same sites, reports a precision of 2.99 years, measured as the average of the absolute values of the differences between known and estimated ages (Polanowski *et al.*, 2014). During the presentation, the precision as measured by the standard deviation for absolute age prediction was reported as 4.8 years. That was a preliminary study demonstrating the fundamental feasibility of this approach, and is not as accurate or precise as tests developed for humans and mice based on analysis of many more CpG sites. While precision is expected to improve with the inclusion of more CpG sites, the maximum precision possible for any DNA methylation-based age estimator is likely limited by the imperfect relationship between chronological age and biological age. To date, that precision has ranged from 3.9% in humpback whales (Polanowski *et al.*, 2014 assuming a 95-year lifespan), to 3.2% of lifespan in humans (e.g. Horvath, 2013) and 1.7% of lifespan in mice (Stubbs *et al.*, 2017). These observations indicate that the SD and 95% CI for age estimation described in Polanowski *et al.* (2014) and in SC67b/SDDNA04 could be substantially improved before an inherent limit is reached. These precision estimates adhere to age determination in individual specimens. Hence, averaged age estimates over cohort will improve over larger sample sizes and may be more precise.

The Committee noted that the implications of this upper limit on precision in estimating age for individuals would need to be evaluated in the context of the specific application for which the age data were being used. For example, although additional precision is helpful, CKMR studies may be informed by relatively crude estimates of age allowing the parent to be discriminated from the offspring (i.e. ordinal age).

Attention: SC

*The Committee welcomed the results of the study to evaluate the feasibility of using epigenetic techniques to estimate age in Antarctic minke whales and **agrees**:*

(1) that the current set of loci did not provide sufficient precision for use in the population dynamics modelling exercise recommended for NEWREP-A; and
(2) that identification of additional sites with an age-related DNA-methylation pattern is encouraged, as it would likely allow more precise estimates of age to be made in the future; and
(3) given that there is an upper limit to the degree of precision that can be achieved using this technique, the utility of epigenetic age estimation to the Committee should be further evaluated by the sub-committees concerned with regard to the degree of precision needed for the specific application of interest.

11.5 Workplan 2019-20

The details of the workplan are given in Table 15.

Table 15

Workplan on topics related to genetics.

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
3.1 DNA quality guidelines	Intersessional group (Annex Y) to review recent revisions to the DNA quality guidelines that pertain to data produced using NGS approaches.	Report and finalise updated guidelines		
4.4.2 Recommendations to avoid sample depletion	Intersessional email group to provide recommendations on genomic approaches to maximize the utility of tissue samples that are in danger of becoming depleted in the future.	Report and provide advice		
4.5 North Pacific minke whale stock structure	Perform genetic analyses detailed in Appendix 5; report results at intersessional workshop on the North Pacific minke whale IR.	Review results and provide advice		
5.1 Simulations	Intersessional email group to review software packages and evaluate utility to the Committee.	Report	Continue as needed	Report (if needed)
5.3 Terminology	Intersessional email group to continue discussions of the use of stock structure-related terms within the Committee.	Report	Continue as needed	Report (if needed)

12. CETACEAN ABUNDANCE ESTIMATES, STOCK STATUS

The Committee received new information from the Standing Working Group on Abundance Estimates, Status and International Cruises (ASI) that had been established (IWC, 2017c, p. 94) to formally review and agree on the status of the abundance estimates submitted to the Scientific Committee across all of the Committee's sub-committees and working groups. It also assists the Committee and the Secretariat in developing a biennial document reporting to the Commission on the abundance and status of whale stocks.

12.1 Summary of abundance estimates and update of IWC consolidated table

Appendix 3 of Annex Q provides detailed information about abundance estimates agreed by the Committee, including estimates received prior to and during 2017, as well as ones evaluated this year. The Secretariat maintains a consolidated table.

Broadly, cetacean abundance estimates are usually obtained in one of three ways. Line transect surveys require observers on ships or aircraft to detect animals while the observers are traveling on paths traversing the survey area. Statistical methods are used to estimate how many animals were not seen, usually by evaluating how detection deteriorates as sighting distance increases and by extrapolating to survey areas beyond visual detection distance. Mark-recapture studies require multiple attempts to 'capture' individuals that are mixing between attempts. For cetaceans, individual animals are usually identified - and hence 'captured'- on the basis of matching photographs of whale markings, or by genetic analysis of biopsy samples of live animals. Statistical methods are used to estimate how many animals were never captured, based on information about the probability of capture, which is inferred from instances when the animal was sometimes captured and sometimes not. Population model based abundance estimates use information from a variety of sources to build a mathematical model of how a population changes over time. Important data and parameters in such models include survival rates, productivity rates, and previous abundance estimates. By fitting (and possibly projecting) this model, an estimate of current abundance is achieved.

Many sophisticated abundance estimation methods are hybrids or extensions of these basic approaches.

This year, the Committee **endorses** the following:

(1) a photo-id mark-recapture estimate of 2011 abundance for Bering-Chukchi-Beaufort Seas bowhead whales;
(2) an aerial line transect estimate of 2013 abundance of East Canada / West Greenland bowhead whales;
(3) aerial line transect estimates of 2015 abundance of East Greenland and West Greenland North Atlantic humpback whales;
(4) ship-based line transect abundance estimates of North Atlantic humpback whales in Iceland/Faroe Islands in 2007 and 2015;
(5) aerial line transect abundance estimates of East Greenland (2015) and West Greenland (2007 and 2015) North Atlantic minke whales;
(6) ship-based line transect abundance estimates of North Pacific Bryde's whales for several areas and time periods;
(7) aerial line transect abundance estimates of East Greenland (2015) and West Greenland (2005, 2007 and 2015) North Atlantic fin whales; and
(8) genetic mark-recapture abundance estimates for Maui's dolphins in New Zealand for several years.

Table 16 summarises key information about the **agreed** abundance estimates. Full details are given in Annex Q (item 3 and appendix 3).

Attention: SC, S, C-A

Abundance estimates are a key parameter in determining status. The Committee:

(1) ***endorses*** the new abundance estimates *presented in Annex Q, Appendix 3 for inclusion in the IWC Table of Accepted Abundance Estimates;*
(2) ***agrees*** *that they should be incorporated into that table and uploaded to the IWC website; and*
(3) ***agrees*** *that the table should continue to be updated intersessionally by the Steering Group (Annex Y).*

12.2 Process to review abundance estimates

Abundance estimates are needed to assess the status of cetacean populations and are used extensively by the Committee, including for providing management advice. These estimates are often computed by standard, but technically advanced methods. In addition, because of the high scientific standards found within the Committee's work, it is not uncommon for the Committee to receive estimates of abundance computed using novel methods and non-standard software/code. The review of these estimates can be complex and time consuming. At last year's meeting, the Committee noted that adequate time is needed to review abundance estimates and agreed that a process to facilitate the review of these estimates be developed (IWC, 2018c). In addition, the Committee noted that reviews would benefit if minimum requirements for the presentation of abundance estimates are established.

Table 16

Abundance estimates, CVs and 95% confidence intervals for estimates agreed at the 2018 meeting.

Whale and Region	Year	Estimate	CV	95% Confidence Interval
North Pacific Bryde's whales				
Area 1W	1995	12,149	0.41	5,579-26,454
	2000	6,894	0.47	2,872-16,549
	2011	25,158	0.38	12,202-51,872
Area 1E	1995	15,695	0.42	7,079-34,801
	2000	19,200	0.56	6,929-53,204
	2011	9,315	0.33	4,957-17-505
Area 2	1995	4,340	0.45	1,876-10,039
	2000	6,083	0.61	2,030-18,229
	2014	6,491	0.36	3,254-12,950
North Atlantic common minke whales				
East Greenland	2015	2,762	0.47	1,160-6,574
West Greenland	2007	9,066	0.39	4,333-18,973
	2015	5,095	0.46	2,171-11,961
North Atlantic fin whales				
East Greenland	2015	6,440	0.26	3,901-10,632
West Greenland	2005	9,800	0.62	3,228-29,751
	2007	15,957	0.72	4,531-56,202
	2015	2,215	0.41	1,017-4,823
North Atlantic humpback whales				
East Greenland	2015	4,223	0.44	1,845-9,666
West Greenland	2015	993	0.44	434-2272
Iceland/Faroe Islands	2007	18,105	0.43	7,226-45,360
	2015	10,031	0.36	4,962-20,278
Bowhead whales				
Bering-Chukchi-Beaufort Seas	2011	27,133	0.22	17,809-41,377
East Canada / West Greenland	2013	6,446	0.26	3,722-11,200
Gray whales				
Western North Pacific	1995	74	0.05	66-81
	2015	200	0.03	187-211
Maui's dolphin				
North Island, New Zealand	2016	57	n/a	44-75

This year, the Committee developed a process to improve the review of abundance estimates, including a prioritisation of the estimates according to the timeline they need to be used by the Committee. This process is described in detail in Annex Q, item 2.1. In addition, minimum requirements to present abundance estimates for review by the Committee were established. Details are given in item 2.2 of Annex Q.

The Committee noted that validation may be needed before estimates computed using novel methods and non-standard software are used to provide management advice (Annex Q, item 2.3). The Committee also noted the need to consider how estimates of abundance from population models are reviewed before they are included in the Table of Accepted Abundance Estimates (Annex Q, item 2.4).

Attention: SC, S

*The Committee **reiterates** the importance of using high quality, fully reviewed abundance estimates for its work. To achieve this the Committee **agrees**:*

(1) to adopt the process to improve the review of abundance estimates given in Annex Q (item 2.1);
(2) the minimum requirements for the presentation of estimates for review by the Committee given in Annex Q (item 2.2);
(3) to host a pre-meeting before next year's meeting (SC68a) to develop (a) a process to validate abundance estimates computed with non-standard methods, noting the value of simulated datasets in this process; (b) a process to review estimates of abundance computed with population models is needed.

12.3 Methodological issues

12.3.1 Model-based abundance estimates (and amendments to RMP guidelines)

The Committee noted that there was a need for RMP guidelines to be modified in order to incorporate spatial modelling approaches to estimate abundance.

Attention: SC

*The Committee noted that whilst much progress has been made with respect to considering model-based estimates (IWC, 2016c), the 'Requirements and Guidelines for Conducting Surveys and Analysing Data within the Revised Management Scheme' need to be modified. The Committee **agrees** that an intersessional steering group (Annex Y) will develop instructions and select a candidate to modify the Guidelines.*

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12.3.2 Review new survey techniques/equipment

The Committee received information on the use of unmanned aircraft vehicles (UAVs) to improve estimation of abundance of river dolphins in the Amazon. Details are provided in Annex Q, item 5.

Attention: SC, G

*The Committee **looks forward** to receiving information on new survey technologies used to improve estimates of abundance of cetaceans.*

12.4 Consideration of the status of stocks

The Committee noted that further consideration on how to report status of cetacean stocks is needed.

Attention: SC

*The Committee **recognises** the need to further consider how to report status of stocks to the Commission in a consistent manner and **agrees** to address this topic at a pre-meeting to be held prior to next year's SC meeting (SC68A).*

12.5 Workplan 2019-20

The Committee **agrees** to the workplan given in Table 167

Table 17

Workplan on abundance estimates and status.

Topic	Intersessional 2018-19	SC68a	Intersessional 2019-20	SC68b
Review of Abundance Estimates	Review estimates identified at SC67B (New Zealand Blue Whales, Arabian Sea humpback whales) – Annex Y	Review intersessional progress and estimates available at SC68A	Review estimates identified at SC68A	Review intersessional progress and estimates available at SC68A
Upload the estimates accepted at the annual meeting to the IWC website and continue to update the IWC Abundance Table	Update the table with estimates accepted at SC67B (Annex Y)		Update the table with estimates accepted at SC67B	
Review and provide advice on plans for future surveys		Receive, review and provide feedback to research plans to conduct abundance estimates		Receive, review and provide feedback to research plans to conduct abundance estimates
Pre-meeting to consider: (a) validation of non-standard software and methods, (b) estimates of abundance computed from population models and (c) Status of populations	Meeting Preparation	Review of progress		
Amend the RMP Guidelines to consider abundance estimates computed with model-based methods.	Identify a candidate to update the RMP Guidelines (Annex Y)	Review an updated document of the Guidelines		
Develop simulation software to evaluate methods for abundance estimates		Review Progress		

13. BYCATCH AND ENTANGLEMENTS

13.1 Review new estimates of entanglement rates, risks and mortality (large whales)

The Committee received three papers relating to the bycatch of large whales. SC/67b/HIM03 provided information on stranded humpback whales stranded along the southeastern coast of Brazil in 2016 and 2017 including records of entanglements over the São Paulo coast. SC/67b/HIM09 focussed on ten baleen whale populations for which bycatch appears to be a component of substantial conservation problems and the authors categorised priorities for action. SC/67b/AWMP08 provided information on Bering-Chukchi-Beaufort Seas stock of bowhead whales. Discussion can be found in Annex J (item 2.1).

13.2 Reporting of entanglements and bycatch in National progress reports

Reports of large whale bycatch are summarised in Annex J (item 2.4) and the issue of partial reporting discussed. Issues related to reporting and progress reports is given under Item 3.2.

13.3 Mitigation measures for preventing large whale entanglement

Mattila, the IWC's technical advisor for reducing unintended human impacts, reported on relevant activities under the entanglement initiative. Details can be found in Annex J (item 2.5). Since last year's meeting, IWC entanglement trainings have been conducted in Sakhalin (Russia), Arica (Chile), Sortland (Norway) and Bahía Solan (Colombia). This brings the total number of trainees in this initiative to 1,130 from 27 countries. In addition, two apprentices were hosted this year, one from Chile and one from Oman. Mattila also presented the IWC's work with entanglement in two workshops at the Society for Marine Mammalogy Biennial conference (2017). The Committee thanked Mattila for his exemplary work in coordinating the Global Whale Entanglement Response Network.

13.4 Review proposal for global entanglement database

The Committee considered progress with the development of a dedicated entanglement database. This will be considered further at the June 2018 meeting of the Global Whale Entanglement Response Network (see Annex J, item 2.3).

13.5 Estimation of rates of bycatch, risks of, and mortality for small cetaceans

13.5.1 Small cetacean bycatches in Peru

The Committee received a report (SC/67b/HIM01) summarising monitoring efforts of beach-cast cetaceans in 11 locations along the Peruvian coast from 2000-2017. Full discussion can be found in Annex J (item 2.1.2) that showed clear evidence of continued high bycatch rates and some intentional takes. Burmeister's porpoises accounted for 66% of the specimens and the low proportion (25%) of dusky dolphins contrasted with 1985-1990 statistics, when dusky dolphins accounted for three quarters of all cetacean captures. This reiterated prior concerns (Van Waerebeek, 1994) about a persistent long-term trend of a significant decline in prevalence of Peruvian dusky dolphin in catch and stranding records.

The observed high mortality levels in Burmeister's porpoise are a serious concern, and action is needed to avoid the same critical situation as with the closely related vaquita. Burmeister's porpoise is already included in a preliminary list for potential Conservation Management Plan development (Genov *et al.*, 2015), and dusky dolphin could potentially also be included. The Committee reiterated recommendations from 2008 regarding bycatch monitoring programmes and mitigation efforts in these fisheries (IWC, 2009, p. 323).

Attention: C-A, CC

*The Committee **draws the attention** of the Commission to its **serious concern** over the high mortality levels from bycatches in Peru and especially those of the Burmeister's porpoise and dusky dolphin. It **stresses** that action is needed to avoid the same critical situation for Burmeister's porpoise as with the closely related vaquita. In this regard the Committee:*

*(1) **reiterates** its advice (IWC, 2009, p. 323) on bycatch monitoring and mitigation in these fisheries;*
*(2) **reiterates** that the Burmeister's porpoise is a potential candidate for a Conservation Management plan;*
*(3) **highlights** opportunities to focus on the bycatch of small cetaceans in Peru through the new IWC Bycatch Mitigation Initiative and **recommends** that they are considered as a potential pilot project; and*
*(4) **offers its assistance** to the Government of Peru; and*
*(5) **requests** that the Commission, through the Secretariat, transmits the Committee's concern and offer of assistance to the Government of Peru.*

13.5.2 Franciscana bycatch in Brazil

Considerable information was provided on the Santos Basin Beach Monitoring Project required by the Brazilian authorities for licensing oil and gas production and transport (see Annex J, item 2.1.2). This provided information *inter alia* on stranded franciscana. From October 2015 to September 2017, 1,123 carcasses were recorded stranded in the area and interactions with fishing gear was reported for over 85% of necropsied individuals with signs of human activities.

Attention: CG-A

*The Committee **draws attention** to the fact that the franciscana remains under strong pressure from human activities, especially bycatch, in Brazilian waters despite fishing net regulations established by the government. The Committee:*

*(1) **advises** that the existing regulation on gillnets, implemented in 2012, is either not being effectively enforced or is not effective in reducing bycatch; and therefore*
*(2) **recommends** the need for this to be investigated further by the Brazilian authorities.*

13.5.3 Estimating bycatch from strandings data

Estimates of common dolphin mortality in the Bay of Biscay based on strandings data (Peltier *et al.*, 2016) had been discussed at SC67a. SC/67B/HIM/05 and SC/67B/HIM/08 provided further analyses related to using stranding data to make inferences about small cetacean mortality. An intersessional group was established at SC67a to provide advice on consistent ways to estimate bycatch across both large and small cetaceans, and specifically, to review the methods applied in Peltier *et al.* (2016) focused on small cetaceans. Discussion of the report of the intersessional group and some additional related papers (SC/67b/ HIM05 and SC/67b/HIM08) can be found in Annex J (item 2.1.2).

In discussion of other ways to estimate bycatch, the Committee noted that Bartholomew *et al.* (2018) had concluded that Remote Electronic Monitoring can provide a time- and cost-effective method to monitor target catch in small-scale fisheries and can be used to overcome some of the challenges of observer coverage. This requires consideration by the Committee.

Attention: CG-A, SC, G

With respect to methods for obtaining bycatch estimates the Committee:

(1) ***agrees*** *with the recommendations of its intersessional group regarding (a) uncertainties in bycatch estimates derived from strandings; (b) the use of bycatch estimates derived from strandings; and (c) assessing whether strandings can identify gaps in observer coverage;*
(2) ***notes*** *the importance of observer programmes, including electronic monitoring, and the limitations of stranding information for determining the type of fishing gear implicated in a bycatch event, or in determining reliable bycatch estimates;*
(3) ***recognises*** *that in small scale fisheries (a) observer programmes are particularly complicated, given the small size of vessels and (b) electronic monitoring may not capture the animals falling from the net during hauling*
(4) ***advises*** *that a robust evaluation of the effectiveness of bycatch mitigation measures requires a combination of monitoring measures, including well-designed and effectively implemented observer programmes, electronic monitoring and stranding programmes;*
(5) ***advises*** *that the above advice is relevant to the situation of the franciscana in Brazil; and*
(6) ***agrees*** *that given the increased use of Remote Electronic Monitoring techniques and the rapid development of camera and associated electronic technology, these techniques should be a focus topic at SC68a.*

13.6 Scientific aspects of mitigation measures

13.6.1 The IWC Bycatch Mitigation Initiative

The Committee considered the outcomes of an assessment on the potential work areas for the new IWC Bycatch Mitigation Initiative (SC/67b/HIM12). This resulted in several recommendations for the Committee in relation to potential work areas, including:

(1) identification of priority fisheries/sites/species/populations to be considered for pilot projects based on conservation need and the establishment of bycatch baselines for relevant cetacean populations where mitigation is to be trialled;
(2) leading in communicating the need for increased research on mitigation measures/management approaches for cetaceans to the broader scientific community;
(3) annually reviewing mitigation measure tables;
(4) providing technical assistance to the coordinator and the expert panel in the development of scientific trials/monitoring programmes to evaluate mitigation measures; and
(5) collaborating with researchers identifying fishing effort using vessel monitoring and tracking systems and assessing bycatch risk, with a focus on small scale fisheries.

With respect to the identification of priorities, five criteria for the selection of pilot projects were identified:

(1) urgency of conservation situation driven by bycatch or concern over situations with little or no data on bycatch, but suspected overlap between high risk fishing gears and vulnerable cetacean species;
(2) enabling conditions necessary for success;
(3) scope for IWC to contribute (e.g. enhanced international cooperation);
(4) ability to monitor effectiveness of mitigation actions; and
(5) potential for the project to contribute to mitigation of bycatch in other areas.

A list of information sources (including SOCER) was created at the meeting to assist Tarzia, the new BMI coordinator, to identify potential projects, after which she will consult with the expert panel to apply the above criteria, including contact with any of the governments involved, to select the projects for review by the initiative's Standing Working Group which can be presented to the Commission. The Committee suggested that identified fisheries in the Republic of Congo, Peru, Ecuador, Pakistan and India appear to fulfil many of the criteria and are locations where past or present IWC work is being carried out which is relevant to bycatch.

Attention: C-R, SC, CC

The Committee discussed the strategic assessment of the Bycatch Mitigation Initiative (BMI) and the role of the Committee. The Committee:

(1) ***welcomes*** *the progress made thus far under the BMI, including the Strategic Assessment;*
(2) ***thanks*** *Tarzia for the excellent work she has carried out since her appointment as co-ordinator;*
(3) ***agrees*** *to incorporate in its workplan the five work areas listed in its report under Item 13.6.1 and also consideration of 'rapid bycatch and risk assessment' tools;*
(4) ***agrees*** *to the criteria listed in its report under Item 13.6.1 when identifying priority fisheries/sites/species/populations; and*
(5) ***recommends*** *to the Commission that the BMI continues and is supported, including the provision of ongoing support for the BMI coordinator.*

13.6.2 Collaboration with FAO
FAO held an Expert Workshop on Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations in March 2018 which had been attended by several members of the Committee. The workshop report contained a review of mitigation measures and a decision tree providing guidance on choosing a bycatch mitigation pathway. The IWC Executive Secretary and BMI Coordinator will attend the FAO Committee on Fisheries (COFI) meeting in July 2018 where the report will be reviewed.

Attention: C-R, S

The Committee ***welcomes*** *the efforts of the FAO to consider cetacean bycatch and* ***recommends*** *that the IWC Secretariat continues to collaborate with the FAO on this issue.*

13.7 New information on cetacean bycatch in the Western, Central and Northern Indian Ocean
Last year (IWC, 2018c, p. 46), the Committee had recommended that in light of the scope and scale of cetacean bycatch in the Western, Central and Northern Indian Ocean and the considerable data gaps associated with intensive and extensive gillnet fisheries, the topic be included in the work plan for this meeting and the Secretariat establish communications on the issue with the Indian Ocean Tuna Commission (IOTC). SC/67B/HIM/07 provided updated information on this topic, as discussed in Annex J (item 2.7). The IWC's Executive Secretary provided an update on engagement with the IOTC, including a recent teleconference with the IOTC Executive Secretary.

Attention: C-A, CC, SC

With respect to bycatches of cetaceans in the Indian Ocean, the Committee:

(1) ***reiterates*** *its willingness to collaborate with the IOTC on this issue; and*
(2) ***encourages*** *the Secretariat to continue to work with the IOTC Secretariat.*

13.8 Workplan 2019-20
The Committee's workplan on bycatch and entanglement is given in Table 18.

14. SHIP STRIKES

14.1 Review estimates of rates of ship strikes, risk of ship strikes and mortality
The Committee received information on a pilot study to better characterise ship strikes in Southeastern Alaska (see Annex J, item 3.1) and looks forward to further updates on this work.

14.1.1 Review progress on ship strike database
The IWC continues to develop a global database of ship strike incidents as discussed in Annex J (item 3.1.1). The primary task is ongoing review of previously reported records by two data coordinators in conjunction with a data review group (SC/67b/HIM11). It is expected that the review process for all historical records will be completed in the next biennium.

Attention: C-R, S

The Committee ***reiterates*** *the importance of the global ship strikes database to its work. It therefore:*

(1) ***welcomes*** *the work undertaken thus far;*
(2) ***recommends*** *the continuation of this work including (a) that of the co-ordinators and Data Review Group on the review of historical records and (b) the Secretariat on upload tools.*

Table 18

Workplan on bycatch and entanglement related issues.

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Bycatch Mitigation Initiative		Review aspects relevant to Committee and respond to requests for advice		Review aspects relevant to Committee and respond to requests for advice
Rates and risks		Review new estimates of entanglement rates, risks and mortality		Review new estimates of entanglement rates, risks and mortality
Mitigation		Review new information on mitigation		
Inferences from strandings	Consider new information and issues that need to be addressed at SC68a	Review new information		
Rapid risk assessment		Consideration of 'rapid risk assessment' tools and outputs		
Electronic monitoring		Consideration of remote electronic monitoring and vessel tracking		
Mitigation measures tables		Develop table of mitigation measures for small cetaceans and update table for large whales from 2017 if needed.		
Global disentanglement database	Discussion at GWERN workshop	Review Progress	Advance database development if considered feasible	Review Progress
Collaboration with FAO	Secretariat attend COFI meeting	Review FAO outputs on bycatch	Continue collaboration	Continue to review
Encouraging innovative research on mitigation	BMI through existing networks, at conferences, workshops and with students – all members of Committee with relevant expertise	Review progress		

14.2 Mitigation of ship strikes in high risk areas

The Pelagos Sanctuary in the Mediterranean is a recognised high risk area for ship strikes to fin and sperm whales. In France, the REPCET reporting system became mandatory on 1 July 2017 for French passenger, cargo vessels (SC/67b/HIM04). As discussed in Annex J (item 3.2.1), 'alerting' systems such as REPCET require a trained observer and a subsequent avoidance action of some sort by the vessel in order to be a considered as a mitigation tool.

The Committee had previously agreed that the available data supported a proposal to IMO to move the shipping lanes off the southern coast of Sri Lanka to reduce the risks of ship strikes to Northern Indian Ocean blue whales. In 2017, major shipping organisations represented at IMO also wrote to the Sri Lankan government requesting the routing change to reduce ship strike risks and improve maritime safety. So far, there has been no response from Sri Lanka.

The Hellenic Trench west of Greece is also an identified high risk area for sperm whales and in 2015 (IWC, 2016d), the Committee recommended that interested parties (including Greece, ACCOBAMS and the shipping industry) move forward with Greece in order to develop a proposal for routing measures.

The IUCN Marine Mammal Protected Areas Task Force process for identifying Important Marine Mammal Areas (IMMAs) may assist in identifying high risk areas for ship strikes. The Committee and the IWC's Ship Strike Standing Working Group have previously encouraged cooperation on this between the IUCN Task Force and the IWC.

Attention: C-A, CC, SC, G

The Committee has continued its work on identifying high risk areas for ship strikes and potential mitigation measures. In this regard the Committee:

(1) ***recommends*** *continued work to develop and evaluate mitigation measures, such as speed restrictions, that might be associated with the designation of a Particularly Sensitive Sea Area (PSSA) in the Pelagos Sanctuary area;*
(2) ***reiterates*** *its previous recommendations on the importance of evaluating the efficacy of the REPCET system for reducing the risk of ship strikes;*
(3) ***requests*** *the Commission, via the Secretariat, to remind the authorities in Sri Lanka of its previous offer of assistance from the IWC on this issue;*
(4) ***requests*** *the Commission via the Secretariat, to follow up on previous correspondence on the ship strike risks to sperm whales off Greece;*
(5) ***agrees*** *to support a workshop to evaluate how the data and process used to identify IMMAs can assist the IWC to identify areas of high risk for ship strikes; and*
(6) ***agrees*** *to continue ongoing IWC engagement with the process to identify IMMAs, including consideration of their utility to address other threats.*

14.3 Co-operation with IMO Secretariat and relevant IMO committees

The Committee has long recognised the importance of co-operation with IMO on matters related to shipping including ship strikes.

Attention: C-R, S

*The Scientific Committee **reiterates** the importance of cooperation with IMO and:*

*(1) **welcomes** the ongoing co-operation the Secretariat has maintained with IMO and its Secretariat on ship strike issues, including meetings during IMO MEPC 72; and*
*(2) **recommends** that this dialogue continue.*

14.4 Work Plan

The Committee's work plan on matters related to ship strikes is given as Table 19.

Table 19

Workplan on matters related to ship strikes

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Rates and risks		Review estimates of rates of ship strikes, risk of ship strikes and mortality		Review estimates of rates of ship strikes, risk of ship strikes and mortality
Mitigation		Review new information on mitigation		
Advice on routing measures related to ship strike risk	Provide advice as required (Annex Y)	Review advice	Provide advice as required (Annex Y)	Review advice
Follow up on previous contacts offering IWC assistance regarding high risk areas	Secretariat to contact Sri Lankan and Greek authorities	Review progress on identified high risk areas in IWC Ship Strike Strategic Plan		
Continued co-operation with IMO	Secretariat to maintain dialogue with IMO Secretariat. Attend relevant IMO meetings.	Review cooperation		
Ship strike database	Continue ongoing data entry into Ship Strike Database and validation of records	Review progress against specific deliverables and time line	Continue ongoing data entry into Ship Strike Database and validation of records	Review progress against specific deliverables and time line
Provision of AIS data	Secretariat to develop MOU with Marine Traffic for provision of data	Consider best way to handle requests for data through the MOU		
Use of IMMAs to identify high risk areas for ship strikes	Hold workshop to evaluate how the data and process used to identify IMMAs can assist the IWC to identify areas of high risk for ship strikes.	Review workshop report		

15. ENVIRONMENTAL CONCERNS

The Commission and the Scientific Committee have increasingly taken an interest in the environmental threats to cetaceans. In 1993, the Commission adopted a resolution on research on the environment and whale stocks and on the preservation of the marine environment, IWC Resolution 1993-12 (e.g. IWC, 1996; 1997; 1998; 1999; 2010). As a result, the Committee formalised its work by establishing a Standing Working Group that has met every year subsequently. This year, it has been established as a sub-committee and its report can be found in Annex K.

15.1 Pollution 2020

15.1.1 Review on intersessional progress on the Pollution 2020 initiative

The individual based model to investigate the effects of pollutants on cetacean populations (SPOC) has been finalised. A peer-reviewed paper detailing the model and applying it to a number of case studies has been published in *Environmental Pollution* (Hall *et al.*, 2018) and the model's R code is available through the repository associated with the paper. The web-based, user-friendly version is now available through the Sea Mammal Research Unit, University of St Andrews server (*http://www.smru.st-andrews.ac.uk/reports/*) and a link will be added to the IWC webpages on the Chemical Pollution page. There are new data on the combined effects of persistent organic pollutants (POPs) on the immune system of killer whales (Desforges *et al.*, 2017) and this will be integrated into the model in the next year.

As noted in Annex K (item 2.1), the contaminant mapping tool will be completed next year, with the inclusion of the data on the concentrations of mercury in cetacean tissues by time and region. This online resource that will be made available through the IWC website and will be updated with new information identified in the SOCER annual reviews.

Research to estimate how long it is likely to take for POPs in the blubber of cetaceans to observably decline, following a reduction in environmental levels, will be completed next year.

Attention: SC

*The Committee **agrees** that the Pollution 2020 initiative should be completed and presented at SC/68a. It also **encourages** a paper to be presented at SC/68a summarising the potential mitigation measures for reducing exposure of cetaceans to polychlorinated biphenyls (PCBs) in particular and persistent organic pollutants (POPs) in general.*

15.1.2 Report on mercury in cetaceans

The impact of mercury exposure is still an issue of concern for cetaceans. SC/67b/E08, reviewed mercury in cetaceans, in response to Commission Resolution 2016-4, 'Resolution on Minamata Convention'. The paper (see discussion in Annex K, item 2.2) highlights continued global exposure and potential effect of mercury on cetaceans. Although cetaceans have a unique detoxifying mechanism which may protect them from the health effects of organic mercury, the resulting mercuric-selenide complexes may cause adverse effects in individuals experiencing other physiological and metabolic challenges. Research into identifying the toxic thresholds for mercury in cetaceans is still required.

The Committee also received several papers presenting information on mercury in cetaceans including river dolphins (SC/67b/E06), humpback whales (SC/67b/E09) and gray whales off Chukotka (SC/67b/E03). The Committee highlighted the need for standardisation in reporting units. It also discussed preferred tissues for mercury analyses. Discussion of these papers can be found in Annex K (item 2.2)

Attention: SC, CG-R

The Committee continued to work on mercury in cetaceans in response to Resolution 2016-4. It therefore:

*(1) **encourages** the continued provision of information on mercury and cetaceans;*
*(2) **encourages** researchers presenting such information to report concentrations on both wet and dry weight bases; and*
*(3) **recommends** that Contracting Governments support the continued monitoring of mercury in cetaceans, as this is required in order to assess the medium- and long-term impact of the Minamata Convention.*

15.1.3 Impact of heavy fuel oils on cetaceans

There is a paucity of information on the impacts of heavy fuel oils on cetacean health (Annex K, item 2.3). However, some new information comparing the occurrence of cancer and elevated PAH levels in St Lawrence Estuary white whales with similar cancers in the local human population, was highlighted. In addition, behavioural changes in white whales in the White Sea following exposure to oil have been observed.

Attention: CG-A, SC, G

The Committee:

*(a) **reiterates** the need to estimate the risk and impact of oil spills, particularly to cetaceans in the Arctic;*
*(b) **notes** that heavy fuel oil could pose an environmental threat in many regions due to its high viscosity and chemical composition;*
*(c) **notes** that heavy fuel oil poses a special threat in the Arctic due to difficulties in recovery and potential impacts of some recovery measures (e.g. dispersant use and in situ burning); and*
*(d) **encourages** the collection of baseline data for cetaceans, including standardisation of measures.*

15.1.4 Other pollution issues

Understanding the effects of oil dispersants and dispersed oil on cetaceans is a gap in our current knowledge. To address this need, the Coastal Response Research Center (CRRC) in the USA has co-ordinated a discussion among scientists with dispersant research expertise, as well as those with Arctic expertise, to determine the state-of-science regarding dispersants or dispersed oil, as it applies to Arctic waters. The Committee looks forward to the publication of the final report.

Attention: CG-A, SC, G

*The Committee **draws attention to** the lack of data the effects of oil dispersants and dispersed oil on cetaceans. It therefore:*

*(1) **encourages** Contracting Governments to support research on the effects of dispersants or dispersed oil to the Arctic and other ecosystems; and*
*(2) **requests** that the results of such research be brought forward to future meetings of the Scientific Committee.*

15.2 Cumulative effects

The Committee welcomed the summary of the Cumulative Effects Workshop (see Annex K, item 3) and looked forward to receiving the report. Overall, the Workshop found that there is considerable uncertainty in addressing this topic and thus in developing assessments and management advice.

The Scientific Committee also received a report on a workshop entitled 'Towards understanding the overlap of selected threats and Important Marine Mammal Areas (IMMAs) across the Mediterranean Sea', which was held jointly by the IUCN Joint Species Survival Commission/World Commission on Protected Areas (SSC/WCPA) Marine Mammal Protected Areas Task Force (the 'Task Force') and by the Agreement on Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS). The workshop provided the opportunity to support the ongoing effort to map specific threats to cetaceans in the ACCOBAMS area by overlaying the Mediterranean IMMAs with the available area-explicit information on shipping and seismic surveys, thereby giving preliminary indications of new Cetacean Critical Habitats in the ACCOBAMS area and facilitating the implementation of conservation actions at the regional level.

Attention: SC, G

*The Committee **recognises** the importance of understanding cumulative effects of threats on populations of cetaceans, as well as its complexity. It therefore:*

*(1) **concurs** with the Cumulative Effects Workshop recommendations (see Annex K, item 3) to improve our knowledge and enable quantitative assessments;*
*(2) **highlights** the recommendation that consideration needs to be given to 'developing a widely applicable approach for providing precautionary advice for populations in which cumulative effects are of concern';*
*(3) **agrees** to establish cumulative effects as a standing item on its agenda;*
*(4) **notes** the work on Important Marine Mammal Areas (IMMAs) and **encourages** additional efforts to identify the relevant threats in these, in order assist with the management of cumulative effects;*
*(5) **endorses** the results of the recent IUCN/ACCOBAMS workshop entitled 'Towards understanding the overlap of selected threats and Important Marine Mammal Areas (IMMAs) across the Mediterranean Sea';*
*(6) **encourages** that such an effort – aimed at overlaying different sources of threat and pressure on existing Important Marine Mammal Areas (IMMAs) – be continued and carried out in more detail in the other marine regions where IMMAs have already been identified; and*
*(7) **offers** its assistance in such assessments.*

15.3 Strandings and mortality events

15.3.1 Update on the IWC Strandings Initiative

The IWC strandings initiative was agreed by the Commission at its 2016 meeting (IWC, 2017d) and details can be found in Annex K (item 4.1). It noted that the rescue and welfare aspects of live strandings will be addressed by the Strandings Initiative but that this aspect is not within the purview of the Committee.

Attention: C-R, S, SC

*The Committee **reiterates** the importance of the IWC Strandings Initiative. It therefore:*

*(1) **welcomes** the excellent progress that has been made in the Strandings Initiative and the appointment of Sandro Mazzariol (Italy) as the Chair of the Strandings Expert Panel and Karen Stockin (New Zealand) as the Stranding Coordinator;*
*(2) **recommends** that the Commission (a) endorses the Strandings Initiative governance structure in Annex K (appendix 2) and (b) endorses the continuation of the Strandings Coordinator position for another two years (until IWC68) subject to available funding and requests the Secretariat make the necessary arrangements;*
*(3) **recommends** that the Strandings Initiative Steering Committee and Expert Panel, with the support of the Secretariat, should explore the best ways to gather information on strandings events and what basic data about these events should be recorded, focussing on what is useful for the Committee and the Commission;*
*(4) **agrees** that a phased approach to this, starting with an initial pilot project, will assist in this endeavour; and*
*(5) **agrees** that criteria for allocating funds for emergency responses should be developed by the Steering Committee and the Expert Panel and should be presented to the Committee at SC/68a.*

15.3.2 New information on unusual mortality events

Cetacean morbillivirus continues to be a major disease issue for cetaceans and a cause of unusual mortality events in dolphins in and around the Atlantic. Focus this year was on an outbreak of cetacean morbillivirus in the South Atlantic Ocean (SC/67b/E14) that is discussed in Annex K (item 4.2).

Attention: CG-R, SC

*The Committee **commends** the impressive rapid and comprehensive response to the cetacean morbillivirus outbreak in Brazilian Guiana dolphins. It therefore:*

*(1) **encourages** further work on the longer-term impact of the outbreak and the investigation of the occurrence and impact of this disease in cetaceans across different geographical areas;*
*(2) **draws attention to** the large number of animals that died during the outbreak (particularly mature females) and the historical high levels of human impacts affecting Guiana dolphins in Rio de Janeiro state, such as bycatch, chemical and noise pollution;*
*(3) **recommends** that immediate actions should be taken to protect affected populations in order to increase the chances of population recoveries;*
*(4) **draws attention to** the increase in Guiana dolphin deaths reported in Sao Paulo and Espirito Santo states in the weeks following the onset of the cetacean morbillivirus outbreak in Rio de Janeiro; and*
*(5) **encourages** the monitoring of the virus presence in neighbouring coastal dolphin populations, particularly species and populations in which immunosuppressive conditions or cumulative threats are identified.*

15.4 Noise

The Committee welcomed an update on international efforts addressing anthropogenic noise and their impacts on cetaceans, particularly regarding the appropriate assessment and protection of acoustic habitat quality as discussed in Annex K (item 5), and commended IWC engagement with organisations such as IMO and the UN.

Guidelines developed by the Convention on Migratory Species (CMS) Secretariat, also on behalf of the ASCOBANS and ACCOBAMS Secretariats, for Environmental Impact Assessments for noise-generating offshore industries were presented to the Scientific Committee. These guidelines had been endorsed through CMS Resolution 12.14 on Adverse Impacts of Anthropogenic Noise on Cetaceans and Other Migratory Species, and provide a pathway to implementing the Best Available Techniques (BAT) and Best Environmental Practice (BEP).

The Committee also considered the results of a study utilising modelling approaches to evaluate relative levels of communication masking for four baleen whale species in the Stellwagen Bank National Marine Sanctuary, in Massachusetts Bay, USA Cholewiak *et al.* (In press).

Attention: SC, G, CG-A

Recalling its previous recommendations on noise and the importance of addressing its impacts on cetaceans, the Committee:

*(1) **welcomes** and **draws attention** to the Convention on Migratory Species Family Guidelines on Environmental Impact Assessments for Marine Noise-Generating Activities (https://www.cms.int/en/guidelines/cms-family-guidelines-EIAs-marine-noise), noting that these guidelines will help improve global standards for environmental impact assessments;*
*(2) **recommends** that levels of anthropogenic noise and its effects on marine species be explicitly considered in the management of marine protected areas;*
*(3) **welcomes** the information received on using marine soundscape planning strategies to reduce interference between hydroacoustic instrumentation (e.g. echosounders and airgun arrays) and marine mammals, and **encourages** work to further develop this approach;*
*(4) **recognises** the commonalities identified among the concurrent efforts of multiple international bodies to develop national guidance on noise strategies, and **encourages** continuing efforts to identify synergies and develop priorities for actions to reduce exposure of cetaceans to anthropogenic noise;*
*(5) **welcomes** the work on modelling cetacean communication space, and **encourages** scientists engaged in the development of modelling techniques that address multiple anthropogenic impacts, such as noise and entanglement in fishing gear to bring these forward to the Scientific Committee;*
*(6) **agrees** that a pre-meeting on noise be organised for SC/68b and that an intersessional steering group be convened (Annex Y) to develop the agenda for that pre-meeting.*

15.5 State of the Cetacean Environment Report – SOCER

The Scientific Committee **thanks** the editors of the State of the Cetacean Environment Report (SOCER) for their work and commended them on compiling this information on the Mediterranean and Black Seas. Next year's region will be the Atlantic Ocean. The Scientific Committee would welcome input from the members for information on this region. A 5-year global compendium is being produced in cooperation with the Secretariat that will receive a dedicated webpage on the IWC website in time for presentation to the 2018 Commission meeting.

15.6 Update on other standing topics

15.6.1 Marine debris[litter]

The Committee received and discussed a number of papers relating to several aspects of marine debris as discussed under Annex K (item 7.1). Exposure to marine debris and microplastics in cetaceans is now widespread and common. However the impacts on cetacean health and populations is not fully understood.

Attention: C-A, SC

*The Committee **draws attention** to the fact that marine debris remains a threat, and that in particular, exposure to plastics (including microplastics) is a rapidly emerging area of concern.* It therefore:

(1) ***agrees** that an intersessional workshop on Marine Debris should take place, preferably to coincide with the World Conference on the Biology of Marine Mammals in Barcelona in December 2019.*

15.6.2 Climate change

Climate change was highlighted at SC/67a as being an overarching issue that is important to various topics, and that where relevant its impact should be discussed in conjunction with that topic (see discussion in Annex K, item 7.2). Notwithstanding that, the Committee may want to initiate a specific activity related to climate change in future (see intersessional correspondence group in Annex Y).

Attention: C-A, CG-A, SC

*The Committee **draws attention** to the fact that climate change remains a threat that interacts with other threats and stressors impacting cetacean populations.*

15.6.3 Cetacean diseases of concern

Monitoring health and disease agents in large whales in the Arctic is continuing to provide important information on changing patterns in prevalence, environmental status, and potential impacts. In addition, morbillivirus and Brucella continue to be important pathogens causing disease and increased mortality in cetaceans in the Atlantic.

Remote methods for assessing health and condition using visual and aerial photography (e.g. SC/67b/CMP13), is a major rapidly developing field, due to the widespread availability and reduced cost of unmanned aerial vehicles (UAVs). Standardisation efforts (e.g. see Annex S) for measuring body condition using UAVs for photogrammetry, and for collecting blow samples, should progress to ensure this useful tool can provide comparable data across studies, taking into account the differences between the various platforms available. Cross-validation with current methods for assessing body condition from visual health assessments is essential.

Attention: SC

*The Committee **agrees** to hold a focussed session next year (SC/68a) on our current understanding of the pathology and epidemiology of morbillivirus and* Brucella *and the potential for identifying and understanding the cumulative effects of exposure to other immunosuppressive stressors in cetaceans.*

15.7 Progress on previous recommendations

15.7.1 Pollution

The SC/67a recommendations were to (a) make the effect of contaminants on cetacean populations (SPOC) model available to the public; (b) review mercury in cetaceans; and (c) include new data into the contaminant mapping tool. These have all been completed.

15.7.2 Cumulative effects

As recommended last year, a workshop on understanding the cumulative effects of multiple stressors was held as a pre-meeting to SC/67b.

15.7.3 Diseases of concern

The Committee noted that the content on the Cetacean Diseases of Concern (CDoC) website will now be utilised and merged with the Strandings Initiative for the development of their training and outreach materials.

Whilst the recommended quarterly CDoC updates remain of interest to the Committee, a means of progressing this on a voluntary basis has not yet been identified although efforts to find such assistance are ongoing.

15.7.4 Strandings

The Strandings Initiative has progressed as recommended at SC/67a and a full progress report can be found in Annex K, Appendix 2.

15.7.5 Noise

In response to a previous recommendation, that Committee has received the recently developed seismic survey guidelines by the New Zealand government, a link to the technical working group reports created during the NZ seismic guidelines review is now available (*http://www.doc.govt.nz/our-work/seismic-surveys-code-of-conduct/work-of-the-technical-working-groups/*). However, these guidelines have not yet been discussed by the Committee.

As recommended and noted earlier under Item 15.5, the intersessional group assisted in the development of a summary of the IWC recommendations relevant to shipping noise for presentation to the International Maritime Organization's Marine Environment Protection Committee in 2018.

15.7.6 Thanks

The Committee would like to thank Teri Rowles for her exceptional support and hard work as Chair of the sub-committee on environmental concerns over recent years. Her extensive knowledge, expertise and guidance has been most appreciated and will be missed.

15.8 Workplan 2019-20

The Committee's workplan on environmental concerns is given as Table 20.

Table 20

Work plan for matters related to environmental concerns (for more details see Annex K, Appendix 4).

Item	SC68a	SC68b
Pollution 2020 (including oil spills)	If new information	Primary topic (including oil spills and mercury), summary report to Commission
Cetacean diseases of concern (incl. HAB toxins)	Primary topic	Primary topic
Strandings	If new information	Primary topic
Noise		Noise focus session
Marine litter	Pre-meeting on litter and plastics focus session	If new information
Cumulative impacts	If new information	If new information
Emerging issues	If new information	If new information
SOCER	Receive report	Receive report
Climate change	Over-arching topic	Over-arching topic

16. ECOSYSTEM MODELLING

The report of the Working Group on Ecosystem Modelling is given as Annex L. This group was first convened in 2007 (IWC, 2008b). It is tasked with informing the Committee on relevant aspects of the nature and extent of the ecological relationships between whales and the ecosystems in which they live.

Each year, that Working Group reviews new work on a variety of issues falling under three areas:

(1) reviewing ecosystem modelling efforts undertaken outside the IWC;
(2) exploring how ecosystem models can contribute to developing scenarios for simulation testing of the RMP; and
(3) reviewing other issues relevant to ecosystem modelling within the Committee.

16.1 Cooperation with CCAMLR on multi-species modelling

The Committee has been considering plans for joint workshops with CCAMLR on ecosystem modelling for some time (e.g. see IWC, 2017c, p.56), although this has not yet happened, the Committee remains interested.

Attention: SC

*The Committee **reiterates** its interest in holding joint workshops with CCAMLR. It **agrees:***

(1) that a two-year delay in the occurrence of the workshop will provide the opportunity to pursue and complete the relevant work with input from CCAMLR as needed; and
(2) that collaboration between SC-IWC/SC CCAMLR should be on going, and that the revised plan for the workshops (IWC, 2018e) be implemented.

16.2 Applications of species distribution models (SDMs) and ensemble averaging

The Committee had agreed in 2015 to review the application of species distribution modelling (SDM) and associated techniques as they pertain to the goals of the Committee and to develop good practice guidelines and recommendations. While the review has occurred (IWC, 2016b), there has been no significant progress in the intersessional correspondence group set up to develop the guidelines.

Attention: SC

*The Committee **reiterates** the importance of developing good practice guidelines and recommendations for species distribution modelling and **agrees** that this should be pursued by an intersessional correspondence group (Annex Y) with a view to reviewing and adopting guidelines within the next biennium.*

16.3 MODELLING OF COMPETITION AMONG WHALES

16.3.1 Individual-based energetic models
Enhancements to an individual-based energetics model (IBEM) were presented to the Committee (SC/67b/EM07). These included the explicit modelling of feeding on migration, individual dives and searching for prey schools. Results showed that carrying capacity and productivity were sensitive to the level of food available during migration, making it important that ecosystem models to cover the entire migratory range of the species. This is an important contribution to the determination of species' function response, which can play a pivotal role in ecosystem modelling. This approach is also discussed under Item 5.1.

16.3.2 Modelling of relationship between whales and prey
The Committee reviewed three papers relevant to modelling of the relationships between whales and prey, SC/67b/EM04, SC/67b/EM06 and de la Mare *et al.* (*in press*). The discussion of these can be found in Annex L (item 3.2).

16.3.3 Modelling of competition among baleen whales
The Committee noted that multi-species individual based energetic models (IBEM) such as those described under Items 16.3.1 and 16.3.2 could be used to model direct and indirect competition of different whale species in the same environment, and that relevant modelling work was nearing completion.

16.3.4 Stable isotope analyses
The Committee received preliminary results of the analysis of stable carbon (δ13C) and nitrogen isotope ratios (δ15N)) on samples from the edge of baleen plates in Antarctic minke whales (SC/67b/SP09). The details can be found in Annex L (item 3.5).

16.4 Standing topics

16.4.1 Effects of long-term environmental variability on whale populations
How long-term environmental variability might affect stock assessments is of particular interest to the Committee. Given the need for a literature review on the subject to facilitate discussions, an intersessional correspondence group (Annex Y) has been established.

16.4.2 Update on body condition analyses for the Antarctic minke whales
For several years, the Committee has been discussing whether there has been a statistically significant (5% level) decline in the blubber thickness and fat weight of Antarctic minke whales over the course of the JARPA surveys. In 2014, the Committee had agreed that there had been such a decline (IWC, 2015b). Since then, scientists from Australia, Japan and Norway have presented a series of models both supporting and challenging this conclusion. There has been collaboration over this period and significant development in the types of models used. In addition, there have been in-depth discussions regarding the proper handling of data, the explanatory variables to be included in the analysis and the appropriateness of various statistical methods.

New analyses were presented this year and detailed discussions can be found in Annex L, item 2. This year the debate focused on three points; (1) the use of a new variable of primary interest (the 'accumulated blubber thickness in each feeding season); (2) the use of FIC and (3) the appropriate handling of the data.

Attention: SC, G

*The Committee has been discussing whether there has been a statistically significant (5% level) decline in the blubber thickness and fat weight of Antarctic minke whales over the course of the JARPA surveys for several years. In conclusion, the Committee **agrees**:*

(1) that, for the data set considered as a whole, all approaches result in point estimates reflecting a decline when fit to a linear trend in time;
(2) however, the extent of the decline estimated differs amongst the methods, and is not statistically significant at the 5% level for all approaches;
(3) for some approaches, when the data are disaggregated by gender and/or area, some point estimates of trend are not negative;
(4) there are some indications of temporal variation that is more complex than linear.

In addition, the Committee:

*(1) **encourages** the authors to publish the results of their study in peer-reviewed journals; and*
*(2) **agrees** that this matter will not be considered during the forthcoming biennium.*

In discussion of the above, Norwegian scientists stated that since an error in parts of the Australian scientists' calculations has recently been acknowledged by them, and parts of the Australian scientists' conclusion and appendix had recently been withdrawn, the overall position regarding the blubber thickness and fat weight analyses now became as follows. There are no new analyses from the Australian scientists on the five response variables which have been considered and discussed in the Committee from 2011 to 2017. The results presented this year by the Norwegian scientists (SC/67b/EM02), which took into account some of the queries from the Australian scientists from last year, confirmed results presented by the Norwegian scientists earlier. Thus, the conclusions by the Committee in 2014 and 2017 on these variables remain valid. For this meeting the Australian scientists had presented analyses related to a new difficult dependent variable 'increase in blubber thickness during summer feeding in Antarctic waters' estimated from the blubber thickness at position BT11. The conclusion above about variables with a non-significant decline now pertains to the new variables only (points (2) and (3) above). The Norwegian scientists' position is that the conclusion drawn above was heavily influenced by the results of the calculations subsequently withdrawn, so that parts of those conclusion are no longer valid.

In response, the Australian scientists stated that results of some calculations carried out earlier were withdrawn because of a previously unidentified problem with a standard statistical package failing to converge on a solution without giving an error message. Subsequent collaborative checking with the Norwegian scientists led to the discovery of this problem. Withdrawing this calculation (which the Australian scientists had carried out to illustrate a property of the Norwegian scientists' methods) had no effect on the main results which the Australian scientists had presented in SC/67b/EM03. Nor did this retraction affect the results of analyses the Australian scientists had presented in 2017 showing non-significant trends in fat weight and blubber thickness (De La Mare *et al.*, 2017a; 2017b). The Australian scientists held the view that the assertion by the Norwegian scientists that "There are no new analyses from the Australian scientists on the five response variables which have been considered and discussed in the SC from 2011 to 2017" was not correct; the Australian scientists had provided full results of fitting models to BT11 in SC/67b/EM03. The main results in SC/67b/EM03 were based on differences between early- and late-season predictions from models with BT11 as the dependent variable. This difference was a simple measure of feeding in Antarctica. The earlier conclusion should not be materially affected by withdrawing the Australian scientists' compromised demonstration in relation to the Norwegian scientists' methods.

16.4.3 Review the information on krill distribution and abundance by NEWREP-A

The Committee received the results of the krill and oceanographic surveys during the third NEWREP-A survey in Area V-E and VI-W (SC/67b/EM05). Discussion of this information can be found in Annex L (item 6.1).

16.4.4 Ecosystem functioning

Resolution 2016-3 tasked the Committee with investigating the contribution of cetaceans to ecosystem functions. Last year, the Committee noted that its focus would be on scientific aspects of the issue and it established an intersessional correspondence group to progress this work. Progress made by that group, including development of a final terms of reference, can be found in Annex L, item 6.2. The Committee notes that the Conservation Committee will focus on the conservation and social science aspects of this issue.

It was noted that there is broad interest in understanding the role of cetaceans in ecosystem functions, and that the Committee's expertise relates to the scientific aspects of the issue. Given the broad international interest, it is suggested that the Committee work in collaboration with interested parties (e.g. CMS, CCAMLR, SCAR and SCOR) to share information and avoid the duplication of work.

C-A, CC, SC

Commission Resolution 2016-3 tasked the Committee with investigating the contribution of cetaceans to ecosystem functions. The Committee notes that the Conservation Committee will focus on the conservation and social science aspects of this issue. In responding to the Resolution 2016-3, the Committee ***advises*** *the Commission that with respect to the scientific aspects on the contribution of cetaceans to ecosystem functioning:*

(1) it is unlikely that the ultimate goal of reliably determining the contribution of cetaceans to ecosystem functioning could be achieved in under a decade, given the complexity of the issue and the data gaps; and
(2) a more immediate and achievable goal is the carrying out of a gap analysis to identify knowledge gaps and to develop a plan to address them.

To further this work, the Committee ***agrees****:*

(1) to hold a workshop to (a) define short- and medium-term objectives to be addressed and (b) to identify what further research is required in order to begin initial modelling of the contribution of cetaceans to ecosystem function; and
(2) that the Secretariat in conjunction with the Steering Group (Annex Y) should contact CMS to determine their interest in participating in such a workshop.

16.6 Workplan 2019-20

The Committee's work plan on ecosystem modelling is provided in Table 21.

Japan referred to its statement on the adoption of the Agenda (Annex Z) and considered that several of the items for the proposed workshop (Item 16.4.4 and Item (7) in Table 1) are outside the competence of IWC. Therefore, it cannot support the proposed workshop or associated funding from the Committee's budget.

Table 21

Summary of the two-year work plan on matters related to ecosystem modelling

Item	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting (SC/68b)
(1) Ecosystem modelling in the Antarctic Ocean	Continue further analyses.	Review results of further analyses	Continue further analyses.	Review results of further analyses
(2) Application of species distribution models (SDMs)	Intersessional group activity (Annex Y)	Review progress		
(3) Effect of long-term environmental variability on whale populations	Continue further analyses. Intersessional group activity (Annex Y)	Review results of further analyses. Review progress	Continue further analyses	Review results of further analyses
(4) Further investigation of individual-based energetic models	Continue further analyses	Review results of further analyses	Continue further analyses	Review results of further analyses
(5) Modelling of competition among whales	Continue further analyses	Review results of further analyses	Continue further analyses	Review results of further analyses
(6) Update of any exercises on krill distribution and abundance	Conduct NEWREP-A krill survey and an international cooperative krill survey. Conduct simulation analyses to resolve issues on survey design.	Review results of survey and analyses.	Conduct NEWREP-A krill survey. Conduct analysis of data taken by the international survey.	Review results of survey and analyses.
(7) Cetaceans & Ecosystem Functioning: a gap analysis workshop or pre-meeting	Review relevant scientific studies before the workshop in addition to preparation of workshop (Annex Y).	Review outcomes of workshop and develop clear work plans with priorities.	Continue analyses	Review results of analyses.

17. SMALL CETACEANS

The report of the Committee on Small Cetaceans is given as Annex M.

17.1 Overview of taxonomy, distribution and abundance for *Inia* and *Sotalia*

In this assessment, two species and two sub species of dolphins were considered, some of which have several common names. In addition, a new species has been proposed but has not yet been recognised (Table 22).

Table 22

Summary of names used in the description of *Inia* and *Sotalia*

Scientific name	Common Name
Inia geoffrensis	boto, Amazon River dolphin
I. g. boliviensis	Bolivian bufeo
I. g. geoffrensis	Common boto
I. araguaiensis	Araguaian boto
(proposed species)	(from the Tocantins and Araguaia basins)
Sotalia fluviatilis	tucuxi, delphín gris, bufeo negro
Sotalia guianensis	Guiana Dolphin

The river and estuarine dolphins of South America are subject to various threats from habitat degradation, competition with fisheries, bycatch and direct exploitation. A major threat to river dolphins in South America is population fragmentation, altered habitat productivity and regulation of natural river flow as a result of dam construction. The cumulative impacts from this type of infrastructure at the macrobasin scale exacerbate the threats to river dolphins and their habitat in the Amazon and Orinoco basins. It was estimated that more than 50% of the range of Araguaian *Inia* is affected by damming.

Two genera were discussed in depth, *Inia* and *Sotalia*, from the vast and convoluted systems within the Amazon, Orinoco, Tocantins and Araguaia River basins. In the case of *Sotalia*, two species are recognised: *Sotalia guianensis* (marine) and *Sotalia fluviatilis*, (freshwater) in the Amazon basin. *S. guianensis* in the Orinoco basin likely represents an independent population unit as it is isolated from other coastal populations. Two intersessional workshops have been proposed that aim to elucidate the status of *S. guianensis* and it is that divisions within this genus will be clearer on the completion of this work in 2020. The taxonomoy of *Inia* has a complex history and at this time, one species and two sub species are

recognised: *Inia geoffrensis*, the Amazon river dolphin, *I. g. boliviensis*, the Bolivian bufeo, and *I. g. geoffrensis*, the common boto. There is a third putative subspecies, *I. g. humboldtiana*, in the Orinoco basin of Venezuela and Colombia. The information currently available suggests that *I. g. boliviensis* should be elevated to species level and that *I. g. humboldtiana* should be recognised. Another new species, *I. araguaiensis*, has been proposed for the dolphins that inhabit the Tocantins and Araguaia basins of central Brazil as this area is geologically and hydrologically separate from the Amazon basin.

Attention: SC, G

Given the incomplete resolution of Inia *taxonomy, the importance of clarifying and solidifying recognition (or elevation to species) of the* Inia *subspecies found in different river basins, the possibility that in such complex habitats localised specialisation is likely, and the need to focus attention on the conservation of demographically independent populations, the Committee* ***encourages*** *support for efforts to resolve* Inia *spp. taxonomy in light of the significant and diverse threats affecting the populations inhabiting the Amazon-Orinoco-Tocantins/Araguaia drainages.*

17.1.1 Inia

For *Inia*, there are estimates of abundance for some rivers, however, there is little information on population trends. It was suggested that new technologies, such as Unmanned Aerial Vehicles (UAV), may help to better refine population survey techniques. From telemetry studies and two long term studies some information on population parameters is available. In particular, the Committee commends an ongoing telemetry study as it begins to address some of the most important scientific questions concerning *Inia* ecology, habitat use, behaviour and, particularly movements.

In addition, and central to IUCN assessments, a generation time for *Inia* has been calculated as 24.8 years from a long-term mark and recapture study. Given the estimated rate of population decline, this equates to a loss of 82% per generation and in excess of 99% over three generations. Such values are well above the threshold for a Red List assessment of a species as Critically Endangered. Concern was also expressed at the high rate of mortality of <1 year calves in one study site, where examined carcasses show evidence of both deliberate killing and net entanglement.

The information presented on population parameters were based on direct observations in a very small geographic area of the Amazon and therefore, a very small proportion of the total range of *I. geoffrensis.* As such, extrapolation to the whole region would be unwarranted, nonetheless these results and their implications for population decline are alarming.

Attention: CG-A, G

The Committee ***draws attention*** *to declines in Inia numbers documented in two study areas and the lack of abundance surveys in most parts of its range. The Committee therefore* ***encourages*** *the collection of data, calculation of abundance estimates and undertaking of analyses to estimate population trends for* Inia *throughout its range, for use in assessments of the status of the species, subspecies, and regionally isolated populations.*

17.1.2 Sotalia

Sotalia fluviatilis, known as tucuxi (Brazil) delphín gris (Colombia) or bufeo negro (Peru and Ecuador) is restricted to the Amazon basin in Ecuador, Peru, Colombia and Brazil and has a more limited distribution than *Inia*. *Sotalia guianensis*, the Guiana dolphin, occurs mainly in nearshore and estuarine waters of the Atlantic from southern Brazil, along the coast of Central America, to Nicaragua and possibly Honduras. Small populations in Lake Maracaibo and in the lower reaches of the Orinoco River, Venezuela, were highlighted as being heavily impacted.

In the Mamirauá Reserve, Brazil, the population of *S. fluviatis*, has shown a precipitous decline in abundance over a 22-year study period. Using the average observed decline of 7.4% per year, and, from literature, a generation time estimate of 15.6 years, the Mamirauá population trend equates to a 97% reduction over 3 generations, qualifying this population as Critically Endangered under IUCN Red List criteria. Unlike *Inia*, which is heavily exploited for use as bait in the piractaninga fishery, the primary driver of the decline in Sotalia in this region is gillnet entanglement.

17.1.3 Threats shared by dolphins in the Amazon and Orinoco River systems and Lake Maracaibo

Throughout the range of both genera, illegal hunting was highlighted as a transnational problem, making it difficult to create and enforce effective conservation measures. This issue is severe for *Inia* throughout its range and, for *Sotalia* in the Orinoco River and particularly in Lake Maracaibo, Venezuela.

Attention: C-A, G, CC

The Committee ***draws attention to*** *the serious situation reported for Lake Maracaibo in Venezuela, where both directed takes and oil pollution are thought to be having serious impacts on populations of* S. guianensis. *The Committee* therefore ***recommends*** *that NGOs and researchers focus on documenting the threats to* Sotalia *and work with local communities to mitigate the impacts on these dolphin populations.*

In addition to direct exploitation, there are numerous other threats to both species throughout their habitat in South America: the recent increase in deforestation effects their prey species, as there is no deposition of seeds and fruits into the rivers to support productivity and sustain fish stocks; hydropower developments and channel dredging affects flows regimes, the connectivity of rivers, the migrations of fish and can fragment dolphin populations, as has already occurred in the Tocantins River basin; heavy metals, such as mercury, have been measured in high concentrations in dolphin tissues; negative interactions with fisheries, in addition to directed takes for use as bait and food, also include bycatch, deliberate poisoning and 'control' killing.

Attention: CG-A, G, CC

*The Committee **draws attention to** the multiple threats associated with development, habitat degradation and fragmentation, and pollutants facing river dolphins in the Amazon, Orinoco and Tocantins basins. It therefore:*

*(1) **advises** the Brazilian, Bolivian and Peruvian Governments, as they carry out their reviews of proposed construction of new dams for hydroelectric energy production, to explicitly consider the potential impacts on river dolphins (e.g. isolation, loss of genetic diversity, habitat degradation;*
*(2) **discourages** water pumping in the Araguaia-Tocantins river basin for agricultural use as such a practice causes dramatic decreases in water levels in rivers, thereby increasing the probability that dolphin populations will be extirpated;*
*(3) e**ncourages** range states of the Amazon basin and its tributaries to support and carry out baseline research into the impacts of the development of commercial waterways in the Amazon (hydrovias) and their potential impacts on dolphin populations and habitats, including but not limited to the ecological impacts of dredging, noise pollution, channelisation by embankments, altered sediment suspension and transfer, and changes in turbidity, light, oxygen availability and primary productivity, and (b) work to minimize or at least mitigate these impacts;*
*(4) e**ncourages** (a) a review of the status of dolphins trapped within dammed stretches of the Tocantins and Madeira rivers and (b) evaluation of possible relocation (translocation) of animals when environmental conditions create a high likelihood that they cannot continue to survive in this severely compromised habitat; and*
*(5) e**ncourages** the review of the effects and the scale of contaminant and heavy metal (e.g. mercury) pollution on river dolphins in key areas of the Amazon (Japura/Caquetá, Içá/Putumayo, in Brazil and Colombia) and Orinoco (Venezuela) basins.*

17.2 *Tursiops* populations occurring in estuarine areas in southern Brazil

Discussion focused on two populations of Lahille's bottlenose dolphins (*Tursiops truncatus gephyreus*) in Patos Lagoon Estuary (PLE) and Laguna (LGN), Brazil. Both have been the focus of long-term ecological studies that provide a good source of information on the conservation status of the subspecies. Mark-recapture studies indicate year-round residency and permanent emigration is unlikely. Population sizes are small (85 dolphins in PLE and 60 in LGN) with low to moderate genetic diversity (mtDNA and nuclear DNA variation) in both areas. Pollutant analyses indicated moderate levels of persistent organic pollutants (POPs). Of additional concern is a chronic dermal infection which is apparent in 14% of the LGN population, which may be related to pollution but this is not clear. The greatest threat to both populations is bycatch in artisanal gillnet fisheries. Whilst there is no clear evidence of a negative trend in abundance, there is a high probability of population decline in the near future, given the small population, the high degree of residency and the continuing mortality as a consequence of IUU (illegal, unreported, unregulated) fishing and other human activities in these areas.

In Santa Catarina, Paraná, and São Paulo provinces, Brazil, north of LGN and PLE, a total of 119 bottlenose dolphins (sub species unknown) and 442 Guiana dolphins were recorded stranded over 2 years. There was strong evidence that entanglement was indicated as the cause of death for bottlenose dolphins. The Committee was informed that the Brazilian Government is looking into this issue and is seeking ways to improve legislative effectiveness in protecting dolphins and other threatened species in these locations.

Attention: SC, CG-R

The Committee draws the attention of the range states (Argentina, Brazil, Uruguay) to its conservation concerns over the entire sub-species of Lahille's bottlenose dolphins (T. t. gephyreus) given their relatively small population sizes and constricted ranges, the high levels of bycatch and the high incidence of individuals with chronic dermatitis. The Committee therefore recommends:

(1) immediate action to reduce the level of bycatch in the southern Brazil populations;
(2) continued monitoring and photo-identification work on the populations throughout the subspecies' range to refine survival estimates and to assess trends in abundance and the prevalence and etiology of the chronic skin infections; and
(3) that the conservation status of the subspecies be prioritised for assessment in the future.

17.4 Franciscana CMP

In 2016, the IWC created a Conservation Management Plan (CMP) for the franciscana – see Item 10.1.4. In 2019, a review will be presented to the Committee. The review will be jointly conducted by the SM and CMP sub-committees and will include input from other relevant sub-committees.

17.5 Report of the 2018 *Tursiops* Taxonomy Workshop

In 2014 (IWC, 2015b) it was agreed that the Committee would undertake a review of taxonomy and population structure in the genus *Tursiops*, over several meetings. Understanding whether there is any consistency in the derivation of various local forms across the range, and to which taxonomic or population unit(s) they belong, has been challenging, and the taxonomy of the various forms is still unresolved. An additional aim of this exercise was to develop a widely applicable taxonomy assessment framework for small cetaceans. The review process concluded with an intersessional workshop, held in La Jolla in January 2018.

The 3-year review and workshop brought together researchers and experts from around the world to discuss this topic, motivated focussed research, and promoted new collaborations. Results from studies presented at previous meetings (2015-2017) and at the workshop itself were compiled and formed the basis for evaluation of taxonomic and population distinction issues in each geographic region.

Attention: SC, G

Having reviewed the extensive information included in the 2015-2017 review and 2018 workshop for evaluation of Tursiops *species, subspecies and population distinctions, the Committee* ***draws attention to*** *the need for* Tursiops *research in the areas identified as data deficient (the African coast of the eastern Atlantic, southern and eastern Mediterranean Sea, eastern South Pacific, Pacific coast north of California and off the Mexican mainland, Central American coast of the eastern North Pacific, Central American Atlantic and Caribbean Sea and Atlantic coast of northern and north-eastern Brazil, eastern Australia and in the western Pacific the islands of Micronesia, Melanesia, Polynesia, the Philippines and Vietnam). The Committee therefore* ***encourages****;*

(1) collection of additional data, including morphometrics, and high-resolution genetic analyses (e.g. ddRAD which may also be useful in other areas where there are similar questions requiring high-resolution analysis), to better characterise divergence between coastal and offshore forms in the western South Atlantic Ocean, to help confirm whether subspecies or species classification is more appropriate for T. t. gephyreus;
(2) further investigation of T. aduncus *lineages in the Indian Ocean and western South Pacific to assess potential subspecies recognition, extending the geographic coverage to include eastern Africa, the region between Pakistan and Indonesia, and the region between Australia and China;*
*(3) continued study of the genetics and morphology of southern Australia bottlenose dolphins with the "*T. australis*" mtDNA lineage, in the context of both* T. truncatus *and* T. aduncus;
(4) examination of the level of male-mediated gene flow between the coastal and offshore forms in the western North Atlantic to determine whether the coastal form should be elevated to species or subspecies status;
(5) more comprehensive morphometric analyses comparing T. truncatus in the Mediterranean, Black Sea, and eastern Atlantic to integrate with genetic data and evaluate whether any regions in addition to the Black Sea (T. t. ponticus) harbour a taxonomic unit above the level of population;
(6) comprehensive morphometric analyses of coastal and offshore T. truncatus in the eastern North Atlantic and comparison to those from the western North Atlantic to better evaluate potential regional differences;
(7) morphometric analyses of Gulf of California coastal and offshore dolphins relative to those from California and the eastern tropical Pacific, with a particular focus on the level of divergence of coastal dolphins in the upper Gulf of California to other areas; and
(8) the collection of additional genetic and morphological data throughout the eastern South Pacific and further studies to investigate coastal versus offshore forms throughout the region, including coastal and offshore waters from Central America to Mexico, and if possible around the southern tip of South America to Argentina.

The Committee also ***agrees*** *to continue compilation of specimen, study, and researcher details, and concentrated effort to improve our understanding of* Tursiops *in data-deficient areas.*
Finally, after reviewing the 2018 Tursiops *Taxonomy Workshop's evaluation of the support provided for taxonomic (subspecies, species) and population-level distinctions proposed in the publications reviewed, the subcommittee* ***concludes*** *that:*

(1) the current taxonomy provided for Tursiops *by the Society for Marine Mammalogy's Committee on Taxonomy is well supported by morphological and molecular genetic data, as well as ecological and distributional data; and*
*(2) discordance in currently available results from morphometric analyses and across different genetic markers of the recently described '*T. australis*' from southern Australia calls into question its validity at this time.*

In addition to the information and recommendations on *Tursiops*, the Committee noted that the review provided an opportunity to formulate some generic conclusions on taxonomic issues related to small cetaceans.

Attention: SC, G

After reviewing the development and use of a strategy for objective evaluation of species, subspecies, and population-level distinctions by the 2018 Tursiops *Taxonomy Workshop, the Committee:*

(1) ***agrees*** *with the strategy implemented at the workshop for the evaluation of species, subspecies and population level distinctions;*
(2) ***encourages*** *use of the criteria and guidelines in Reeves et al. (2004) for the assessment of species-level taxonomy, in Taylor et al. (2017) for subspecies-level taxonomy, and in Martien et al. (2015) for Demographically Independent Populations; and*
(3) ***concludes*** *that future taxonomic questions should be examined within an appropriately wide and inclusive geographic context and that multiple lines of evidence are necessary when positing taxonomic changes.*

The Committee applauded Natoli, Rosel and Cipriano for their considerable work and organisational skills during this effort.

17.6 Poorly documented takes for food, bait or cash and changing pattern of use

17.6.1 Intersessional Workshop on the use of Small Cetaceans for Food and Non-Food Purposes in South America

The poorly documented take of small cetaceans for use as wildmeat has been assigned as a priority topic. An ICG (and see Annex Y) has been tasked with the development of a toolbox of techniques that could guide and co-ordinate research into this topic, and as such a series of workshops were proposed to fulfil this task. The second of these workshops focused on South America and incorporated a detailed review of the use of Amazon river dolphins as bait in the piracatinga fishery, which, in turn, fed into the priority topic of the 2018 meeting.

Information was summarised for all countries, except Guyana and Suriname, and it was recognised that products from small cetaceans have been used throughout the region for both food and non-food purposes. This type of use is referred to as 'aquatic wildmeat'. The usefulness of various tools and techniques was discussed, including data gathering techniques and forensic investigation. A database, comprising more than 3000 references, was used to map existing knowledge and understand data gaps. A framework was also established that had the purpose of standardised future data collection. The workshop participants populated a database from which regional patterns were mapped. Areas that were highlighted as a cause of conservation concern were; Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Peru and Venezuela.

The take of Amazon river dolphins as bait in the piracatinga fishery was also reviewed. All range countries of *Inia* and *Sotalia* have laws in place to protect dolphins and prohibit intentional killing. Fishing for piracatinga is banned in Brazil and its trade is prohibited in Colombia, due to its impact on river dolphins and other wildlife. The practice of using dolphins as bait has recently expanded to Peru, Bolivia and Venezuela, following the imposition of restrictions in Brazil, however, no other range country has developed specific legislative or regulatory action, beyond the general protection of river dolphins, in response to the emergence of this practice.

The workshop concluded that some species and population required urgent attention both due to the extent of their use as wildmeat and from other threats.

17.6.1.1 SCIENTIFIC CONCLUSIONS AND RECOMMENDATIONS

Attention: SC, G, CG-A

The Committee ***endorses*** *the scientific conclusions and recommendations from the recent intersessional workshop on the use of Small Cetaceans for Food and Non-Food Purposes in South America aimed at improving regional knowledge and conservation research. In particular, the Committee:*

(1) ***agrees*** *that potential divisions within the genus* Inia *should be evaluated and genetic conservation units established;*
(2) ***agrees*** *that an evaluation of historical data on river dolphins should be undertaken to better understand other threats (e.g., from bycatch), to provide further insights into current trends;*
(3) ***encourages*** *the use of new technologies, such as drones and satellite telemetry, to establish trends, habitat use and dispersion patterns of Inia within Amazon River Basin and*
(4) ***encourages*** *new efforts to improve regional research capacity.*

The Committee ***draws attention*** *to the evidence showing that several small cetacean species and/or populations are being negatively impacted by their use as wildmeat in South America, and therefore* ***recommends*** *that abundance and distribution surveys, in tandem with investigation into the magnitude of aquatic wildmeat use, be conducted on these species. Appropriate survey designs should be implemented that consider the statistical power required to detect trends and the resultant data should then be used to estimate the impact of deliberate take for wildmeat on the following populations:*

(1) Boto in Purus and Japurá rivers, Brazil, and Içá/Putumayo river in both Brazil and Colombia, using previously established standardised methods (studies should also be expanded into other areas where take for bait may be a cause for concern);
(2) Chilean dolphin in Chile;
(3) Burmeister's porpoises in both Chile and Peru, noting that current evidence suggests that the Peruvian population is distinct;
(4) Dusky dolphins in Peru, noting that evidence shows that landings of this species has decreased and populations may have been heavily impacted;
(5) Guiana dolphins and other small cetaceans in Amapá, Pará, Maranhão, Piauí, Ceará, Espírito Santo, São Paulo and Paraná, in Brazil, where there is a documented use of bycatch for wildmeat purposes;
(6) Bottlenose dolphins and pantropical spotted dolphins) in Bahia Solano, Colombia, noting that deliberate takes for a long line fishery is ongoing;
(7) Tucuxi throughout its range, in Brazil, Colombia, Ecuador, as it shares most of the same threats as Inia geoffrensis*, and may also be used as bait in the piracatinga fishery; and*
(8) Guiana dolphin (Sotalia guianensis) in Lake Maracaibo in Venezuela, noting that deliberate take for food is ongoing.

*The Committee also **draws attention to** the Boto dolphins that have been isolated within the dam system of the Tocantins and Maderia Rivers in Brazil. Given the confined condition of the dolphins' habitat, the Committee **agrees** that the status of these dolphins be evaluated, to include abundance, genetic, habitat, prey availability assessments, with a view to developing a translocation protocol, including under what circumstances such a protocol should be enacted.*
*Finally, given the concerns over the extensive habitat modification that will result from the Mega Project 'Arco Minero del Orinoco', a large scale mining operation proposed along the river and watershed of Venezuela, the Committee **recommends** that population sizes and trends of both* Inia geoffrensis *and* Sotalia guianensis*, in the Orinoco River basin, be monitored before and during this project.*

17.6.1.2 CONSERVATION AND MANAGEMENT ISSUES

Attention: CG-R, S, CC

*The Committee **draws attention to** the management recommendations within the Report of the Workshop on the Use of Small Cetaceans for Food and Non-Food Purposes in South America, in particular, the need to have a regionally co-ordinated fisheries management plan for the Amazon River basin and a regional strategy for the conservation of river dolphins. Given continued concern over the use of dolphins as bait in the piracatinga fishery, the Committee:*

*(1) **commends** the Government of Brazil on its swift action in declaring a moratorium on the piracatinga fishery and respectfully requests that it maintains the moratorium to allow sufficient time to evaluate the effectiveness of protective measures and ensure the necessary protection of river dolphins;*
*(2) **reiterates** previous recommendation of the IWC Scientific Committee that range states (Bolivia, Brazil, Colombia, Peru and Venezuela) engage in a co-ordinated effort to strengthen legislative, enforcement, management and scientific efforts to ensure protection of the Amazon River dolphins;*
*(3) **encourages** range state authorities to work together and exchange information on the movement of piracatinga products across international borders; and*
*(4) **requests** that progress reports be submitted to the Scientific and Conservation Committees.*
*(5) **recommends** that the Commission asks the IWC Secretariat to send a letter to the Buenos Aires Group highlighting the issue of dolphins being used as bait in the piracatinga fishery and requesting joint efforts to enhance enforcement on wildlife and trade laws.*

17.6.2 Wildmeat Database

In 2016 (IWC, 2017) an intersessional group was established to work with the IWC Global Database Repositories Convenor, to develop an overarching aim for any future cetacean wildmeat database and identify the specific questions that such a database might address. The results of this work were presented, including a research agenda the formulation of key questions that could be addressed through the development and analysis of an aquatic wildmeat database. The Aquatic Wildmeat Database, developed independently of the IWC, was presented again and the Committee was updated on its improvements made following suggestions made last year. The future value of this data repository was highlighted and this and related issues will be considered intersessionally (see Annex Y).

The work of the Steering Group (see Annex Y) will continue and a third workshop, focusing on Africa, will be conducted intersessionally. The framework for an IWC Wildmeat database established at the workshop in South America will be further refined and will be used at the forthcoming workshop.

17.7 Small cetacean task team

The Scientific Committee continues to support the Task Team Initiative and the latest Task Team, for the South Asia River Dolphin, is in the process of being established with Dipani Sutaria and Nachiket Kelkar nominated as co-conveners. The task team currently comprises 14 members with representation from Bangladesh, India, Nepal and Cambodia and includes university associated researchers and NGOs (WWF and the Wildlife Institute of India).

*Under its Task Team Initiative (e.g. IWC, 2016), the Committee **strongly supports** the work of a Task Team for the South Asia River Dolphin and **agrees** that its first meeting which will occur before the 2019 meeting, if sufficient funding is available.*

17.8 Progress on previous recommendations

17.8.1 Vaquita

The Report of the Tenth Meeting of the International Recovery Team for Vaquita (CIRVA-10) was summarised and the results of the acoustic monitoring program for vaquitas were presented (SC/67b/SM01). This shows a continued decline in vaquita detections with no change in the trend since the last report in 2016. A brief review of the VaquitaCPR project was presented. This initiative, conducted in October and November 2017, aimed to capture vaquitas and bring them into human care. Ninety experts from nine countries were involved, including researchers experienced in the capture and handling of harbour porpoises, animal care professional, and veterinarians. Two vaquitas were successfully captured (an immature female [V01F] and an adult female [V02F]). In both cases, medical and behavioural evaluations were conducted to determine the suitability of the animals for transport to the floating pen or shore-based facility. Through the whole process the animals' health was continuously monitored by a team of experienced marine mammal veterinarians. The first vaquita caught (V01F) was in good condition initially, but did not acclimate to either the vaquita care centre pool or to the sea-pen facility, and the vaquita was released. V02F was also considered to be in good condition for transport to the sea-pen, however, after initially showing signs of adapting to the facility, the animal stopped swimming and an emergency release was initiated. The release was unsuccessful and the vaquita was quickly recaptured for administration of emergency care. Following three hours of emergency response, the animal went into cardiac arrest and did not respond to resuscitation attempts. Analyses of tissues and material obtained from VH02 is ongoing and a full report on VaquitaCPR will be reported at SC68A.

The survival of the vaquita depends on gillnet-free habitat and efforts to remove gillnets, both derelict and active, have increased dramatically in the last three years, particularly, during the ongoing 2017-18 totoaba season. The net removal programme demonstrates that illegal totoaba gillnets are still routinely set in great numbers in vaquita habitat. Despite enhanced enforcement efforts, there is a continued failure to prevent illegal fishing. CIRVA have stated that immediate action is needed to improve the situation through implementation of a series of recommendations. In particular, CIRVA recommended that the Government of Mexico establish an enhanced enforcement area, extending the boundaries of the existing vaquita refuge.

Attention: SC, CC, CG-R

The Committee has stressed for many years that the vaquita population is at a critically low level, and the most recent evidence demonstrates that the cause of the decline – use of illegal large-mesh gillnets – continues, making extinction in the wild increasingly likely; *the long-term decline in the vaquita reported previously has continued in 2017.* The Committee yet again **re-emphasises the serious concerns** it has raised on the status of the vaquita, and in particular its recommendations of the past two Committee meetings. Whilst again **commending** the Government of Mexico for its attention and response to the CIRVA findings and recommendations, the Committee:

*(1) respectfully **requests** that reports continue to be provided annually to the IWC Scientific Committee on actions and progress towards saving the vaquita;*
*(2) **strongly endorses** the recommendations of CIRVA10 that:*

(a) the CIRVA10 acoustic monitoring programme, critical for evaluating the effectiveness of conservation actions, be continued as in previous years to provide an annual empirical estimate of population trend;
(b) all Mexican enforcement agencies increase their efforts on land and in water immediately and continue this enhanced enforcement programme for the duration of the period of illegal totoaba fishing (at least until June 2018) to eliminate all setting of gillnets in the range of the vaquita;
(c) emergency regulations be promulgated immediately to strengthen the current gillnet ban and enhance enforcement and prosecution by:

- *(i) eliminating all fishing permits for transient fishermen and limiting fishing access to only those fishermen who can demonstrate residency in the fishing villages;*
- *(ii) confiscating any vessel that does not have the appropriate vessel identification, permits, and the required vessel monitoring system;*
- *(iii) requiring vessel inspection for each fishing trip at the point of departure and landing;*
- *(iv) prohibiting the sale or possession of gillnets on land and at sea within the area of the current gillnet ban and on adjacent lands within a specified distance of the coastline.*
- *(v) requiring that all gillnets be surrendered or confiscated and destroyed.*

(vi) eliminating the exemptions for all gillnet fisheries, including the curvina and sierra fisheries.

(d) efforts to remove gillnets from vaquita habitat be continued and enhanced and the numbers and locations of new nets recovered be published monthly;

(e) the number of inspections, interdictions, arrests, sentences, and other enforcement actions be published monthly, together with information on observed levels of illegal activities obtained from intelligence operations, for example from drones;

(f) successful prosecution and subsequent penalties be sufficient to deter illegal fishing; and

(g) development of gillnet-free fisheries be enhanced and linkages to incentivise the conversion of the fleet to gillnet-free operations be strengthened.

17.8.2 Yangtze finless porpoise

A rangewide survey of Yangtze finless porpoises (*Neophocaena asiaeorientalis asiaeorientalis*) was conducted in 2017, giving a preliminary abundance of around 1,000 individuals. This indicates that the rapid decline observed between 2006 and 2012 has now slowed, and that numbers may even be increasing in some areas. Nevertheless, the Critically Endangered status of this species remains unchanged. The survey results were encouraging and regarded as a possible indication that *in situ* conservation of Yangtze finless porpoises is feasible, given the marked increase of the number of individuals in Dongting and Poyang Lakes. For the population to make a sustained recovery in both numbers and range, current measures directed towards improving the habitat in the Yangtze River as well as the Dongting and Poyang Lakes must be continued and expanded. The Government of China was commended for the efforts undertaken to improve the YFP habitat. Nevertheless, concern remain over threats such as vessel strikes, bycatch, underwater noise and bridge construction. In addition, the planned construction of a dam across the channel connecting Poyang Lake to the river is an additional concern.

Attention: SC, CG-R

Given the extensive and pervasive nature of the threats facing the Yangtze finless porpoise population, the Committee:

(1) ***commends*** *the efforts of the Government of China to improve its habitat; and*

(2) ***reiterates*** *that the primary conservation actions should focus on (a) restoring and maintaining suitable habitat throughout the Yangtze River and associated lakes, including the maintenance of a network of* in situ *reserves and (b) ensuring that genetic diversity is preserved and that harmful human activities are limited.*

17.8.3 Maui Dolphin

The Government of New Zealand reported that its review of management measures is scheduled for later this year. An update was provided on observer coverage of the set net fishery in Taranaki and the trawl fisheries adjacent to existing closure areas (95.5%, and 88.3%, respectively). Outside of this target coverage area, an additional 114 trawl fishing days were observed. No captures of Māui dolphins were reported by observers or fishermen in commercial fisheries in the 12-month reporting period to 31 March 2018. A species-specific, spatially explicit, multi-threat risk assessment is being developed for Māui and Hector's dolphins, the results of which will inform an updated Threat Management Plan later in 2018.

Attention: SC, CG-R, CC

The Committee notes that no new management action regarding the Māui dolphin has been enacted since 2013. It therefore concludes, as it has repeatedly in the past, that existing management measures in relation to bycatch mitigation fall short of what has been recommended previously and expresses continued grave concern over the status of this small, severely depleted subspecies. The human-caused death of even one individual would increase the extinction risk. In addition, the Committee:

(1) ***re-emphasises*** *that the critically endangered status of this subspecies and the inherent and irresolvable uncertainty surrounding information on most small populations point to the need for precautionary management;*

(2) ***reiterates*** *its previous recommendation that highest priority should be assigned to immediate management actions to eliminate bycatch of Māui dolphins including closures of any fisheries within the range of Māui dolphins that are known to pose a risk of bycatch to dolphins (i.e. set net and trawl fisheries);*

(3) ***notes*** *that the confirmed current range extends from Maunganui Bluff in the north to Whanganui in the south, offshore to 20 n. miles, and it includes harbours - within this defined area, fishing methods other than set nets and trawling should be used;*

(4) ***welcomes*** *the update on Maui dolphins provided and looks forward to receiving the species-specific, spatially explicit, multi-threat risk assessment in 2019.*

(5) ***respectfully encourages*** *the New Zealand; Government to commit to specific population increase targets and timelines for Māui dolphin conservation,*

(6) ***respectfully requests*** *that reports be provided on progress towards the conservation and recovery goals as updates become available.*

17.8.4 Cruise report from North Western Africa
For the third year, survey results were reported from cruises conducted in north western Africa waters. Fourteen schools comprising some five species and totalling 433 individuals were sighted, including bottlenose dolphins, both pantropical and Atlantic spotted dolphins and, spinner dolphins. This area is poorly surveyed and the continuation of this work was encouraged. The Committee **suggests** that a more substantive analysis of the data from all surveys be conducted and reported back next year, particularly as SC68A priority topic will be on African small cetacean species.

17.8.5 Monodontids Workshop Report
NAMMCO hosted a workshop and produced a Global Review of Monodontids. Researchers and subsistence hunters from across the Arctic and subarctic participated. Several IWC scientists also participated, including Litovka, Reeves, and Suydam. The report[9], summarises what is known about the status of 12 stocks of narwhals and 22 stocks of white whales. There may be more stocks than this as information on stock structure is incomplete for some areas. The summary information and identification of threats and concerns within the report will be helpful in prioritising future research. Some stocks are doing well, but conservation actions are desperately needed for some others. The IUCN Red List status and documentation for both species was updated to Least Concern in December 2017 and that the information summarised in the NAMMCO review was very useful for those assessments.

Attention: C-A

*The Committee **welcomes** the report of the NAMMCO workshop reviewing the monodontids[9]. It **draws attention to** the recommendations contained in the report and **encourages** their implementation, particularly those pertaining to the stocks of greatest concern.*

17.9 Takes of small cetaceans
7.9.1 New information on takes
The Committee received the summary of takes of small cetaceans in 2016–17 extracted from the online National Progress Reports and prepared by the IWC Secretariat, in addition to information obtained online.

No direct takes of small cetaceans were reported in the 2017 National Progress Reports. The Committee **notes** that it would be helpful if the Secretariat encouraged all member countries and IGOs (e.g. NAMMCO) to submit information on direct takes as a routine procedure.

The content of the Japan Progress Report on Small Cetaceans, a public document available from the website of the Fishery Agency of the Government of Japan[10], was summarised. It was noted that catch statistics in the Japan Progress Report on small cetacean cover catches in the calendar year, that is, from 1 January to 31 December, following the guidelines for IWC National Progress Report, while the catch quota of small cetacean fisheries are set seasonally. Thus, in some cases, the calendar yearly catch may exceed the seasonal (yearly) catch in appearance, but in such cases, the actual seasonal catch is aligned with the allocated catch quota. The Committee noted that the catch of 1,057 Dall's porpoises in the hand harpoon hunt was significantly lower than previously recorded reported and below the quota. It was stated that this is a result of the destruction of the community that conducts this hunt, rather than a change in the cetacean population, following the earthquake and tsunami of 2011.

7.9.2. Live captures
The Pacific Scientific Research Institute of Fisheries and Oceanography (TINRO) will consider a quota of 13 killer whales for 2018 and a public hearing was held on 3 May 2018 to make comments on this plan. This proposed new quota considers killer whales in the Sea of Okhotsk as one population, which is estimated to have an abundance of over 3,000 individuals. This number is considered minimal as only 50% of the sea was surveyed. In addition, the information available to the Russian Government on colour and fin patterns, feeding behaviour and distribution do not allow clear identification of different ecotypes, and that all genetic samples analysed to date belong to a single population. It was noted that most published information on Okhotsk Sea killer whale abundance and stock structure is in Russian-language literature, or as part of internal documentation.

Attention: C-A, CG-A
With respect to live captures, and specifically the capture of killer whales from the Sea of Okhotsk, the Committee:

*(1) **reiterates** its long-standing recommendation that no small cetacean removals (live capture or directed harvest) should be authorised until a full assessment has been made of their sustainability;*
*(2) **notes** that this is especially important for killer whales because populations are generally small and have strong social bonds and removals have unknown effects on their demographic structure; and*
*(3) r**eiterates** its concern that removals of killer whales are occurring from the Okhotsk Sea population.*

[9] https://nammco.no/wp-content/uploads/2018/05/report-global-review-of-monodontids-nammco-2018_after-erratum-060518_with-appendices_2.pdf
[10] *http://www.jfa.maff.go.jp/j/whale/w_document/attach/pdf/index-9.pdf*

In light of the verbal report received at this meeting that Russian authorities intend to proceed to consider limits of allowable live-capture removals of killer whales in the Sea of Okhotsk on the basis that there is no stock structure and there are no ecotype differences between the populations in this region, the Committee:

(1) ***encourages*** *more extensive effort to examine these issues; and*
(2) ***requests*** *that relevant analyses be provided for the Scientific Committee's consideration at its next meeting.*

17.10 Status of the voluntary fund for small cetacean conservation research

In 2017, donations for the Voluntary Fund for Small Cetacean Conservation Research totalling £13,122 were received from the Government of Italy. At the end of the financial year 2017, this brought the total of the fund to £81,077.

The Committee **expresses its sincere gratitude** for Italy's contributions and notes that these funds support critical conservation research projects of direct relevance to the work of the Committee.

Five projects were offered funding in 2016 and were implemented in 2017. One of the projects has since been withdrawn and one project, the Indus river dolphin abundance survey, was completed and reported on in 2017. The remaining three projects, on the 'Chilean Dolphin' in Chile, the 'Use of small cetaceans as wildmeat in China' and the 'Development of a business model for sustainable fisheries in the Upper Gulf of California, Mexico', are all near completion and will be reported on fully next year. Updates are available on the IWC website.

17.11 Work plan and budget requests

17.11.1 Priority topics for 2019 to 2024

The sub-committee on Small Cetaceans discussed ongoing priorities and will continue the development of these intersessionally; however, given the location of the meeting it is likely that the focus will be on African species or areas during 2019-20. Other potential priorities identified in discussions were *Inia* (e.g. taxonomy), *Sotalia guianensis*, *Phocoena phocoena*, *Delphinus delphis*, southern hemisphere beaked whales, *Steno bredanensis*, Northwest Pacific *Orcinus orca* and 'the Caribbean'.

17.11.2 Work plan for 2019 – 2020

The workplan on issues related to small cetaceans is given in Table 23.

Table 23

Work plan on small cetaceans

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Franciscana CMP	ICG (Annex Y) to co-ordinate outcomes of CMP across sub-committees	Report	ICG (Annex Y) to synthesis actions from 2019 SC report and develop a work plan	Report
Wildmeat	ICG (Annex Y) to plan and conduct African Workshop.	Report	ICG (Annex Y) group to summarise workshop series and develop future work plan.	Report
Small Cetacean Task Team	Intersessional Workshop on South Asian river dolphins.	Report	Act on recommendations from 2018/19 River dolphin workshop.	Report
Sotalia	SG (Annex Y) to plan and conduct workshop #1 (at SOLOMAC)	Report	SG (Annex Y) to plan and conduct workshop #2	Report

18. WHALE WATCHING[11]

The report of the sub-committee on whale watching is given as Annex N.

18.1 Assess the impacts of whale watching and swim-with-whale operations on cetaceans

18.1.1 Review progress of Modelling and Assessment of Whale Watching Impacts (MAWI)

Modelling and Assessment of Whale Watching Impacts (MAWI) has been on the Committee's agenda for several years. In April 2018, an intersessional workshop was held to identify the key research questions for understanding the potential impacts of whale watching on cetaceans (SC/67b/Rep03). A number of issues were highlighted, including: (a) the need to better understand the impact of recreational whale watching vessels as compared to commercial vessels; (b) the importance of looking at the potential impact of whale watching at short-term (e.g., behaviour change), mid-term (e.g., shift in habitat use) and long-term (e.g., population dynamics) time scales; (c) the use of existing and new data to explore the mid- and long-term impacts, as opposed to replicating short-term studies; and (d) the importance of building scientific capacity in the locations where the research would take place. More information can be found in Annex N, item 2.1.

[11] In response to a request from the Chair of the Whale Watching Working Group of the Conservation Committee, we have changed our past practice of treating whalewatching as a single word to the use of two words.

Attention: SC, C-R

The Modelling and Assessment of Whale Watching Impacts (MAWI) initiative held a workshop in Italy in April 2018, in conjunction with the 32nd European Cetacean Society conference.

*The Committee **endorses** the following recommendations from this workshop:*

(1) the incorporation of both social and natural sciences to better understand whale watching impacts;
(2) the development of a Strategic Framework, supported by a Decision Tree, to aid in the prioritisation of policy and research choices;
(3) the development of toolkits and resources that can be accessed globally; and
(4) the standardisation of data collection.

*The Committee also **agrees** that a third MAWI workshop be held intersessionally, ideally just before or after the 2nd World Marine Mammal Science Conference in 2019, in Barcelona, with the following objectives:*

(1) to determine in detail which data should be collected to best answer the natural and social science research questions developed in SC/67b/Rep03;
(2) to identify the best locations for conducting research projects that address these questions; and
(3) to continue to develop modelling approaches for assessing the long-term impacts of whale watching on cetacean populations (using data on short- and mid-term impacts).

18.1.2 Review specific papers assessing impacts

The Committee received several papers regarding impacts to cetaceans from whale watching activities. Those papers included (1) efforts to assess stress hormones in baleen of southern right whale calves, (2) 'solitary sociable' cetaceans, (3) land-based observations in the Canary Islands to assess and mitigate potential impacts of whale watching vessels on cetaceans, (4) a Whale Welfare Assessment Tool (also presented and discussed in Plenary) and (5) the 15th year of a summary of papers published in the previous year related to a better understanding of impacts, mitigation and compliance to regulations. Additional details on these papers and projects can be found in Annex N, item 2.2.

Attention: SC, CG-A

The term 'solitary sociable dolphin' or cetacean is usually taken to apply to cetaceans that have little or no contact with conspecifics and who regularly closely approach humans, often including touch, social, sexual and play behaviours (Wilke et al.*, 2005). Given that solitary sociable cetaceans often end up in circumstances where they are harmed and killed and that they may come to present a threat to human swimmers, the Committee:*

*(1) **agrees** to continue intersessionally to monitor the phenomenon of solitary sociable cetaceans as part of its work;*
*(2) **advises** that, where these animals occur, research be conducted to determine whether the emergence of harmful behaviours either to the animal or to people can be reversed; and*
*(3) **advises** local authorities and other concerned parties to keep people away from them in order not to encourage behaviour that may prove harmful to the animal or swimmers.*

*In addition, the Committee **agrees** that the Whale Welfare Assessment Tool (currently being developed at the Royal Veterinary College, University of London, in the context of the IWC Whale Killing Methods and Welfare Issues Action Plan), for which a hypothetical whale watching case study was trialled (Annex N, item 2.2), be applied to real-world whale watching situations. The southern resident killer whales in Washington, USA and the bottlenose dolphins in Bocas del Toro, Panama were proposed. These two populations are subject to intense whale watching pressure and may be suffering welfare and health impacts related to this pressure. Both locations have data relevant to the assessment tool and therefore seem ideal as pilot projects for its application.*

18.1.3 Consider documented emerging areas of concern (e.g., habituation, new areas/species, new technologies, in-water interactions) and how to assess them

The Committee received several papers about emerging areas of concern regarding whale watching, including (1) human-induced behavioural changes, (2) impacts from recreational in-water interactions with cetaceans and (3) purposeful and inadvertent feeding by humans.

The Secretariat for the Convention of Migratory Species (CMS) submitted several documents to SC/67b including a global review of in-water interactions with aquatic mammals. That review had resulted in a CMS resolution that encouraged Parties to facilitate research allowing for an assessment of the long-term effects and biological significance of disturbances from 'swim-with-marine-mammal' programmes. The topic of swimming with cetaceans is also addressed under Item 18.6.

The Committee received reports about several studies to assess the impacts and compliance with regulations of commercial 'swim-with-whale' operations in Australia. The discussion of this issue can be found in Annex N, item 2.3.

Attention: SC, CC, S

*The Committee **agrees** that the habituation intersessional correspondence group, now named human-induced behavioural changes of concern, should continue (see Annex N, table 3).*

Given the substantial effort the Convention on Migratory Species (CMS) Secretariat has made in preparing several documents for the Committee to consider this year, the Committee:

*(1) **recommends** a continuation and an expansion of this exemplary collaboration between the IWC and CMS Secretariats and their various committees;*
*(2) **endorses** the intention of CMS to work with the IWC Scientific Committee on guidelines for in-water interactions with aquatic mammals and **offers** to provide the scientific underpinning for these guidelines;*
*(3) **agrees** that the Committee's intersessional correspondence group on swim-with-whales work intersessionally with the CMS Aquatic Mammals Working Group to develop draft guidelines; and*
*(4) **offers** to review draft guidelines when they are ready, with a view to **agreeing** a joint product of the IWC and CMS and hosted by both websites as a global resource.*

See also Item 18.6 for additional recommendations related to swimming with cetaceans.

18.2. Consider information from platforms of opportunity of potential value to the Scientific Committee
The Committee received examples of several platforms of opportunity where data have been collected concerning habitat use, behaviour, changes in distribution and potential risks from shipping for multiple different species in several different areas. Of particular interest was Peninsula Valdés, Argentina, where approximately 460,000 photographs have been taken from whale watching boats and provided to researchers from the Instituto de Conservación de Ballenas and Ocean Alliance (SC/67b/WW04). See Annex N, item 3.

The Committee offered numerous suggestions as to how to handle the large number of images and **encourages** the researchers to network with other researchers around the world, particularly humpback whale researchers dealing with similarly large numbers of photographs and multiple catalogues, to improve the processing time of the photographs.

18.3 Whale watching in east Africa and the wider Indian Ocean
A proposal for Concerted Action for Arabian Sea humpback whales was passed by CMS with strong support from range states. This was discussed in Annex N, item 4.

Attention: CC, S, CG-A

Noting the Committee's discussions over several years on the status of the Arabian Sea humpback whales (see Item 10.2.1), the Committee:

*(1) **welcomes** the CMS proposal for Concerted Action for Arabian Sea humpback whales;*
*(2) **notes** that humpback whales are the target of one emerging whale watching operation in the south of Oman and **highlights** the likelihood that the population could become the target of future whale watching activities;*
*(3) **emphasises** the need for regulators and scientists to work with the industry to ensure that whale watching does not add to the many other pressures on this small, isolated, non-migratory and endangered population.*

The Committee therefore:

*(1) r**ecommends** that building capacity to conduct needed research and to ensure consistent training of whale watching operators be a high priority for Omani authorities and other parties working on the recovery of the endangered Arabian Sea humpback whale population;*
*(2) **notes** that boat operators for cetacean watching operations appear to turn over at a high rate in this area, and **recommends** that training workshops should be regularly offered and conducted;*
*(3) **welcomes** the offer from the Pacific Whale Foundation to help organise and conduct another training workshop, but **recommends** a more comprehensive plan be implemented by the Omani authorities, working with the IWC and other interested parties, to build local capacity for such training; and*
*(4) **agrees** to retain a review of whale watching in east Africa and the wider Indian Ocean region in its work plan (see Annex N, table 4) and to conduct an intersessional review of whale watching in these areas, to be presented at SC/68a.*

18.4 Review Whale Watching Strategic Plan (2018-2024) and joint work with the Conservation Committee
18.4.1 Review and provide recommendations on the draft Strategic Plan
At SC/67a, the Conservation Committee's SWG on Whale Watching requested the Scientific Committee to review a draft of the next iteration of the IWC's Strategic Plan (2018-2024) on Whale Watching (see SC/67b/WW02). This was accomplished primarily during a SC/67b pre-meeting and then further discussed in Annex N (item 5 and appendix 2).

Attention: CC

*The Committee **draws the attention** of the Conservation Committee's Standing Working Group on Whale Watching (SWG) to Annex N, appendix 2, which provides a full set of comments on the draft Strategic Plan (2018-2024) on Whale Watching. The most important comments and recommendations from the appendix are highlighted below:*

(1) The addition of an Action 1.5: Develop a communications strategy to actively promote IWC whale watching resources (e.g., the Handbook, reports and training opportunities), with approaches tailored to target key audiences. These audiences include the public and whale watching managers, researchers, operators, and on-board naturalists. Communication actions could include preparing publicly accessible summaries of IWC whale watching reports, improving the whale watching pages on the IWC website (which is already underway with the new Whale Watching Handbook, see Item 18.5), and promoting resources on social media, at key meetings and via press releases to industry bodies and trade publications. The implementation of this action could be coordinated intersessionally via the Secretariat. A joint intersessional working group, which includes key Secretariat staff, could develop a communications strategy for consideration at IWC/67 (the Brazil Plenary meeting) and/or the joint session of the CC/SC at SC/68a.

(2) The replacement of the actions of Objective 2 in the draft Strategic Plan with the following:

a) Action 2.1 – Continue the Modelling and Assessment of Whale Watching Impacts (MAWI) initiative, to develop tools and methodologies to assist researchers and managers in their efforts to assess potential impacts of whale watching on cetaceans and to mitigate them. This initiative is ongoing and could focus on:

i) Investigating modelling methods to link short- (e.g., behavioural reactions) and medium-term (e.g., changes in population distribution) responses with potential impacts from whale watching to long-term (i.e., >10 to 20 years) consequences (e.g., vital rates).

ii) Establishing standard data collection methodologies, including from platforms of opportunity.

iii) Identifying key locations for whale watching research projects and programmes, taking into consideration logistics, capacity and management urgency;

b) Action 2.2 – Develop a long-term integrated research programme to better understand the potential impacts of whale watching on the demographic parameters of cetacean populations. Seek to:

i) Investigate whether there is a causal relationship between whale watching exposure and the survival and vital rates of exposed cetacean individuals and populations;

ii) Understand the mechanisms involved in causal effects, if they exist, in order to define a framework for improved management;

c) Action 2.3 – Develop processes and mechanisms for whale watching activities to collect and provide scientifically robust and useful data to researchers and research programmes; and

d) Action 2.4 – Develop an approach (e.g., hold an intersessional workshop; establish a joint intersessional working group) to integrate social and ecological scientific research within the IWC to inform whale watching management and promote potential benefits. This is a coordinated action between the SWG and the sub-committee.

*In particular, Action 2.2 will require a dedicated person to guide and coordinate the development and implementation of a research programme or plan. The best option would be for the SWG to contract with someone, full- or part-time, to carry out this task, whilst recognising the budgetary concerns. Therefore, the Committee **recommends** that the search for funding for this and all other actions in the Strategic Plan be focused, broad-ranging, and innovative. An alternative, if budgetary issues are prohibitive, is to have the research programme developed intersessionally by an intersessional correspondence group or the convenor and co-convenor of the Committee's sub-committee on whale watching.*

*Lastly, the Committee **reiterates** its previous recommendation to improve the coordination between the SWG and the Committee's sub-committee on whale watching in the development and implementation of a Strategic Plan on Whale Watching. This year's 21 April pre-meeting to review the draft Strategic Plan was intended to improve coordination and provided an opportunity to contribute to the draft Strategic Plan but it did not completely achieve the goal of coordination, as a limited number of SWG members were able to attend the pre-meeting.*

18.4.2 Develop procedures to provide scientific advice as requested in the plan (including the online handbook) and make the Committee more effective at providing information to the Commission

The revised Actions 2.1-2.4 in Item 18.4.1 outline how the sub-committee on whale watching will collect information needed to inform the Conservation Committee's SWG on Whale Watching. Procedures for providing this advice will be discussed and determined cooperatively with the Conservation Committee, during the joint meeting immediately after SC/67b and intersessionally through the intersessional correspondence group (see Annex N, table 3,).

18.5 Whale watching handbook

18.5.1 Review and provide comments on the IWC's Whale Watching Handbook

The Whale Watching Handbook (Handbook) was presented. Before being made available to the public it will also be translated into French and Spanish with support from CMS. Annex N (item 6) provides additional comments and suggestions for fine-tuning and improving the already-admirable Handbook.

Attention: CG-R, SC, S, CC, C-R

*The Committee **welcomes** the presentation of the online Whale Watching Handbook and **agrees** that it is comprehensive, scientifically substantive, user-friendly and well designed.*

*To ensure the IWC Whale Watching Handbook comes to the attention of the international whale watching community, including managers, operators and the public, the Committee **recommends** that all Contracting Governments provide a link to the Handbook on the relevant agency pages of their own government websites once the Handbook goes 'live'.*

*The Committee also **recommends** that the Conservation Committee and the Commission develop a plan for identifying and securing long-term funding for the further development (e.g., translations into additional languages, writing additional case studies or country profiles) and the ongoing maintenance (e.g., periodic reviews of content) of the IWC Whale Watching Handbook. The Handbook must be updated regularly to remain a vibrant, living document.*

18.6 Review reports from intersessional correspondence groups

The Committee received information from the intersessional correspondence groups (ICG) of swim-with-whale operations and communication with IORA. Annex N provides details of (1) the discussion related to the intersessional work of the ICG on swim-with-whale operations (item 7.1) and (2) the discussion related to the intersessional work of the ICG on IORA communication (item 7.2).

Attention: S, SC, CC, CG-A, CG-R

Regarding swim-with-cetacean operations, the Committee:
*(1) **agrees** that the intersessional correspondence group on swim-with-whale operations (Annex N, table 3) should continue;*
*(2) **draws attention** to guiding principles for whale watching, including in-water interactions, that are being or have been developed by various regional bodies, such as the Convention on Migratory Species and UNEP in the Wider Caribbean (see Annex N, item 2.3 and UNEP-CEP, 2012), that advise that swimming with cetaceans be discouraged where it is not already established; and*
*(3) **recommends** that, in jurisdictions where swim-with-cetacean activities have not been occurring or are just starting, this practice be prohibited until there is scientific evidence that supports allowing it, noting that the risks to both humans and cetaceans are substantial if operators are inexperienced and not following any relevant guidelines; and*

*The Committee also **welcomes** the increased communications between IORA and the IWC over the past year. The IORA Sustainable Whale and Dolphin Watching Tourism Network was established and Australia will convene the Network in its first year of operation and will produce a biannual newsletter. Consequently, the Committee:*

*(1) **agrees** that the intersessional correspondence group on communication with IORA (Annex Y) should continue; and*
*(2) **encourages** greater engagement between the IWC and IORA on whale watching, beyond the exchanges amongst the intersessional correspondence group (Annex N, table 3).*

18.7 Review progress on scientific recommendations

18.7.1 Global influence of recommendations

The Committee received information about the influence of previous recommendations in numerous countries. Details can be found in Annex N, item 8.1.

18.7.2 Tracking progress on previous recommendations

The sub-committee on whale watching reviewed 27 of its recommendations and agreed statements from the past two years. Of those, 15 were completed or partially completed, nine are on-going, and three have not yet been addressed. Annex N, item 8.2, provides details about those recommendations and agreed statements. There is also ongoing work to update and finalise the terms of reference for the sub-committee on whale watching.

18.7.3 Update on dolphin watching in Bocas del Toro, Panama

Concern continues about the number of dolphins from the small population in Bocas del Toro, Panama that are found dead. Nine deaths in 2016 and 2017 are known to have occurred, five of them confirmed boat strikes. These losses are unsustainable. Research to better understand impacts on the population includes measuring stress hormones in biopsy samples and acoustic monitoring. A regulatory update to strengthen management of whale and dolphin watching in Panama, including Bocas del Toro, was released in October 2017, with the support of the Ministry of Environment.

Attention: SC, C, CG Panama

*The Committee **reiterates** its grave concern regarding the intense and uncontrolled dolphin watching in Bocas del Toro, Panama. This concern has been expressed and reiterated for several years due to continuing mortalities, including from vessel strikes, in this small population (probably fewer than 100 animals). In this regard, the Committee:*
*(1) **welcomes** the ongoing research to monitor this dolphin population and the impacts it is facing from dolphin watching;*
*(2) **reiterates** its welcome of Panama's increased responsiveness to protect the local dolphin population by minimising negative impacts from dolphin watching (IWC, 2018a) and **welcomes** the regulatory update, supported by the Ministry of Environment, which is meant to lead to stronger management of whale and dolphin watching in Panama, including Bocas del Toro; and*

*(3) **expresses serious concern** at the number of deaths reported in 2016 and 2017 and **recommends** action from the Government of Panama as a matter of urgency, including the immediate and committed implementation of the updated regulations.*

18.8. Work plan and budget requests for 2019-2020

18.8.1 Work plan for 2019-2020

The work plan for matter related to whalewatching is shown in Table 24.

Table 24

Summary of the work plan for matters related to whale watching. Many of these items have intersessional correspondence groups (ICG) or intersessional advisory groups (IAG). Those groups will work intersessionally and provide updates at SC/68a (see Annex X)

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Assessing impacts	-	Papers to be presented	-	Papers to be presented
Third MAWI workshop	Workshop planning	Receive update on planning	Workshop (Annex Y)	Report
Update IWC whale watching guidelines and principles	Revise guidelines and principles	Review	Continue if needed	Receive update
Indian Ocean review	ICG (Annex Y)	Papers to be presented	-	-
East Africa review	Work to prepare review	Paper to be presented	-	-
Intersessional correspondence groups	See Annex Y	Receive reports	See Annex Y	Receive reports
Joint meeting with Conservation Committee Standing Working Group on Whale Watching (SWG) to discuss incorporation of social science in joint work streams	Meeting planning	Receive update	Meeting planning	Joint meeting with SWG
IWC Whale Watching Handbook	-	Receive updates	-	Receive updates

19. SPECIAL PERMITS

19.1 General considerations on improving the evaluation process

This issue is considered as part of the process to revise 'Annex P' (see discussion in Item 28.3).

19.2 NEWREP-A

Summaries of NEWREP-A papers are given in Annex U1.

19.2.1 Report on ongoing research

In plenary, the Committee received and briefly discussed four papers on ongoing work – as indicated below, some of these were discussed more fully in sub-groups.

SC/67b/SP08 presented the results of the third biological field survey of NEWREP-A during the 2017/18 austral summer season. In discussion, it was noted that the high apparent pregnancy rate (95.3%; 122 of 128 mature females) of Antarctic minke whales was consistent with previous results (e.g. from JARPA and JARPA II).

SC/67b/ASI07 presented a summary of results of the NEWREP-A dedicated sighting survey during the 2017/18 austral summer season whilst SC/67b/ASI11 presented the research plan for the next systematic vessel-based sighting survey in the Antarctic under NEWREP-A 2018/19. The new NEWREP-A 2018/19 sighting survey plan has been endorsed by the Committee; Annex Q (item 4.2) provides more details on both these papers.

SC/67b/EM05 presented results of the krill and oceanographic surveys undertaken during the third NEWREP-A survey in Area V-E and VI-W (see Annex L, item 6.1 for details).

19.2.2 Update on previous recommendations

19.1.2.1 AGE DATA AND RMP/IST (RECOMMENDATION 1)

SC/67b/RMP03 provided updated draft specifications for an RMP/IST type simulation exercise to evaluate management procedures based on modified catch limit algorithms that use information on recruitment inferred from age data from Antarctic minke whales. Details and discussion are given in Annex D, section 2.3.2.

Attention: S

*The Committee **agrees** that methods currently used or proposed to be used in the Committee that use age data should (as necessary) be investigated to evaluate the relationship between their results and the accuracy and precision of the age data that they use where this is pertinent to the results of import from these methods. The Committee **agrees** to include this as an agenda item for next year's meeting.*

19.1.2.2 BIOPSY SAMPLING AND TELEMETRY FEASIBILITY STUDIES (RECOMMENDATIONS 4 AND 5)

SC/67b/SP04 summarised the results of a feasibility study on biopsy sampling and satellite tagging of Antarctic minke whales under NEWREP-A. The authors concluded that in the context of the NEWRREP-A objectives, (a) the efficiency of biopsy sampling is much lower than that of lethal sampling for Antarctic minke whales and (b) that the amount of tissue derived from biopsy samples is insufficient to conduct the suite of biomarkers targeted by NEWREP-A. They therefore concluded that biopsy sampling was not a feasible approach to fulfil the objectives of NEWREP-A.

This paper prompted considerable discussion in the Committee, both with respect to 'efficiency' of the method and the amount of material required.

One issue raised was that there was the need for better clarification of terminology used in the paper (e.g. 'sampling' versus 'killing) in order, for example, to interpret properly the conclusion that biopsy sampling took approximately three times longer than lethal sampling. It was not clear, for example, whether the median times for biopsy and lethal sampling provided were truly comparable because of the lack of information on when the time for these methods started and ended. In particular, handling time for lethal sampling appeared to not be included in the total time calculations.

The authors responded that in SC/67b/SP04 'the efficiency' of sampling techniques was defined as 'Success Proportion' rather than 'Time of Experiment' because 'Success Proportion' represents a better indicator of the efficiency. To fulfil the purposes of NEWREP-A, random sampling is required in which generally only one animal from a school is sampled. Notwithstanding this clarification, they provided definitions of 'Time of Experiment' (see details in Yasunaga *et al*. in Annex U2).

Another issue raised was that the NEWREP-A review workshop (ref) had suggested 'involving people with expertise in successfully biopsy sampling common minke whales in the North Atlantic', meaning collaborating in the field with experienced foreign experts. However, Table 2 of SC/67b/SP04 showed an ongoing decline in success proportion (number of biopsy samples / number of targeted whales which were chased for sampling by the SSVs) between 2015/2016 and 2017/2018 rather than the increase one would expect with increasing experience. The authors responded that they had consulted with foreign scientists although they were not on the vessels, that they used experienced marksmen and that the decline was an artefact of weather and sea state conditions under which samples were collected. However, the counter-comment was made that in authors' analyses, the best model did not include "weather conditions" as a significant factor.

In response the authors provided results of a GLM analysis based on the binomial distribution assumption to examine the differences in success proportion in the biopsy sampling experiment using research seasons as explanatory variables. The coefficients for each year were not significant, suggesting that the differences of success proportions among the seasons are not statistically significant and consequently provide no evidence that shooters' efficiency has decreased significantly over the three research seasons (see details in Yasunaga *et al*. in Annex U2).

Some Committee members (see Clapham et al. I, in Annex U2) disagreed with the authors' conclusion that the study revealed that biopsy sampling was not feasible for the NEWREP-A programme. Rather, they believed that it showed that it was both feasible and appropriate. They also disagreed that the amount of tissue obtained was insufficient, citing the large number of research programmes that successfully use biopsy samples to fulfil research objectives including using a single sample for a variety of biomarkers (e.g. stable isotopes, fatty acids, hormones, genetics).

In response, the authors agreed that the amount of epidermal tissue collected by biopsy sampling is enough for the requirement of genetic, epigenetic and stable isotope analyses. However, they stressed that the amount of adipose tissue collected by biopsy sampling was not large enough to measure progesterone, lipid content and fatty acid in the context of the objectives of NEWREP-A (see details in Yasunaga *et al*. in Annex U2).

In their closing comments, the authors stated that in response to the recommendation of the Expert Panel, dedicated experiments for biopsy sampling of Antarctic minke whales had been carried out which had generated the results presented at this meeting and from which the authors had drawn their conclusions. No further dedicated time for biopsy experiments was planned at this stage, but this could be reconsidered at the mid-term review. Meanwhile, NEWREP-A will only collect additional biopsy samples opportunistically.

With respect to the best approach to assess the efficiency of biopsy versus lethal sampling, a standard approach for measuring the efficiency of biopsy sampling and to compare this to the process of lethal sampling was proposed (Clapham et al. II, in Annex U2).

Attention: S

The Committee had last year agreed on establishing an intersessional Advisory group tasked 'to provide advice on developing an experimental protocol for ascertain whether it is possible to reliably biopsy minke whales and, if so, under what circumstances (experience, vessel type, equipment, environmental conditions, etc.). This group could use as starting point the advice provided by the Expert Panel' (JCRM 19 suppl:431-490). Due to a clerical error the group did not convene. Attention was drawn to a protocol to evaluate non-lethal techniques presented to SC66b (Mogoe et al., 2016). This protocol included four questions to help identify the feasibility and practicability of non-lethal methods.

*The Committee **agrees** to re-establish the Advisory group (Annex Y), under Palka for consideration at SC68a. It also **agrees** that suggestions for refining questions in the method used by Mogoe and colleagues (2016) should be added to the tasks of this group.*

19.1.2.3 EPIGENETIC AGEING (RECOMMENDATION 8)

Recently, epigenetic (DNA-methylation) ageing has been successfully used to estimate age in humpback whales (Polanowski *et al.* 2014). As noted under Item 11.4.4, this year, the Committee invited Jarman, the leading specialist in this technique to give an overview presentation to the Committee as a special night session. This covered topics such as current and future prospects for this class of methods (see Annex I, item 5.5).

SC/67b/SDDNA04 presented a feasibility study on epigenetic ageing in Antarctic minke whales in response to Recommendation 8 from the Expert Panel (for details see Annex I, item 5.5).

Some suggestions were made on how to improve resolution (in particular, evaluate more loci and then restrict to those loci highly correlated with age); the current set of loci do not provide sufficient precision for use in the population dynamics modelling exercise recommended for NEWREP-A. Given that there is an upper limit to the degree of precision that can be achieved using this technique, the Committee noted that the utility of epigenetic age estimation (and other methods of age determination) will depend on the degree of precision needed for the specific application of interest (see recommendation under Item 11.4.1).

19.1.2.4 DETERMINING SEXUAL MATURITY IN BLUBBER (RECOMMENDATION 9)

SC/67b/SCSP05 presented results from the NEWREP-A research component focused on determining sexual maturity in female Antarctic minke whales, during the feeding season based, on concentrations of progesterone in blubber. The authors concluded that the progesterone concentration in blubber samples cannot be used as a diagnostic index to discriminate between mature and immature female Antarctic minke whales and that lethal sampling is required to obtain information on sexual maturity for use in population dynamic models.

Some members of the Committee disagreed with that conclusion, as they demonstrated that the amount of misclassification in immature versus mature females would be small (~1%, see Wade *et al.* in Annex U2) and thus that progesterone levels in biopsy samples would allow discrimination between mature and immature animals.

They noted that the stated purpose of the study was to discriminate between immature and mature females for fitting population dynamics models such as the catch-at-age analysis; the only misclassification that occurred was a total of 3 (out of 230) whales between the resting and the immature classes, and therefore the only misclassification rate that is important remains ~1% of the total sample.

Some other members noted, also in relation to recommendation 10, that misclassification for discriminating between resting and immature animals was higher and thus the method less reliable for that task.

In response to a request, the authors provided a histogram showing the numbers of immature, resting, ovulating and pregnant animals (Figure 1 of Yasunaga *et al*. in Annex U2). Based on the assumption of cut off values (1.0 ng/g) of progesterone set in Wade *et al.* (see in Annex U2), six of 56 immature whales and three of 11 resting whales were misclassified. Misclassification ratios were thus10.7% and 27.2%, respectively, and these were not considered negligible by the authors (see details in Yasunaga *et al*. in Annex U2).

19.1.2.5 SAMPLE SIZES REQUIRED TO DETECT CHANGE IN ASM (RECOMMENDATION 26)

SC/67b/SCSP01 focused on the need to complete NEWREP-A recommendation 26 on the calculation of sample size. The Committee discussed its previous conclusions in this regard. In 2016, the Committee assessed that three of six aspects of the Expert Panel's recommendations had been adequately addressed in relation to sample sizes. Some members of the Committee consider that until the proponents fully implement the Expert Panel recommendations for calculating sample sizes, the proponents have not demonstrated that they are able to meet their stated objectives in relation to the NEWREP-A programme. The proponents' position and that of some Committee members is that the work has been completed to a reasonable level and that any further work on sample sizes will be afforded a low priority.

The Proponents reiterated their position regarding the work on and status of recommendation 26 ('Provide a thorough power analysis of sample sizes required to detect change in ASM and follow the other recommendations in this item') from the NEWREP-A Review Workshop (IWC, 2016). In view of the proponents, the work on recommendation 26 has been completed to a reasonable level. Details can be found in GOJ (2015; 2016a) and GOJ (2016b). The IWC SC has already concluded that the approach being taken to address the recommendation is appropriate (IWC 2018). Consequently, the proponents have concluded that the reasonableness of the proposed sample size (333) has been adequately demonstrated. The proponents recognize that in 2016 the Scientific Committee suggested some further refinement work; however, they consider that such refinement work goes beyond the original scope of recommendation 26 from the NEWREP-A review workshop. Nevertheless, in deference to the Committee, it was the proponent's intention to address the refinement work for this year's Scientific Committee. However, because of unanticipated specialist personnel unavailability, this has had to be postponed. The proponent's intention is to continue contributing to this work subject to logistical constraints and the availability of specialist analysts.

19.1.2.6 COMMITTEE'S ADVICE

The table in Annex U4, provides a detailed update of the Committee's view of progress on previous recommendations. An overview is given in Table 25.

Table 25

NEWREP-A – Overview on progress with recommendations.

Recommendations in are not in priority order. Recommendations that relate to purposes A, B, C and D are higher priority for completion. Recommendations coded uniquely as "*E: Relevant to improve existing components of the proposed programme*" are excluded from this table as they were optional. Key for 'Purpose': *A: To evaluate the contribution of a particular objective or sub-objective of the programme to meet conservation and management needs*; *B: To evaluate the feasibility of particular techniques (whether lethal or non-lethal)*; *C: Relevant to a full evaluation of whether any new lethal sampling is required*; *D: Relevant to issues related to sample size (irrespective of method used to obtain data).*

Recommendation	Purpose	Deadline	Proponents self-evaluation on progress as of SC67b	Committee's comments
(1) Age data and RMP/IST	A, C, D	August 2016	Completed to a reasonable level	SC66b: A range of opinions as to the extent to which this recommendation has been addressed. SC67a: No new information. SC67b: Some information presented (See section 19.1.2.1).
(2) Stock definition	A, D	May 2016	In progress.	SC66b: No progress. SC67a: As in SC66b. SC67b: As in SC66b.
(3) Mixing rates (simulations on precision and bias)	A, D	May 2016	To be completed by the mid-term review.	SC66b: No progress. SC67a: As in SC66b. SC67b: As in SC66b.
(4) Biopsy feasibility study	B, C, D, E	Field season 2017-2018	Completed.	SC66b: Some progress (SC/66b/IA05). SC67a: Some progress (SC/67a/ASI07). SC67b: Partially completed, further refined analysis is needed (see 19.1.2.2). A WG was formed to review and improve methods.
(5) Telemetry feasibility study	B, E	Field season 2018-2019	Completed.	SC66b: Some progress (SC/66b/IA05). SC67a: Some progress (SC/67a/ASI07). SC67b: Completed.
(8) DNA methylation ageing technique	B, C, D	March 2017	Completed.	SC66b: No progress. SC67a: As in SC66b. SC67b: Partially completed, further refined analysis is encouraged. See section 19.1.2.3.
(9) Hormones in blubber and sexual maturity	B, C, D	March 2018	Completed.	SC66b: No progress. SC67a: As in SC66b. SC67b: Blubber hormones analysis completed. On accuracy see section 19.1.2.4.
(10) SCAA and misassignment 'resting' females/immature females.	A, C, D	August 2016	To be completed by the mid-term review*.	SC66b: No progress. SC67a: As in SC66b. SC67b: New information presented (SC/67b/SCSP05).
(11) SCAA, density- dependence, and stock mixing	A, C, D	May 2016	Completed*.	SC66b: Partially completed: updates on stock mixing and mixing rates still necessary. SC67a: As in SC66b. SC67b: As in SC66b.
(12) Time-varying natural mortality and SCAA	A, C, D	August 2016	To be completed by the mid-term review*.	SC66b: No progress. SC67a: As in SC66b. SC67b: As in SC66b.
(13) Time varying ASM data and SCAA	A, C, D	May 2016	To be completed by the mid-term review*.	SC66b: No progress. SC67a: As in SC66b. SC67b: As in SC66b.
(15) Krill acoustic sampling	B, E	March 2017	Completed.	SC66b: Completed.
(17) Power analysis for krill abundance	A, E	August 2016	To be addressed.	SC66b: Will be addressed in consultation with CCAMLR specialists SC67a: No progress. SC67b: As in SC66b.
(18) Stomach contents vs krill survey	A, B, C	May 2016	To be addressed.	SC66b: Will be addressed in consultation with CCAMLR specialists SC67a: No progress. SC67b: As in SC66b.
(22) Energy intake (requirements)	A, B, D	August 2016	To be addressed. Need clarification from the IWC SC	SC66b: No Progress. SC67a: As in SC66b. SC67b: As in SC66b.
(23) Stable isotopes in baleen plates	B	August 2016	Completed.	SC66b: Will be addressed in consultation with other research institutions. SC67a: Some progress presented. SC67b: Completed.
(26) Sample sizes required to detect change in ASM	D	May 2016	Completed to a reasonable level	SC66b: Overall, the approach being taken to address the recommendation is appropriate, but some further refinements are required. SC67a: No Progress. SC67b: As in SC67a.

*See note in Table #, Annex U4.

19.3 JARPN II

The new information provided on JARPN II is relevant only to the discussion of the NEWREP-NP 'non-lethal vs lethal' feasibility study (see Item 19.3).

19.4 NEWREP-NP

19.4.1 Report on ongoing research

Three papers were presented on progress made during the 2017 surveys of different aspects of the NEWREP-NP programme (SP03, 06, 07, see Annex U3 for summaries).

In particular, SC/67b/SP03 reported the results of the satellite tagging ofn North Pacific sei whales. A total of 44 tagging attempts were made using SPOT6 tags with the LKArts attachments system. A total of 15 tags were deployed on sei whales, and eight whales were tracked. Two sei whales were tracked for more than 35 days, and both showed longitudinal movement. The authors concluded that the tagging experiment showed that deploying such tags from sighting/sampling vessels was practical, but identified technical improvements to try to increase the tracking period.

In discussion, it was noted that the proportion of successful deployments was low (7 failures in 15 attempts); and suggestions on how to improve this included: (a) strategic placement of tags on the upper body of whales to ensure tag longevity and reduce potential physical impacts (e.g. lesions) and (b) replacement of the current screw-on anchor system with an integrated tag design to decrease the possibility of tag breakage. It was noted that guidelines for cetacean tagging should become available within the next year and published in the IWC Journal. It was noted by the authors that the cause of the failures in SP03 were difficult to evaluate since a tag in an optimal position on the whale had also failed. New tags with a modified anchor system and stopper will be used during the next season.

The Committee welcomes new information on the feasibility of satellite tagging sei whales and notes the valuable movement data collected from two of the longer-term (>35 days) deployments. The Committee **encourages** the collection of more telemetry data and notes that this may help improve abundance estimation (by providing information on correction factors) and provide inferences on stock structure.

SC/67b/ASI10 presented a summary of results of the NEWREP-NP dedicated sighting survey in the western North Pacific in 2017 whilst SC/67b/ASI06 presented the research plan for the next systematic vessel-based sighting survey in the western North pacific under NEWREP-NP in 2018 and 2019. As indicated under Item 24.3, the new NEWREP-NP sighting cruise plan has been endorsed by the Committee; Annex Q (item 4.2) provides more details on both these papers.

19.4.2 Update on previous recommendations

The table in Annex U4, provides a detailed update of the Committee's view of progress on previous recommendations. An overview is provided in Table 26 (see next page).

Table 26

Summary of status of recommendations relevant to NEWREP-NP

No. of recommendation	Priority by the Committee	Timeline	Proponents self-evaluation on progress as of SC67b	Scientific Committee Evaluation
(1) Lethal vs non-lethal quantitative review of data	Very high	Before start	SC67a: Completed.	SC67a: Different opinions as to whether the recommendation has been met. SC67b: No progress.
(3) Sexual maturity (blubber and serum)	High	Before start	SC67a: Completed.	SC67a: The Proponents demonstrated intention to include analysis of blubber for progesterone, but there are few details of how. SC67b: Partially addressed.
(4) Sightings surveys	High	Before start and annually	Addressed and ongoing.	SC67a: Completed: survey plan was presented. SC67b: Completed: survey plan was presented.
(5) Stomach contents	High	Before start	SC67a: Completed.	SC67a: Completed.
(7) Immune function assays	High	Before start	SC67a: Completed.	SC67a: Completed.
(8) Lipophilic compounds	High	Before start	SC67a: Completed.	SC67a: Completed.
(10) Coordination with IWC-POWER	High	Before start and annually	Addressed and ongoing	SC67a: Completed annually.
(11) Coastal component: sampling strategy	High	Before start	Disagree with Panel	SC67a: No progress as proponents disagree with Panel. SC67b: No progress.
(12) Offshore components: sampling strategy	Very high	Before start	SC67a: Completed.	SC67a: Completed.
(13) downweight historical age-composition data	Very high	Before start	Disagree with Panel.	No progress.
(15) efficiency of biopsy sampling (additional captures unnecessary)	Very high	High priority ASAP in 2017	Disagree with Panel.	No progress.
(17) Telemetry	High	Before start	Ongoing	SC67a: Partially addressed. SC67b: New information (SC/67b/SCSP03).
(21) Sample size (potential reduction of lethal sample size)	Very high	Before start	To be considered by the mid-term review.	SC67a: The possibility for further work has been considered. SC67b: No progress.
(22) Sample size (in general)	Very high	Before start	Not relevant.	SC67a: Small progress. SC67b: No progress.
(23) Impact of catches on common minke whales (subset of 2013 *Implementation*)	Very high	Before start	Disagree with Panel.	SC67a: Major concerns addressed. SC67b: Completed. Refined analyses were presented. It could be reconsidered in the next *Implementation Review.*
(24) Impact of catches on common minke whales (new abundance)	Very high	Before start	Disagree with Panel.	SC67a: Major concerns addressed. SC67b: Completed. Refined analyses were presented. It could be reconsidered in the next *Implementation Review.*
(25) Sei whale (abundance, $MSYR_{1+}$=1%, $MSYR_{mat}$=4%)	Very high	Before start	SC67a: Completed.	SC67a: Completed.
(27) Higher priority to analyses and modelling	High	Before start	Ongoing	SC67a: It is not clear that additional qualified personnel have been hired. SC67b: No progress.
(28) Sample and data archiving, relational database(s)	High	Before start	Ongoing	SC67a: Partially addressed for DNA data and associated biological information.
(29) Contingency plan	High	Before start	Ongoing	SC67a: Partially addressed.

20. WHALE SANCTUARIES

20.1 Review of the Southern Ocean Sanctuary Management Plan

The Schedule amendment establishing the Southern Ocean Sanctuary (SOS) requires the Sanctuary to be reviewed at succeeding ten-year intervals, unless otherwise revised by the Commission. The first review of the SOS took place in 2004 (IWC, 2005) and the second review was completed in 2016 (IWC, 2017). In 2014 (IWC, 2015c), the Commission adopted eight objectives for the SOS (summarised in Annex R, item 3). The Commission also provided terms of reference for the review to be undertaken by the Scientific and Conservation Committees. The Scientific Committee review made several recommendations (IWC, 2017c). These recommendations were taken into account in a draft Southern Ocean Sanctuary Management Plan (SC/67b/SAN01) developed by Australian scientists and discussed in Annex R (item 3). It was noted that, while the draft Plan does contain performance measures, it does not contain criteria for its own review.

The purpose of the draft Management Plan is twofold: (1) to inform the Commission and public about the sanctuary objectives and actions planned for the next ten years; and (2) to propose strategies toward the achievement of the SOS's goals using the best means available and provide clear performance measures for each proposed action.

The operative part of the Plan is a Research and Action Plan that involves assessing and addressing threats and research on the recovery of whale populations and their habitats. The Research and Action Plan is structured based on the Commission's agreed objectives for the SOS. Each objective is linked directly to a measurable objective, action or approach and performance measure.

The Committee also discussed the potential contributions that data and results from the Japanese whale research programme in the Southern Ocean (NEWREP-A) could make to the objectives and goals of the Plan and the Committee agrees to incorporate reference to NEWREP-A under Objectives 4-6.

The amended Plan, with Objectives 1 and 8 (relating to policy) and the chapeau of Objective 5 redacted to clarify that the Committee did not address these elements of the Plan, is given as Annex R (Appendix 2).

A statement from the Government of Japan regarding its position on the SOS and this draft Management Plan is attached as Annex R, Appendix 3.

Attention: C-A, CC, SC,

The Committee reviewed the components of a draft Management Plan for the Southern Ocean Sanctuary (SOS) that are related to science and therefore within its remit and:

(a) ***endorses*** *the measurable objectives, approach/actions and performance measures of Objectives 2 -7 of the amended draft Southern Ocean Sanctuary (SOS) Management Plan (Annex R, appendix 2); and*
(b) ***agrees*** *to include a new standing item on the agendas of all relevant sub-committees and working groups: 'new information relevant to the SOS Management Plan' in order to assist the Commission in monitoring and measuring progress on the scientific objectives of the Plan.*

21. SATELLITE TAGGING DEVELOPMENT AND BEST PRACTICES

21.1 Tag Workshop Meeting, Silver Spring, MD, USA 6-8 September 2017

A workshop on cetacean tag development, tag follow-up and tagging best practices was held at the National Marine Fisheries Service in Silver Spring, Maryland, USA from 6-8 September 2017. The workshop was co-sponsored by the Office of Naval Research (ONR), the International Whaling Commission (IWC), and the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA/NMFS). The purpose of the workshop was to review and evaluate progress in tag design and attachment since the 2009 ONR Cetacean Tag workshop (ref - attached), with an emphasis on (a) recent tag attachment improvements, (b) follow-up studies that examined the effects of tagging, and (c) reviewing and providing input on draft cetacean tagging best practices guidelines.

Several presentations were made, with a focus on sharing information and discussion of the best available science of design and effects of tagging to facilitate future advancements in tag design and application, maximising attachment durations to the extent required to answer the questions being posed, whilst minimising potential impacts to the animals.

Discussion on the status of tag attachment development and follow-up studies occurred, along with extensive discussion regarding the cetacean tagging best practices guidelines. While much was accomplished towards the collective goals of the workshop, one item not covered in sufficient detail was discussion on the future directions in tag attachment technology. Therefore, a second smaller workshop will be convened in June of 2018 with a subset of the original attendees that focus specifically on tag attachments. The final report will merge the results of the September 2017 workshop and the June 2018 workshop.

22. IWC LIST OF RECOGNISED SPECIES

The Committee has agreed to follow the guidance of the Society for Marine Mammalogy's Committee on Taxonomy. This year (see Item 17.5), in completing its review of the taxonomy of *Tursiops*, the Committee noted that the current taxonomy provided by the SMM Committee for *Tursiops* was well supported by morphological and molecular genetic data, as well as ecological and distributional data.

23. IWC DATABASES & CATALOGUES

23.1 Guidelines for IWC catalogues and photo-ID databases

At last year's meeting, the Committee agreed IWC Guidelines for Photo-identification Catalogues (IWC, 2018f), noting that adding technical Appendices would be valuable in the future. Draft items for inclusion as Appendices were discussed by the *Ad hoc* Working Group on Photo-identification (Annex S, item 5.1) covering five issues: (1) cataloguing software; (2) image matching software; (3) seminal papers defining individual identification, by species; (4) photo quality guides; and (5) photo/data collection apps. Work will continue on developing these appendices intersessionally (Annex Y).

23.2 Progress with existing or proposed new catalogues

23.2.1 Integration of eastern South and Central Pacific blue, humpback, and fin whale photo-catalogues
There was no new information specific to this item this year.

23.2.2 Southern Hemisphere and Indian Ocean humpback whale catalogues

23.2.2.1 ANTARCTIC HUMPBACK WHALE CATALOGUE

The Antarctic Humpback Whale Catalogue (AHWC), maintained at College of the Atlantic, USA, was established in 1987 and during the past 30 years its data have been used in dozens of studies and publications (Stevick *et al.*, 2017). With a recent loss in funding, the catalogue database is now 'frozen' and is not being actively updated. The Working Group expressed strong disappointment at this news as well as the hope that the AHWC's funding situation will change and enable the catalogue to continue.

Attention: SC, G

The Scientific Committee has been informed that due to a loss of funding, the Antarctic Humpback Whale Catalogue curated by the College of the Atlantic, USA will no longer be updated. The Committee:

(1) ***draws attention*** *to the great value this catalogue (established in 1987) has provided to the Committee, including receiving photographs from the IWC IDCR and SOWER cruises and providing information for the Committee's Comprehensive Assessment of Southern Hemisphere humpback whales;*
(2) ***welcomes*** *news that the existing catalogue will remain a resource for scientists; and*
(3) ***encourages*** *potential funders to support future continuation of the catalogue.*

The Committee also received an update on the development and status of 'Happywhale', a web-based marine mammal photo-ID crowd-sourcing platform (SC/67b/PH05)[12]. This is discussed in Annex S (item 2.2). In recent months Happywhale provided images to catalogues relevant to the IWC and IWC-SORP of Southern right whales, Antarctic blue whales, and Antarctic killer whales. It will also contribute to the ongoing in-depth assessment of North Pacific humpback whales (see Annex F item 4.2.1).

23.2.2.2 ARABIAN SEA WHALE NETWORK'S FLUKEBOOK

In 2016 (IWC, 2017), the IWC approved funding for the development of a regional data platform for the Arabian Sea Whale Network (ASWN), to be implemented in collaboration with Wild Me, the developers of Flukebook. This year the Committee received information SC/67B/PH/03 that described Flukebook, a non-profit, open source cetacean data archiving and photo matching tool as discussed in Annex S (item 2.1; SC/67B/PH/03). The ASWN is joining Flukebook with two primary objectives: (1) to consolidate and more effectively manage humpback whale and other cetacean data collected in Oman over the past 20 years; and (2) to provide an online platform that will allow comparison and regional-level analysis of cetacean data collected by different research groups throughout the Arabian Sea (so far photographs are mainly from Oman, with a few from Pakistan and India). The Committee **looks forward** to updates on this work.

23.2.3 Southern Hemisphere Antarctic and pygmy blue whales: Catalogues and databases

23.2.3.1 SOUTHERN HEMISPHERE BLUE WHALE CATALOGUE (SHBWC)

The SHBWC has become the largest repository of Southern Hemisphere blue whale photo-identifications. It now includes a total of 1,519 individual blue whale photo-identifications from areas off Antarctica, Chile, Peru, Ecuador-Galapagos, Eastern Tropical Pacific (ETP), Australia, Timor Leste, New Zealand, southern Africa, Madagascar and Sri Lanka. The Committee received information on the progress made with the catalogue (SC/67B/PH/04), especially in light of the recommendations made last year to conduct catalogue comparisons in the Indo-Australian region (IWC, 2018b). This is discussed in more detail in Annex S (item 3.2). Comparison work (SC/67B/SH16) found (a) no matches between Australia, New Zealand and Sri Lanka, reinforcing the hypothesis of separate populations; and (b) exchange within Australia, suggested a single population; and (c) re-sights found in New Zealand suggest some site fidelity. Additional work is underway. The relevance of the catalogue to population assessments is discussed in Annex H Item 7.1.1.2.

23.2.3.2 ANTARCTIC BLUE WHALE CATALOGUE (ABWC)

In 2017, the Antarctic Blue Whale Catalogue compared photographs from the IWC IDCR/SOWER cruises in 1989/1990, 1993/1994, and 1997/1998 as well as opportunistic photographs collected by collegial scientists, naturalists, and tourists 2015-2018. The catalogue now contains almost 460 individuals. The results of the comparison of new Antarctic blue whale identification photographs to the ABWC is summarised in SC/67B/PH02 and discussed in Annex S (item 3.1); 17 new individual blue whales were identified. The collection of Antarctic blue whale identification photographs provide data for capture-recapture estimates of abundance (SC/67B/SH08) as well as information on the movement of individual blue whales within the Antarctic region. The relevance of the catalogue to population assessments is discussed Annex H, Item 7.1.1.1.

Attention: SC

(1) The Southern Hemisphere Blue Whale Catalogue provides data useful for estimating abundances and examining connectivity between feeding and breeding grounds. The Committee ***agrees*** *that the catalogue continue.*
(2) The Committee ***agrees*** *that the Antarctic Blue Whale Catalogue continue its work collecting adding photo-identification data to the catalogue in order to assist with developing estimates of population abundance for Antarctic blue whales.*
(3) The Committee ***agrees*** *that the development of a simple guide (physical and electronic versions) to help tourists and naturalists take photos that are suitable for photo-identification should be undertaken. This will support the photo-ID*

[12] https://happywhale.com

catalogues from the Antarctic region for use in population assessments by the IWC, particularly for blue whales, right whales, fin whales, and humpback whales.

23.2.4 Southern Hemisphere fin whale photo catalogues

The Committee received information on on a new photo-identification catalogue of Antarctic fin whales. Photographs from SOWER cruises 2004-2008 are included as well as those collected opportunistically near the South Orkney Islands during a Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) fisheries research voyage (SC/67B/PH01). This is discussed in Annex S (item 4.1). The catalogue serves as a foundation for future photo-ID studies, especially those proposed for the western Antarctic Peninsula. The relevance of the photo-identification of fin whales to population assessments is discussed Annex H, Item 7.1.2.

Attention: S, SC

*1) The Committee **encourages** continuation of the Antarctic Fin Whale Catalogue which can potentially provide data toward estimating abundance or identifying movement patterns.*
*2)The Committee **agrees** that an exhaustive search be conducted to locate SOWER photos that are missing from the IWC archives, including those of fin whales.*

23.2.5 Western Pacific gray whale photo catalogues

The Committee received information on two photo-identification catalogues relating to the Sakhalin Island feeding aggregation: one (SC/67B/ASI04), based on work undertaken as part of an industry-sponsored Exxon Neftegas Limited-Sakhalin Energy Investment Company joint monitoring program discussed in Annex S, item 4.2); and the other conducted by the Russia gray whale project (SC/76b/CMP/7) discussed in Annex O (item 2.1.3). The Committee welcomed news that the two catalogues would be unified under the auspices of the IWC.

23.3 Work plan

The work plan on work related to catalogues is provided in Table 27.

Table 27

Work plan on issues related to catalogues.

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Appendices for IWC Guidelines for Photo-identification	Continue compilation	Appendices ready for review	Continue compilation	Appendices ready for review
Upload all available New Zealand blue whale identification photographs to SHBWC (also pertains to Annex H item 7.1.1)	Cross-reference between separate area catalogue holdings before uploading to SHBWC avoid duplication; intersessional correspondence group (Annex Y)	Included in SHBWC report	-	-
Development of how-to photo-ID materials for naturalists and citizen scientists (also pertains to Annex H item 7.1.1.2)	Prepare hard copy and PPT photo-ID guides	Guide completed and available (pending funding)		
4) Search for missing SOWER photographs, especially fin whale photos from 2006/2007	Search Secretariat archives and contact SOWER researchers for personal copies of photos	Report		

23.4 Potential future IWC databases

23.4.1 Global database for disentanglement activities

As discussed under Item 13.2, development of a dedicated entanglement database will be considered further at the June 2018 meeting of the Global Whale Entanglement Response Network (see Annex J, item 2.3).

23.4.2 Global bycatch database

No new information was presented on the development of a global bycatch database was presented this year. Consideration of such a database could take place as part of the Bycatch Mitigation Initiative and should it be taken further, follow the guidelines for the proposal of new databases developed last year (IWC, 2018, pp. 403-404).

23.4.3 Development of simple technical guidelines for new proposals

No changes were suggested to the guidelines developed at last year's meeting (IWC, 2018, pp. 403-404).

24. IWC MULTINATIONAL RESEARCH PROGRAMMES AND NATIONAL RESEARCH CRUISES THAT REQUIRE IWC ENDORSEMENT

24.1 IWC-POWER

The Committee received the results of the 8th annual IWC-POWER cruise conducted between 3 July and 25 September 2017 in the eastern Bering Sea. Researchers from Japan, USA and IWC participated on the surveys (SC/67b/ASI12). The Committee also received the report of the planning meeting for the 2018 IWC-POWER cruise, which will be conducted in the central Bering Sea, and cruise plans for the 2019 and 2020 cruises (SC/67b/Rep02). Details and preliminary results of the 2017 IWC-POWER survey and future plans for 2018, 2019 and 2020 are provided in Annex Q, item 4.1.

Attention: SC, C-A, CG-R

*The Committee **reiterates** to the Commission the great value of the data contributed by the IWC-POWER cruises which cover many regions of the North Pacific Ocean not surveyed in recent years and so address an important information gap for several large whales. The Committee:*

*(1) **thanks** Japan who generously supplies the vessel and crew, for their continued support of this IWC programme;*

*(2) **thanks** the USA who provided an acoustician and acoustic equipment for the 2017 cruise and will do so for the 2018 cruise;*

*(2) **agrees** that the 2017 cruise was duly conducted following the requirements and guideline of the Committee (IWC, 2012) and looks forward to receiving abundance estimates based on these data;*

*(3) **endorses** the plans for the 2018, 2019 and 2020 POWER cruise and **recommends** a meeting of the Technical Advisory Group along with the planning meetings for 2019 and 2020 cruises;*

*(4) **strongly recommends** that Russia facilitates the proposed research by providing permits for the IWC-POWER cruise to survey the Russian Exclusive Economic Zone in 2019;*

*(5) **looks forward** to receiving a report from the 2018 survey at the next SC meeting.*

24.2 Southern Ocean Research Partnership (IWC-SORP)

The Southern Ocean Research Partnership (IWC-SORP) was established in March 2009 as a multi-lateral, non-lethal scientific research programme with the aim of improving the coordinated and cooperative delivery of science to the IWC. The Partnership currently has 13 member countries: Argentina, Australia, Belgium, Brazil, Chile, France, Germany, Italy, New Zealand, Norway, South Africa, the United States of America, and Luxembourg was welcomed at this meeting. New members are warmly welcomed.

There are five ongoing IWC-SORP themes:

(1) 'The Antarctic Blue Whale Project';

(2) 'Distribution, relative abundance, migration patterns and foraging ecology of three ecotypes of killer whales in the Southern Ocean';

(3) 'Foraging ecology and predator-prey interactions between baleen whales and krill';

(4) 'Distribution and extent of mixing of Southern Hemisphere humpback whale populations around Antarctica?' focused initially on east Australia and Oceania; and

(5) 'Acoustic trends in abundance, distribution, and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean'.

Bell presented the IWC-SORP Annual Report 2017/18 on the continued progress of research undertaken researchers involved in the five themes since last year (SC/67b/SH21). This progress includes the production of 33 peer-reviewed publications during 2017/18, bringing the total number of peer-reviewed publications related to IWC-SORP since the start of the initiative to 126. In addition, 125 IWC-SORP related papers have been submitted to the Scientific Committee, 22 of them this year.

Fieldtrips were undertaken to a variety of places during the past year, including the western Antarctic Peninsula, Marion Island, the Ross Sea, the Chesterfield-Bellona Reef complex west of mainland New Caledonia, and the Great Barrier Reef, Australia. Thousands of images for photo-identification have been collected; a variety of satellite tag-types deployed on Antarctic minke whales, humpback whales and killer whales as well as biopsy samples collected from these same species; video suction cup tags have been deployed on Antarctic minke whales and humpback whales; and hundreds of hours of acoustic recordings have been made and analysed. The support of tour companies in providing opportunistic research platforms to facilitate these activities and external data contributors were acknowledged by the Committee.

Attention: SC, G

The Committee reiterates the great value of the IWC-SORP (Southern Ocean Research Partnership) programme to its work. The Committee:

(1) ***encourages*** *the continuation of the Southern Ocean Research Partnership programme;*

(2) ***commends*** *the researchers involved who are key to the overall success of the Partnership in IWC-SORP for:*

(a) the impressive quantity of work carried out across diverse member nations;

(b) their contributions to the work of the Committee; and

(3) ***encourages****:*

(a) the continued development, testing and implementation of leading edge technology; and

(b) the continued development of collaborations between ships of opportunity and external bodies that can provide platforms for research and/or contribute data, inter alia, photo-identification data, to IWC-SORP and the wider Committee

24.2.1 Workplan

The work plan for issues related to IWC-SORP is given in Table 28.

Table 28

Workplan for the Southern Ocean Research Partnership.

Topic	Intersessional 2018/19	2019 Annual Meeting (SC/68a)	Intersessional 2019/20	2020 Annual meeting
Analyses	Continued analysis of data/samples from previous IWC-SORP voyages/fieldwork	Report	Continued analysis of data/samples from previous IWC-SORP voyages/fieldwork	Report
Voyages	Argentine coastguard *'Tango'* voyage along Western Antarctic Pensinsula (early 2019)	Cruise report		
	Almirante Maximiano voyage along Western Antarctic Pensinsula (early 2019)	Cruise report		
	Australian-led *RV Investigator* voyage to Ross Sea (early 2019)	Cruise report		
	New Zealand-led *RV Tangaroa* voyage to Ross Sea (early 2019)	Cruise report		
	German-led *RV Polarstern* voyage to Scotia Sea (early 2019)	Cruise report		
	Baleen whale and krill research voyages along Western Antarctic Peninsula	Reports	Baleen whale and krill research voyages along Western Antarctic Peninsula	Reports
Ships of opportunity	Continued use of ships of opportunity to conduct cetacean research	Reports	Continued use of ships of opportunity to conduct cetacean research	Reports
Acoustics	Retrieval and redeployment of passive acoustic recorders	Report	Retrieval and redeployment of passive acoustic recorders	Report
	Completion of annotated library of acoustic detections	Report		

24.3 National cruises that require IWC oversight

The Committee welcomed plans for national research cruises to be conducted in the intersessional period of 2018-2019. Details on the cruise plans and cruise reports are presented in Annex Q, item 4.2.

Attention: SC, C-A

The Committee ***recognises*** *the great value to its work provided by data from national cruises. The Committee:*

(1) ***endorses*** *the proposed sighting survey plans for cruises to be conducted with IWC oversight in the southwestern Okhotsk Sea by Russia, and in the North Pacific and the Antarctic by Japan; and*
(2) ***encourages*** *submission of abundance estimates from these studies the future.*

24.4 Review of cruise reports from national programs with IWC oversight

The Committee considered a process to optimise the review of cruise reports from national research programs with IWC oversight. Details are given in Annex Q, item 2.7

Attention: SC, CG-R

*The Committee **recognises** the value of information provided by national cruises with IWC oversight. The Committee noted that a process to optimise the review of national cruise reports is needed and*

*(1) **recommends** contracting governments to submit reports of multi-year cruises with IWC oversight biennially, in years between Commission meetings (e.g., SC "A" years);*
*(2) **agrees** that cruise reports will be summarised in a table;*
*(3) **notes** that that in certain circumstances, cruise reports may require additional evaluation; and*
*(4) **agrees** that the 'Requirements and Guidelines for Conducting Surveys and Analysing Data within the Revised Management Scheme' should be modified at next year's meeting to accommodate procedural changes with respect to the submission and review of national cruise reports.*

24.5 Work Plan
The Committee's work plan for continuing the IWC-POWER programme in 2019 and 2020 is provided below in Table 29.

Table 29

Workplan for issues related to IWC-POWER.

Item	Intersessional 2018-19	SC68a	Intersessional 2019-20	SC68b
IWC-POWER Cruise	Conduct 2018 survey and planning meeting for the 2019 Cruise (Bering Sea)	Review cruise report, report from the planning meeting and new abundance estimates from IWC-POWER cruises.	Conduct 2019 survey and planning meeting for the 2020 Cruise	Review cruise report, report from the planning meeting and new abundance estimates from IWC-POWER cruises.

25. SCIENTIFIC COMMITTEE BUDGET FOR THE CURRENT BIENNUM

25.1 Status of previously funded research, workshop proposals, data processing and computing needs

25.1.1 Funded proposals for the current biennium 2017-2018
Table 30summarises the status of the work funded by the Committee last year. The majority have been completed, but several remain ongoing. The projects all contributed considerably to the work of the Committee and the Committee thanked all of those involved.

25.1.2 Funded proposals in previous years still ongoing
A number of projects from previous years are still ongoing (see Table 30). These are all still of great value to the Committee and should be completed before the next meeting. Details of all ongoing projects can be found in SC/67B/01 Rev1.

25.1.3 Report on funds reallocations and contingencies for the Research Fund, Voluntary Fund for Small Cetaceans and SORP Voluntary Fund
SC/67b/01Rev1 provides information on the actual position against budget for the Research fund for 2017 as well as the position to 31st March for the 2018 financial year. The paper gives summary level and detailed information for the Research fund as well as the expected level of contingency available, which remains static at around 10% of the Research budget, or £32k. The document also provides details of the reallocations of budget amongst budget headings for 2017 and the 2018 year-to-date. Annex 1 gives a detailed position along with a status report for each budget line. Section 3 also provides details of voluntary funds which relate to Scientific Committee business – the Gray Whale Tagging Fund, the Small Cetaceans Fund and the SORP fund. For each there is an update of 2017 expenditure and 2018 to-date information along with details of commitments to future work in these funds.

Table 30

Summary of progress on proposals funded at SC67a

SC/67a RP no.	Title	Status
SC01	Invited Participants - SC/67b	Completed
IA01(67a)	Workshop for an in-depth assessment of North Pacific humpback whales	Ongoing (Annex F)
EM01	Two joint SC-CAMLR and IWC-SC Workshops	Ongoing (Annex L)
AWMP01	AWMP first intersessional Workshop and genetic work	Completed (SC/67b/Rep06)
AWMP02	AWMP second intersessional Workshop	Completed (SC/67b/Rep06)
CMP01(67a)	5th Workshop on the rangewide review of population structure and status of North Pacific gray whales	Completed (SC/67b/Rep07rev1)
BRG04	Satellite tagging best practices Workshop	Ongoing, Item 21
WW01	Intersessional Workshop: data gaps and modelling requirements for assessing the impacts of whale watching	Completed (SC/67b/Rep03rev1)
RMP01	Intersessional Workshop: *Implementation Review* of North Pacific Bryde's whales	Completed (SC/67b/Rep02)
RMP01(67a)	Intersessional Workshop: *Implementation Review* for Western North Pacific minke whales	Completed (SC/67b/Rep05)
WW01(67a)	Review CC Strategic plan on whalewatching pre-meeting on intersessional workshop	Completed (Annex N)
E05/E01(67a)	Cumulative impacts - pre-meeting or intersessional meeting	Completed (Annex K)
SM01	Intersessional Workshop: resolving *Tursiops* taxonomy	Completed (SC/67b/SM18rev1)
SM01(67a)	Intersessional Workshop: boto mortality	Completed (SC/67b/Rep01)
SH07	Defining blue whale population boundaries and estimating associated historical catches, using catch data in the Southern Hemisphere and northern Indian Ocean	Completed (SC/67b/SH23)
AWMP02	AWMP developers fund	Completed (Annex D)
IA02	Assessment modelling for an in-depth assessment of North Pacific sei whales	Ongoing (SC/67b/IA01)
RMP02	Essential computing support to the Secretariat for RMP	Completed (Annex D)
Research		
BRG01	Aerial photographic survey of southern right whales on the South Africa Cape nursery ground	Completed (SC/67b/SH01)
BRG03	Passive acoustic monitoring of the eastern South Pacific southern right whales, improving CMP outputs	Completed (SC/67b/CMP18)
SH03a	Northern Indian Ocean humpback subspecies determination-genetics	Ongoing (Annex H)
IA03	IWC-POWER cruise	Completed (SC/67b/Rep04)
SH01(67a)	Coding for Australian blue whale photo catalogue	Ongoing (Annex PH)
E02(67a)	Mercury in cetaceans (requested by the Commission)	Ongoing (SC/67a/E08)
SH02	Southern Hemisphere Blue Whale Catalogue	Completed (SC/67a/PH04)
SH08	Development of a permanent blue whale song reference library	Completed (SC/67a/SH11Rev1)
HIM01	Ship Strike Database Coordinator	Completed (SC/67a/HIM11)
E01	Cetacean Diseases of Concern	Ongoing (Annex K)
E03(67a)	IWC strandings initiative	Ongoing (Annex K)
E04	SOCER (State of the Cetacean Environment Report)	Completed (SC/67a/E01)

The Committee received a brief report on the IWC-SORP Research Fund. Following an open, competitive Call for Proposals (26 July to 17 August 2016) a total of £144,058 GBP was allocated from the IWC-SORP Research Fund to 10 research projects, ahead of the 2016-2017 austral summer survey season. Progress on these projects is detailed in SC/67b/SH18.

The Committee also noted that since SC67a, substantial vessel time has also been secured by IWC-SORP researchers for the 2019 and 2020 austral field seasons.

Attention: C, F&A, S

A full report on the new Call for Proposals, opened in September 2017 and closed in January 2018, was also received. A total of 19 proposals were received and evaluated by the Assessment Panel under the coordination of the Chair of the Scientific Committee. The Committee thanks Fortuna for convening the Assessment Panel and expressed its gratitude to the Panel members who all provided valuable and thoughtful input into the assessment process. The Committee welcomes the outcome of the Assessment Group and agrees with the allocation of a total of £493,544 GBP from the IWC-SORP Fund to 15 projects (Table 31).

The Committee agrees on these recommended allocations and requests the Secretariat to submit them to the Finance and Administration Committee, as soon as feasible, for it consideration. Should the Commission endorse these financial recommendations, the Committee requests the Secretariat to inform successful and unsuccessful proponent immediately after the next Commission's meeting.

Table 31
List of the funding allocations by project recommended by the IWC-SORP Assessment Panel

ID	Chief Investigator	Title	Requested amount (£)	Recommended amount (£)	Level of funding (Partial/Full)
1	Baker & Steel	Is migratory connectivity of humpback whales in the Central and Eastern South Pacific changing? A decadal comparison by DNA profiling	27,598	26,375 (deducted in house instrument expenses)	P
2	Charrassin	Application of satellite telemetry data to better understand the breeding strategies of humpback whales in the Southern Hemisphere	21,200	21,200	F
3	Branch	Modelling somatic growth and sex ratios to predict population-level impacts of whaling on Antarctic blue whales	32,594	32,594	F
4	Friedlaender & Constantine	Pregnancy rates in Southern Ocean humpback whales: implications for population recovery and health across multiple populations	29,334	19,984 (equipment deducted and some analytical costs)	P
5	Herr	Recovery status and ecology of Southern Hemisphere fin whales (*Balaenoptera physalus*)	82,300	81,900 (equipment deducted)	P
6	Friedlaender & Constantine	A circumpolar analysis of foraging behaviour of baleen whales in Antarctica: Using state-space models to quantify the influence of oceanographic regimes on behaviour and movement patterns	34,711	34,711	F
7	Buchan & Miller	A standardized analytical framework for robustly detecting trends in passive acoustic data: A long-term, circumpolar comparison of call-densities of Antarctic blue and fin whales	43,369	41,369 (publication costs)	P
8	Lang & Archer	Inferring the demographic history of blue and fin whales in the Antarctic using mitogenomic sequences generated from historical baleen	22,710	22,710	F
9	Zerbini & Clapham	Assessing blubber thickness to inform satellite tag development and deployment on Southern Ocean whales	22,646	22,426 (supply costs deducted)	P
10	Širović & Stafford	Acoustic ecology of foraging Antarctic blue whales in the vicinity of Antarctic krill studied during AAD interdisciplinary voyage aboard the *RV Investigator*	34,183	30,107 (airfares deducted)	P
12	Kelly &Maire	Development of statistical and technical methods to support the use of long-range UAVs to assess and monitor cetacean populations in the Southern Ocean	30,576	30,576	F
13	Reisinger & de Bruyn	An integrative assessment of the ecology and connectivity of killer whale populations in the southern Atlantic and Indian Oceans	33,650	33,650	F
14	Bengston Nash	Implementation of humpback whales for Antarctic sea-ice ecosystem monitoring; Inter-program methodology transfer for effective circumpolar surveillance	91,202	51,555 (equipment costs deducted)	P
17	Carroll, Torres, Graham	Circumpolar foraging ecology of southern right whales: past and present	21,290	21,290	F
18	Iñíguez Bessega	Habitat use, seasonality and population structure of baleen and toothed whales in the Scotia sea and the western Antarctic Peninsula using visual and passive acoustic methods and genetics	26,579	23,097 (equipment costs reduced, communication & network costs deducted)	P
		TOTAL	693,195	493,544	

Finally, the Committee was informed that the next Call should open prior to SC/68b (i.e. late 2019/early 2020) in readiness for IWC68 (2020). This timing would allow strategic prioritisation of the research toward which the Call is directed in order to meet IWC-SORP and IWC/SC priorities; allow knowledge gaps to be identified; and allow the IWC-SORP SSC to seek additional funding to augment the funds available in the IWC-SORP Research Fund.

26. COMMITTEE PRIORITIES AND INITIAL AGENDA FOR THE BIENNUM 2019-2020

The Committee's priorities and work plan by broad subject matter are provided in Tables under the relevant agenda items.

*The Committee **agrees** that the Chair, Vice-Chair and Head of Science, in co-operation with the Convenors, should examine the individual work plans by topic and develop an overall Committee biennial workplan and priorities taking into account the overall work load, meeting venues and efficiency. This should be submitted to the Commission meeting as an Annex to their two-year overview.*

27. SCIENTIFIC COMMITTEE BUDGET FOR THE BIENNUM 2019-2020

27.2 Budget for the next biennium

As in 2016, the Committee has developed a two-year budget, based on the proposed work plans. The process given in Annex S IWC, 2016) was applied, with extensive discussion carried out in each of the sub-committees and Working Groups to establish priorities among the presented proposals. Funding was not approved for one project (*Gulf of Penas, Southern right whales*) as further information is needed before funding can be agreed. The savings from 2018, some self-reductions and adjustments between years allowed inclusion of all funding proposals for 2019 and 2020 in the new budget of £315,800 per year.

Table 32

Workshop proposals agreed during this meeting (TBD: to be decided).

Title	Relevance	Date	Venue
Western gray whale update of CMP and conservation issues within modelling framework	CMP		
Marine debris	E	December 2019	Barcelona, Spain
Noise pre-meeting	E	Pre-meeting 2020	TBD
Cetaceans & ecosystem functioning: a gap analysis*	EM	TBD	TBD
Joint IWC-IUCN workshop to evaluate how the data and process used to identify Important Marine Mammal Areas (IMMAs) can assist the IWC to identify areas of high risk for ship strike	HIM	April 2019	Greece
Comprehensive Assessment of North Pacific humpback whales	NH		
Comparative biology, health, status & future of NA right whales	NH	Late 2019	Boston, USA
Implementation Review: North Pacific minke whales	RMP		
Catch series: Southern right whales	SH	Pre-meeting 2020	TBD
Intersessional workshop of the task team on South Asian River dolphins	SM	Feb 2019	TBD
Guiana dolphin pre-assessment	SM	October 2019	Curitiba, Brazil
Modelling whale watching impacts (MAWI)	WW	December 2019	
POWER planning meeting	ASI	Oct 2018	Tokyo, Japan
Wildmeat workshop	SM	Late 2019/early 2020	Africa
Tagging best practices	ASI	Jun 2018	Seattle, USA

* Japan referred to its statement on the adoption of the Agenda (Annex Z) and considered that several of the items for the proposed workshop (Item 16.4.4) are outside the competence of IWC. Therefore, it cannot support the proposed workshop or associated funding from the Committee's budget.

Table 33 shows the Committee budget requests for the biennium for each of the proposed priority activities.

27.2.1 Invited Participants

INVITED PARTICIPANTS

Invited participants (IPs) are a vital component of the working of the IWC's Scientific Committee. IPs contribute in many ways including as sub-committees and Working Groups Convenors, co-Convenors and rapporteurs, subject area experts and Convenors of intersessional groups. All sub-committees and Working Groups benefit from this budget item. This year under this budget item, 62 scientists from Australia, Argentina, Belgium. Brazil, Canada, Chile, China, Colombia, France, Germany, Italy, Japan, Mexico, Netherlands, Norway, Oman, Peru, Slovenia, South Africa, Spain, UK, USA were supported.

27.2.2 Workshops

RP16 WESTERN GRAY WHALE UPDATE OF CMP AND CONSERVATION ISSUES WITHIN MODELLING FRAMEWORK

The CMP is over 10 years old and requires updating. Initial work has been undertaken but the results of the rangewide workshop need to be incorporated and conservation-related questions need to be developed that can be addressed within the new population modelling framework developed as a result of the Committee's work. This is primarily related to the CMP and AWMP groups, however, it is also of importance to the work of IA and ASI in terms of precedents for future assessments and the work of HIM in terms of examining scenarios that take into account bycatch and the uncertainty associated with estimating it.

RP06 MARINE DEBRIS WORKSHOP

There remains an urgent need to better understand and address the threats posed by marine debris to cetaceans. The most effective way to do this, building on earlier work by the IWC and taking into account the greatly expanded interest in this topic by many other international bodies, is to hold a workshop. It is proposed that the workshop is held in Barcelona in December 2019 just before the World Conference on Marine Mammalogy (the joint meeting of the SMM and ECS).

RP05 NOISE PRE-MEETING

The sub-committee on Environmental Concerns will address Anthropogenic Noise as a focus topic during the Scientific Committee meeting in 2020. A pre-meeting workshop is proposed for SC68b, to address emerging issues related to the management of underwater noise and its impacts on marine species.

RP08 CETACEANS & ECOSYSTEM FUNCTIONING: A GAP ANALYSIS

Experts on the role and impact of cetaceans on ecosystem functioning will participate in a workshop/pre-meeting to discuss the current state of knowledge on the ecosystem functioning provided by cetaceans as requested by the Commission in Resolution 2016-3. This Resolution directed 'the Scientific Committee to further incorporate the contribution made by live cetaceans to ecosystem functioning into [its] work' and asked 'the Scientific Committee to screen the existing research studies on the contribution of cetaceans to ecosystem functioning, to develop a gap analysis regarding research and to develop a plan for remaining research needs'.

RP17 JOINT IWC-IUCN WORKSHOP TO EVALUATE HOW THE DATA AND PROCESS USED TO IDENTIFY IMPORTANT MARINE MAMMAL AREAS (IMMAS) CAN ASSIST THE IWC TO IDENTIFY AREAS OF HIGH RISK FOR SHIP STRIKE

The identification of 'high risk areas' for ship strikes of cetaceans is a key step toward establishing mitigation actions, through scheduling, re-routing or speed reduction. IUCN's proposed initiative to identify Important Marine Mammal Areas (IMMAs), would likely assist this effort. The SC has encouraged cooperation with the IUCN Task Force on this. The IUCN TF has completed three regional IMMA workshops, including the Mediterranean Sea. This proposed joint workshop will focus on identifying overlap between shipping and the IMMAs identified in the Mediterranean Sea.

Table 33
Summary of budget requests for the 2019-20 period. For explanation and details of each project see text.

RP no.	Title	Sub-committee/ working group	2019 (£)	2020 (£)
Invited Participants				
	Invited Participants - SC/68a and SC/68b	SC	85,000	65,000
Meeting/Workshop				
RP16	Western gray whale update of CMP and conservation issues within modelling framework	CMP	10,500	0
RP06	Marine debris	E	0	20,000[1]
RP05	Noise pre-meeting	E	0	12,000
RP08	Cetaceans & ecosystem functioning: a gap analysis	EM	0[2]	0
RP17	Joint IWC-IUCN workshop to evaluate how the data and process used to identify Important Marine Mammal Areas (IMMAs) can assist the IWC to identify areas of high risk for ship strike	HIM	10,000	0
RP19	Comprehensive Assessment of North Pacific humpback whales	NH	1000[3]	0
RP37	Comparative biology, health, status & future of NA right whales	NH		20,000
RP21	*Implementation Review*: North Pacific minke whales	RMP	13,000[4]	15,000
RP29	Catch series: Southern right whales	SH	0	15,800
RP25	Intersessional workshop of the task team on South Asian River dolphins	SM	7,000[5]	0
RP26	Guiana dolphin pre-assessment	SM	0	9,990
RP27	Modelling whale watching impacts (MAWI)	WW	0	17,000[6]
Modelling/computing				
RP20	In Depth Assessment of North Pacific sei whales	ASI	5,000	0
RP22	Develop an age-structured emulator for the individual-based energetics model (IBEM)	RMP	7,000	0
RP23	Essential computing support	RMP	11,500	11,500
RP36	Simulating line transect data to investigate robustness of novel analysis methods	ASI	6,000	0
Research				
RP01	IWC-POWER cruise	ASI	22,500[7]	22,500[8]
RP11	Abundance estimates of the franciscana dolphin in Buenos Aires province, Argentina	CMP	7,100	0
RP09	Gulf of Penas, Southern right whales	CMP	0	0[9]
RP10	Population dynamics of southern right whales at Península Valdés, Argentina	CMP	19,130	0
RP12	ES Pacific Southern right whales acoustic monitoring	CMP	13,700	16,800
RP13	Sample holotype specimen of *Megaptera indica* at the Muséum National d'Histoire Naturelle (Paris)	CMP	0	1,975
RP14	Assessing isolation of Arabian Sea humpback whales and continuity across the Arabian Sea through geographic variation in song	CMP	16,400	0
RP15	Quantitative assessment of threats to Arabian Sea humpback whales using existing photographic and UAV data	CMP	9,500	0
RP24	Collaborative analysis of WNP minke whale stock structure	SD-DNA	6,247	0
RP28	Updated catch series and assessments of four pygmy blue whale populations	SH	0[10]	12,865
RP30	Multi-ocean analysis of southern right whale demographic parameters and environmental correlates	SH	13,600	13,600
RP31	Southern Hemisphere fin whale song	SH	0	12,000
RP34	Photo-Identification information placards for naturalists and citizen scientists	SH	1000	0
RP07	IWC strandings initiative – emergency response and investigations	E	4,500	4,500
Databases				
RP18	Ship strikes database coordinator	HIM	7,000[11]	7,000[12]
RP33	Antarctic Blue Whale Catalogue: comparison of new photographs from 2014-20	SH	3,000	800
RP32	Southern Hemisphere blue whale photo catalogue	SH	16,810	3,000[13]
RP38	Secretariat database management	SC	3,000	3,000
Reports				
RP03	Mercury in cetaceans	E	0[14]	0
RP04	State of the Cetacean Environment Report	E	3,000[15]	3,000[16]
RP02	Amendment of RMP Guidelines to incorporate spatial modelling approaches to estimate abundance	RMP	3,000	0
General items				
	Implementation: resolutions and instructions from Commission & follow up from previous years' recommendations	SC	10,313	28,470
Total request			£315,800	£315,800

Notes: [1]Budget was reduced from £22,200, [2]£20,300 was the expected financial need for 2019 but savings from 2018 allowed for the reduced budget of £0; [3]£11,400 was the expected financial need for 2019 but savings from 2018 allowed for the reduced budget of £1,000; [4]£15,000 was the expected financial need for 2019 but savings from 2018 allowed for the reduced budget of £13,000. [5]Budget was reduced from £8,958, [6]£20,000 was the expected financial need for 2020 but financial savings for 2018 allowed for the reduced budget of £17,000, [7]£32,500 was the expected need for 2019 but financial savings from 2017 allowed for the reduced budget of £22,500, [8]£32,500 was the expected need for 2020 but financial savings from 2018 allowed for the reduced budget of £22,500, [9]The requested budget was £15,000 but further information is required before funding can be considered. The project will be re-evaluated at the 2019 SC meeting, [10]£6,185 was the expected financial need for 2019 but financial savings from 2018 allowed for the reduced budget of £0, [11]budget was reduced from £10,000, [12]budget was reduced from £10,000, [13]funding of approximately £7,280 may be requested for 2020 next year depending on progress, [14]£4,000 was the expected financial need for 2019 but savings from 2018 allowed for the reduced budget of £0, [15]budget was reduced from £4,000, [16]budget was reduced from £4,000.

27.2.1 Invited Participants

INVITED PARTICIPANTS

Invited participants (IPs) are a vital component of the working of the IWC's Scientific Committee. IPs contribute in many ways including as sub-committees and Working Groups Convenors, co-Convenors and rapporteurs, subject area experts and Convenors of intersessional groups. All sub-committees and Working Groups benefit from this budget item. This year under this budget item, 62 scientists from Australia, Argentina, Belgium. Brazil, Canada, Chile, China, Colombia, France, Germany, Italy, Japan, Mexico, Netherlands, Norway, Oman, Peru, Slovenia, South Africa, Spain, UK, USA were supported.

RP19 COMPREHENSIVE ASSESSMENT OF NORTH PACIFIC HUMPBACK WHALES

At SC67a, following discussion of the results of an assessment workshop held in April 2017, a Steering Group was established to facilitate a second North Pacific humpback whale assessment workshop, and to coordinate work required for this meeting. This meeting was not held prior to SC67b and the workshop is now planned for prior to the 2019 meeting of the Scientific Committee, with a view to completing or significantly advancing the assessment.

RP37 BALAENID WORKSHOP: BIOLOGY, HEALTH, STATUS

The North Atlantic right whale's population rate of increase is much lower than that of all other well-studied balaenid populations. This workshop will compare reproductive biology, health and status of North Atlantic right whales with those of other balaenid populations with the goal of determining their potential for growth and assessing the role of anthropogenic mortality as a driver of current population decline. Possible causes of the NARW's lower reproductive rate need reassessment include: sub-lethal effects of entanglements; environmental contaminants or marine biotoxins; inadequate prey base; stress from noise; genetic factors; and infectious diseases. This review will also help understanding of population changes for other balaenid populations.

RP21 *IMPLEMENTATION REVIEW*: NORTH PACIFIC MINKE WHALES

These workshops are essential in order for the Committee to conduct a full *Implementation Review* for Western North Pacific common minke whales following the Committee's Requirements and Guidelines. Conducting *Implementation Reviews* are a required activity under the RMP.

RP29 CATCH SERIES: SOUTHERN RIGHT WHALES

A new review of available catch data for measuring regional takes of southern right whales is overdue and the availability of new sources suggests that it is timely to do this. The expected outcome of this workshop is updated regional estimates of southern right whale catches, which can be used to conduct regional assessments of southern right whale past exploitation and develop population trajectories to measure past abundance and current recovery levels.

RP25 INTERSESSIONAL MEETING OF THE TASK TEAM ON SOUTH ASIAN RIVER DOLPHINS

The South Asian river dolphin, *Platanista gangetica*, is listed as an endangered cetacean species by the IUCN Red List assessment. Across its range, in the countries of India, Pakistan, Nepal, and Bangladesh, the species remains highly threatened by a range of anthropogenic activities at multiple scales. These range from localised threats caused by hunting, fisheries bycatch, or local disturbances as well as from large-scale alterations of the rivers by dams, barrages, waterways and river-linking schemes. In particular, large-scale and rapidly accelerating water development in the Indo-Ganges-Brahmaputra floodplains make the outlook for the South Asian river dolphin conservation grim. In recognition of this situation, the Scientific Committee has established a Task Team for the species and the team of experts will meet in person and discuss how to go forward.

RP26 GUIANA DOLPHIN PRE-ASSESSMENT (*SOTALIA GUIANENSIS*)

An intersessional workshop will assess the geographic extent of Guiana dolphin threats and conservation measures needed in both national and international contexts. The outcomes of the workshop shall include: (1) a Comprehensive Assessment of the status of Guiana dolphins; (2) recommendations to potentially improve management actions and the monitoring efforts associated with the current conservation plans of actions; and (3) a consolidated report to be presented to the SC at next year's meeting for review.

RP27 MODELLING WHALE WATCHING IMPACTS (MAWI)

There is little research on the potential mid- and long-term impacts of whale watching on cetacean populations. This is due to the complexity of the required modelling approaches, lack of clarity regarding the data needed to inform them, and the need to identify locations suitable for data collection. Without addressing these issues understanding the potential mid- and long-term impacts of whale watching is not possible. The workshop will bring together modellers and field researchers to achieve the following outcomes: (1) identify existing modelling approaches that could be used to understand the potential mid- and long-term impacts of whale watching, and determine whether new approaches are required; (2) determine which data currently being collected are suitable for answering questions regarding the mid- and long-term impacts of whale watching, and what new data are required; and (3) determine the feasibility of data collection, and identify locations where this has already been done or could be achieved.

27.2.3 Modelling/computing

RP20 ASSESSMENT MODELING FOR AN IN-DEPTH ASSESSMENT-NORTH PACIFIC SEI WHALES

The IA sub-committee is currently conducting a Comprehensive Assessment for North Pacific sei whales. This involves evaluating the status of a population using a population dynamics model that is specific to the biological parameters and movement behaviour of that particular population and is fitted to monitoring data. During the intersessional periods after

the 2018 SC meeting and possibly also after 2019 SC meeting, it is expected that population dynamics models will be finalised and run using the existing data. This will result in an assessment of the status of the population.

RP22 DEVELOP AN AGE-STRUCTURED EMULATOR FOR THE INDIVIDUAL-BASED ENERGETICS MODEL (IBEM)

An IBEM provides an alternative population dynamics model to the usual cohort models, particularly because density dependence in births, growth and age-specific mortality are emergent properties of a species in a given environment (which can be stochastic). The IBEM is computationally infeasible for conducting *IST*s; the proposal is to develop a computationally efficient cohort model (emulator) which uses demographic parameters and their covariances generated using the IBEM.

RP23 ESSENTIAL COMPUTING SUPPORT TO THE SECRETARIAT

Regular *Implementation Reviews* are required under the RMP and AWMP. Computing support is alos required for Comprehensive and in-depth assessments. The Committee is currently about to undertake an *Implementation Review* for the North Pacific common minke whales, and more will follow. The Committee has developed a complex trials structure for *Implementation Reviews.* A key task in this process is to develop and validate the code for the simulation trials that are the core component of this process. Experience has shown that the Secretariat staff alone cannot handle this complete process themselves, so computing support is needed.

RP36 SIMULATING LINE TRANSECT DATA TO INVESTIGATE ROBUSTNESS OF NOVEL ANALYSIS METHODS

The IWC SC has already invested time and money in developing simulated line transect data to evaluate the robustness of the Norwegian minke whale and Antarctic minke whale survey data. This project will update the old code for the simulator to make it more user-friendly so that it can be made available to all SC members and to produce some standard data sets in accordance to the specifications of the ASI sub-committee.

27.2.4 Databases/catalogues

RP01 IWC-POWER CRUISE

The Committee has strongly advocated the development of an international medium- to long-term research programme involving sighting surveys to provide information for assessment, conservation and management of cetaceans in the North Pacific, including areas that have not been surveyed for decades. This is one of the most important international collaborations undertaken by the IWC and the cost to the IWC is minimal given the generous contribution of a vessel by Japan and acoustic equipment by the USA . Committee objectives have been developed for the overall plan and requested funding will allow for the continuing work of the initial phase and progress on developing the medium-term phase. The IWC contribution is for: (1) IWC researchers and equipment; (2) to allow the Committee's Technical Advisory Group to meet to review the multi-year results thus far and develop the plans for the next phase of POWER based on the results obtained from Phase I; and (3) to enable analyses to be completed prior to the 2020 Annual Meeting.

RP11 ABUNDANCE ESTIMATES OF THE FRANCISCANA DOLPHIN IN BUENOS AIRES PROVINCE, ARGENTINA

Abundance estimates of franciscanas will be based on a series of aerial surveys along the coast of Buenos Aires Province, with the same survey design of surveys carried out in 2003 and 2004 (Crespo *et al*., 2010). The new estimate will allow comparing density values with those obtained in the previous surveys. This item represents only one third of the funds required for the project, with the remainder being provided by the Government of Argentina.

RP09 GULF OF PENAS, SOUTHERN RIGHT WHALES

Eastern South Pacific (ESP) Southern right whales (SRW) are classified as critically endangered as there are no more than 50 SRW in this population and there is no information on the ESP SRW breeding and feeding grounds. Gulf of Penas is one of the most remote and exposed areas in Chile, with limited access and wild weather that have prevented its exploration. The largest baleen whale mass mortality of almost 400 sei whales occurred in this area and almost remained unnoticed. Recently, a local living nearby the Gulf of Penas recorded the presence of SRWs, including several calves. The Gulf might be the unknown breeding ground of the ESP SRW. This area will be explored during the austral winter breeding season with a group of researchers and government officers to confirm this finding and if so, start immediately working towards the protection and management of the species and the area.

RP10 POPULATION DYNAMICS OF SOUTHERN RIGHT WHALES AT PENÍNSULA VALDÉS, ARGENTINA: THE INFLUENCE OF KELP GULL LESIONS ON THE HEALTH, CHANGES IN INCREASE AND MORTALITY RATES IN THE CONTEXT OF A DENSITY-DEPENDENT PROCESS

The recent mortality of southern right whales at Península Valdés, Argentina is the highest ever recorded for the species. Understanding the causes is critical to propose management and mitigation actions. Preliminary results from glucocorticoids in baleen from stranded calves show that stress from injuries due to Kelp Gull attacks negatively affects their physiological homeostasis, potentially leading to death. Also, aerial counts show an important reduction in population rate of increase as a whole (from 7% in the past to 0.5% at present), and changes in distribution (mainly of adults) and density along the Argentinian coast.

RP12 PASSIVE ACOUSTIC MONITORING OF THE EASTERN SOUTH PACIFIC SOUTHERN RIGHT WHALE

The Eastern South Pacific southern right whale population is Critically Endangered and in 2012 the IWC adopted a Conservation Management Plan (CMP). Over the years, few opportunistic sightings have been recorded and no breeding area has yet been identified. Until a breeding ground is found many CMP priority actions cannot be implemented. Thus, in 2016 the IWC Scientific Committee decided to support this passive acoustic monitoring (PAM) project to facilitate the identification of potential breeding areas along the coast of Chile and Peru. This project seeks to obtain temporal coverage over a complete annual cycle and spatial coverage depending on the number of sites. The PAM project is likely the most

cost-effective way to investigate the seasonal and temporal distribution of southern right whales along the coast of Chile and Peru. The information will be crucial to identify aggregation areas and facilitate the implementation of CMP for this population.

RP13 SAMPLE THE HOLOTYPE SPECIMEN OF *MEGAPTERA INDICA* (GERVAIS, 1883) AT THE MUSÉUM NATIONAL D'HISTOIRE NATURELLE (PARIS)

Several lines of evidence suggest that humpback whales in the Arabian Sea/Northern Indian Ocean comprise a discrete, isolated and non-migratory population that merits a taxonomic revision. Genetic analyses of available samples are now underway in order to determine whether sub-species/species designation is merited. The resultant nomenclature will necessarily draw on a description of the type specimen of *Megaptera indica*, which is held at the Muséum National d'Histoire Naturelle in Paris. This work will develop an approach for examining and sampling this specimen so that the taxonomy of Arabian Sea humpback whales can be accurately defined, better informing regional conservation efforts, highly relevant to the IWC's stated interest in the establishment of a Conservation Management Plan for Arabian Sea humpback whales.

RP14 ASSESSING ISOLATION OF THE ARABIAN SEA HUMPBACK WHALE POPULATION AND CONTINUITY ACROSS THE ARABIAN SEA THROUGH GEOGRAPHIC VARIATION IN SONG

A study of geographic variation in humpback whale song indicates that the Arabian Sea song from Oman is distinct from the Southwest Indian Ocean (SWIO) song, and evidence from a small Indian sample suggesting continuity in song between the western and eastern Arabian Sea. This work will be followed up on with a detailed comparison of song across the Arabian Sea and continued assessment of song differences with the SWIO: The project will (1) assess the connectivity of Arabian Sea humpback whales from Oman to India by comparing existing samples of song between the two regions from several different years; and (2) assess and re-examine the differences in song exhibited between Oman and the SWIO with more recent data, particularly in light of evidence that SWIO singers were found off Oman during the Boreal summer of 2012.

RP15 A QUANTITATIVE ASSESSMENT OF THREATS TO ARABIAN SEA HUMPBACK WHALES USING EXISTING PHOTOGRAPHIC AND UAV DATA

The research will assess the prevalence of anthropogenic and natural threats to Arabian Sea humpback whales through a robust and quantitative assessment of available photographic data. These data include the entire Oman photo-ID catalogue, imagery recently acquired using UAVs (drones) and images provided by third parties. The latter include several images from elsewhere in the populations range. The project will provide an assessment of the relative prevalence of a suite of indices typically associated with major threats (fisheries entanglements, ship-strikes, other scars) as well as scars associated with natural sources (barnacles, cyamids, Penella sp., killer whales). Project outcomes will include assessment of the risks posed by each threat, as well as the development of a set of metrics with which further changes can be monitored. Project results will be reported to the IWC SC in 2019 and will contribute to the development of a draft Conservation Management Plan for this population.

RP24 COLLABORATIVE ANALYSIS OF WNP MINKE WHALE STOCK STRUCTURE USING JAPANESE MICROSATELLITE DNA DATABASE AND SPATIALLY EXPLICIT POPULATION STRUCTURE ANALYSES.

This item will help address the recommended 'analysis 2' from the report of the workshop on Western North Pacific common minke whale stock structure (SC/67b/Rep05) in support of the next intersessional meeting on WNP common minke whale stock structure. This specific aspect of the work will apply spatially explicit population structure analyses that provide greater power than the program STRUCTURE together with geographic context. The data will be analysed as a total dataset (not based on any assignment in STRUCTURE), but also include temporal subdivision to assess possible seasonal changes in patterns of connectivity. The latter aspect may be critical to understanding the true pattern of structure, but it will also be the most time-consuming, requiring extensive replication of the analyses. The results of these analyses will provide an assessment of structure in the context of biogeography using methods that have considerably more power than the program STRUCTURE and using an approach that will consider temporal patterns of movement.

RP28 UPDATED CATCH SERIES AND ASSESSMENTS OF FOUR PYGMY BLUE WHALE POPULATIONS

The SH sub-committee is conducting in-depth assessments of populations of Southern Hemisphere blue whales. Assessments have previously been conducted for two of the six populations (Antarctic blue whales, and Chilean blue whales), but not for the four pygmy blue whale populations addressed by this research. This project will provide crucial catch separation data and associated uncertainty needed to conduct stock assessments and provide the first stock assessments for each of the four populations. Such data are critical inputs for the assessments planned by the SC.

RP30 MULTI-OCEAN ANALYSIS OF SOUTHERN RIGHT WHALE DEMOGRAPHIC PARAMETERS AND ENVIRONMENTAL CORRELATES

This study aims to compare population demographics of southern right whales in Southern Hemisphere wintering grounds and investigate correlations between reproductive success and abundance trends, and environmental variables. This study is a component of the proposed SORP project - The right sentinel for climate change: linking foraging ground variability to population recovery in the southern right whale.

RP 31 ANALYSIS OF FIN WHALE SONG VARIABILITY ACROSS SOUTHERN HEMISPHERE

Fin whale songs consist of short pulses repeated at regular interpulse intervals (IPIs). These songs have been suggested as a tool to distinguish populations. Features that have be used for fin whale song separation include: spectral structure of individual pulses; their patterning; the IPIs; and presence of a higher frequency component of the pulses. Based on this higher frequency component, there appear to be two fin whale song types in the Southern Ocean. We propose to use a

combination of song feature measurements to identify whether fin whale songs in the Southern Hemisphere could be indicative of population structure. Data to be used include recorders deployed in the Western Antarctic Peninsula, Weddell Sea, and Eastern Antarctica (Kerguelen and Casey) from 2014-16. Additional SH lower-latitude recordings are available in southeastern Pacific and South Indian Ocean. Overall, the analysis will enable a comprehensive review of fin whale song variability across the SH.

RP34 PHOTO-IDENTIFICATION INFORMATION PLACARDS FOR NATURALISTS AND CITIZEN SCIENTISTS

Pre-cruise training and reference placards describing examples of photo-identification subjects (large whales) will be developed for distribution to the tourist vessel industry in the South Georgia and Antarctic Peninsula region. Information will include primary ID features used for seven species likely to be encountered; right, blue, sei, fin, humpback, sperm and killer whales (key species). A Powerpoint presentation will be developed for distribution to naturalists working on tourist vessels, to orient them and their clients to the basics of whale identification photography. Minimal training is required for a considerable improvement to the quality of identification photographs that are collected by naturalists and citizen scientists and ultimately provided to the established photo-ID catalogues from the region. A formal collaboration with the global photo-ID platform, HappyWhale will be established.

RP07 IWC STRANDINGS INITIATIVE – EMERGENCY RESPONSE AND INVESTIGATIONS

Over the next two years, the Emergency Response and Investigations fund will support response, collection of data to determine the cause(s) or contributing factors for the event and/or to fill critical data gaps identified by the SC or Commission. The Initiative will be evaluated annually and policies and procedures adapted according to feedback from responses and through Steering Group/Expert Panel advice.

27.2.5 Databases and catalogues

RP18 SHIP STRIKE DATABASE COORDINATOR

The ongoing development of the IWC ship strike database requires data gathering, communication with potential data providers and data/database management. This project will provide support for expanding and maintaining the database.

RP33 ANTARCTIC BLUE WHALE CATALOGUE: COMPARISON OF NEW PHOTOGRAPHS FROM 2014-2020

In year one (2019) this project will compare the identification photographs of an estimated 45 individual Antarctic blue whales collected during ICR cruises 2014-17, to the Antarctic Blue Whale Catalogue. These identifications would increase the size of the catalogue (458 individuals) by almost 10%. In year two (2020) additional photos representing approximately 12 IDs are expected from collaborating scientists and citizen scientists that will be compared to the catalogue. The expected outcome is an expanded dataset that may improve estimates of population abundance and reveal new information on movement patterns.

RP32 SOUTHERN HEMISPHERE BLUE WHALE PHOTO CATALOGUE

The Southern Hemisphere Blue Whale Catalogue (SHBWC) is an international collaborative effort to facilitate cross-regional comparison of blue whale photo-identifications catalogues. To date more than 1,500 individual blue whales have been contributed to the SHBWC from researchers groups working on areas off Antarctica, Chile, Peru, Ecuador-Galapagos, Eastern Tropical Pacific, Australia, Timor Leste, New Zealand, Madagascar and Sri Lanka. Therefore, the SHBWC has become the largest repository of Southern Hemisphere blue whale photo-identifications. Results of comparisons among different regions will improve the understanding of basic questions relating to blue whale populations in the Southern Hemisphere such as defining population boundaries, migratory routes, visual health assessments, and to model abundance estimates. The results will contribute primarily to the IWC Southern Hemisphere blue whale assessments.

RP38 DATABASE MANAGEMENT

The IWC Secretariat hosts several databases for the SC. These have annual service costs associated with them including, web/database servers, storage, backups, software licences and other associated infrastructure or costs.

27.5.6 Reports

RP03 MERCURY IN CETACEANS: BIOGEOCHEMICAL CYCLING, TOXICOLOGICAL IMPACTS

In response to the Commission resolution on mercury, the objective of the work is to comple the global review of mercury in cetaceans, resulting in the documentation and mapping of decadal trends. The Scientific Committee will also invite experts in mercury in the environment and its cycling and in mercury and selenium cetacean toxicology to participate to provide further detail and interpretation of the current status and potential impact of mercury on cetacean populations at an ocean basin scale.

RP04 PRODUCTION OF ANNUAL STATE OF THE CETACEAN ENVIRONMENT REPORT (SOCER) FOR THE SCIENTIFIC COMMITTEE AND COMMISSION (2019 AND 2020)

SOCER is a long-standing effort to provide information to Commissioners and Committee members on key current global developments that are affecting the cetacean environment. Focus will be on the Atlantic Ocean (2019) and the Pacific Ocean (2020). It will, in both years, also present key current global developments that are affecting the cetacean environment. It will also contain a glossary of technical terms used and species names. A 5-year compendium spanning all regions is also being produced.

RP02 AMENDMENT OF THE RMP GUIDELINES TO INCORPORATE SPATIAL MODELLING APPROACHES TO ESTIMATE ABUNDANCE

The 'Requirements and Guidelines for Conducting Surveys and Analysing Data within the Revised Management Scheme', referred to as the 'RMP Guidelines' (IWC, 2012) constitutes a document prepared by the Scientific Committee to state the requirements and to guide the collection and analysis of survey data to compute abundance estimates for use in the Revised Management Procedure (RMP). Currently this document provides detailed guidance for developing estimates using design-based line transect shipboard and aerial surveys. Amendments are required to consider other methods, for example, model-based analysis of survey data and mark-recapture models. This project will update the RMP Guidelines as required by the Scientific Committee. This update will be completed in consultation with the project's steering committee and presented for consideration of the SC by SC68b. The expected outcome is a new, revised document of with the 'RMP Guidelines'.

27.5.7 General items

***IMPLEMENTATION*: RESOLUTIONS AND INSTRUCTIONS FROM COMMISSION & FOLLOW UP FROM PREVIOUS YEARS' RECOMMENDATIONS**

This line is required to accommodate additional work requested by the Commission at IWC67 and work generated by meetings, workshops and projects funded and concluded in the first year (2019). This line can also accommodate new project proposals generated during the 2019 Scientific Committee meeting.

28. WORKING METHODS OF THE COMMITTEE

28.1 Rules of Procedure of the Scientific Committee

Attention: C, S

*As per usual practice in the last biennium the Committee has been reviewing its working methods to improve transparency and align its processes with the biennial pace of the Commission. These changes and a number of changes that were made in previous years and approved by the Commission (i.e. SORP Voluntary Fund, new process to allocate and manage the Research Fund and the Small Cetacean Voluntary Fund Rules of Procedure) require a number of adjustments and additions to the Commission Rules of Procedure, Financial Regulations and Scientific Committee Rules of Procedure. The Committee **agrees** to submit all proposed amendments to the Commission for its consideration (Annex W).*

*The updated Rules also refer to the online 'Scientific Committee Handbook' that has been updated at this meeting. The Committee **requests** the Secretariat to post the updated version online as soon as feasible. The Committee also **agrees** to that a pdf version of the Handbook be made available as a document for the Commission meeting.*

28.2 Biennial reporting and related matters

At its 2015 meeting, the Joint Conservation Committee and Scientific Committee Working Group (Joint CC/SC WG) agreed to undertake a collation and analysis of conservation-relevant recommendations from the Scientific Committee and organise these recommendations into key issues/areas highlighting those that feature regularly, including the creation of a pilot database. Double, Convenor of the Global Databases and Repositories Steering Group (GDR), presented an update on the development of this database. The Scientific Committee is fully engaged in this process and, this year, a standing agenda item was added to all sub-committee agendas to ensure a regular, more formal review of progress in delivering recommendations than was the case in the past.

Attention: SC, CC

*The Committee **welcomes** the development of the IWC Database of Recommendations, noting that this tool will give recommendations more prominence and improve the ability to measure progress. The Committee **agrees** to:*

(1) continue to improve its standardised way to present recommendations to include core information[13] to facilitate input into the database; and
(2) to work closely with the Secretariat to assist with the overall process of data entry.

28.3 Additional proposals for revisions to 'Annex P'

The Committee continued this year the work begun last year to update Annex P in response to Commission Resolution 2016-2 and recommendations by previous Expert Panels.

Attention: C-R, SC,

*The Committee **recommends** the revisions to the previous Annex P reported in Annex P in response to Resolution 2016-2 and recommendations made by Expert.*

[13] IWC/MAY18/CCSC/01

28.4 Succession plan for key Scientific Committee experts

Last year, the Committee had identified the need to consider 'succession planning' for key participants, particularly in relation to the *Implementation Reviews* and assessment processes. Informal discussions continued informally during the intersessional period and invitations were issued to three modellers to evaluate their interest in becoming active members of the IWC Scientific Committee, but only one could attend. Concern regarding succession planning of these other key positions on the Committee still remains and an intersessional group has been re-established to look at this and report back to the Committee next year (Annex Y).

The Committee also refers to its discussion related to a Deputy Head of Science in its review if the governance report (see Item 28.6.2).

28.5 Update on Data Availability requests

Suydam provided a summary of requests received under the Data Availability Agreement shown in Table 34.

Table 34

Summary of requests under the Data Availability Agreement.

Date	Requested by	Objective/Subject	Outcome
June 2015	de la Mare Australia) – Procedure B	(a) Consistent with recent advice of the Scientific Committee with particular respect to minke whale nutritive condition analyses, to develop a set of models that best capture the Committee's previous recommendations, taking into account the structure of the underlying processes giving rise to the data; and (b)To provide analyses relevant to the determination of sample sizes for detecting specified trends in the age at sexual maturity (ASM).	SC/66B/EM/02, SC/67A/EM/01, SC/67A/EM/02, SC/67A/EM/03, SC/67A/EM/04, SC/67A/EM/07, SC/67A/EM/08, SC/67B/EM/01 Rev1, SC/67B/EM/02, SC/67B/EM/03, SC/67B/EM/08, See EM Annexes, 2016 to 2018. Differing results between research groups about changes in body condition of Antarctic minke whales
January 2018	Baker (USA	The intent of the request is to examine plausible stock hypotheses. Analyses will rely primarily on tests of Hardy-Weinberg expectations, exact tests of differentiation, randomized Chi-squared tests (contingency tables), Analyses of Molecular Variance (AMOVA), as well as mixed-stock analyses, clustering methods and kinship (parent offspring pairs), to investigate dispersal and differences in haplotype frequencies, genotypes and sex for various geographic and temporal strata.	On-going

28.6 Any other matters

28.6.1 Welfare Assessment Tool

Since our last discussion in 2015 on animal welfare related matters relevant to the Committee (IWC, 2016, p.86), Dr. Nicol (Professor of the Royal Veterinary College, London) developed a 'Welfare Assessment Tool' following the recommendations of the Workshop to 'Develop Practical Guidance for the Handling of Cetacean Stranding Events' (South Africa, 2016) on this matter. This year, the Committee received a report from Nicol on the latest phase of the development of such a tool, that is being developed to help assess non-hunting related threats in the context of the IWC's Welfare Action Plan and in a joint project between the RVC and Humane Society International, supported by the UK Department for Environment, Food and Rural Affairs (Defra). The approach is based on application of the 'five domains model' (Beausoleil and Mellor, 2015; Mellor *et al*., 2015) and two hypothetical case studies have been explored, one related to marine debris and the other to whale-watching.

Trial assessments were presented and the Scientific Committee was asked for assistance and advice in the development of real examples for consideration. The Committee welcomed the information provided and further discussions were held informally. The Tool was also considered by the Whale Watching Subcommittee (see Annex N) and will be presented for consideration by the Commission at the next meeting of the Working Group on Whale Killing Methods and Associated Welfare Issues.

28.6.2 Review of the IWC review report

The final report from the Governance Review was released on the 16th April 2018 (downloadable here: https://archive.iwc.int/?r=6890). The Independent Review Panel report represents the view of the three panellists, based on a survey, in-person interviews and analysis of documents. It represents only the first step of the Governance Review process. The Chair of the Operational Effectiveness Working Group of the Finance and Administration Committee asked the Scientific Committee to provide a voluntary feedback to the Commission on recommendations related to the Committee.

The Scientific Committee formed an *ad hoc* Working Group to develop an initial response, which was then discussed in Plenary. The initial WG membership was restricted to the Scientific Committee Chair and Vice Chair, all Heads of Delegations present at the meeting, sub-groups Convenors that are also delegates, and former Scientific Committee Chair present at the meeting. This subset represented the view of Committee members that, given their roles, had a strong knowledge on the current and past structure and procedures of the Committee. More delegates and invited participants joined the discussion in Plenary. The final version of this preliminary feedback, which has the support of all 32 delegations attending the meeting and additional members of the Scientific Committee is provided in Annex X.

The Scientific Committee organised its discussion and feedback on Review Panel's recommendations and comments around five mutually exclusive subject areas (pre-eminence of the Scientific Committee, IWC strategic planning, communication, Scientific Committee function in relation to Commission and other subsidiary bodies, Secretariat function in relation to the Scientific Committee). Within each subject area, those recommendations of perceived importance to the WG were identified. Where feasible, a timeline for developing a response was proposed.

Attention: C, SC

*Given the fact that both the Chair of the Commission (Morishita) and the Chair of the F&A Working Group on Operational Effectiveness (Phelps) reminded the Committee that the Commission has not yet decided the fate of the 'IWC review report', nor has yet requested a full engagement by the Committee, the Committee **agrees** to submit the preliminary feedback on the report (Annex X) for the Commission's consideration.*

*In addition, given the productive exchange of opinions and ideas on several aspects of the Committee working methods that occurred in during its discussions, the Committee **agrees** to establish an Intersessional Correspondence Group on 'Improving on-going working practices of the IWC Scientific Committee' under DeMaster (see Annex Y). The ICG will provide a written summary of its proposals to the Scientific Committee 60 days prior to the start of the annual meeting of the Scientific Committee in 2019. This ICG will also be in charge dealing with the preparation of a draft document for the follow-up on Governance Review, should the Commission instruct the Committee to do so at its next biennial meeting.*

28.6.3 Additional discussion on other issue related to the Committee working procedures

A number of suggestion for improving the ability to follow a topic during the Scientific Committee meeting were discussed by the Committee and the Convenors group. In order to facilitate the full participation of members of the Committee to various sub-groups and, especially, to the discussion of cross-cutting issues relevant to different groups, the Committee **agrees** that next years the Convenors should: (a) organise joint-sessions early in the meeting and release draft reports of those discussion, as soon as feasible; (b) adopt a simple coding system for 'hot topics' (e.g. North Pacific common minke whales: NPMW, Antarctic minke whales: AMW; biopsy sampling; etc.), which will be included in the daily timetable together or instead of the Agenda item. The Convenors group will carefully consider these issues intersessionally.

29. PUBLICATIONS

The Secretariat reported on the excellent progress made with the *Journal* this year, and in particular that the previously noted backlog has now been dealt with. This has been particularly assisted by the excellent work of the new Associate Editors including Fortuna, Leaper, New, Jackson, Punt, Tiedemann, Zerbini. The Committee **thanked** the Publications Team for its dedication and hard work and **reiterated** the importance of the *Journal* and *Supplements* to its work.

30. ELECTION OF OFFICERS

This was the final year of office for the Chair (Fortuna) and the Vice-Chair (Suydam). In accordance with its Rules of Procedure, the Vice-Chair becomes the new Chair for the next three years. The Committee elects Zerbini (Brazil) to be the new Vice-Chair by consensus. The outgoing Chair will provide the formal report to IWC67 in Florianopolis, Brazil of the SC Reports from the 67a and 67b SC meetings.

The Committee rose in appreciation to thank the outgoing Chair. It wished to formally record its immense gratitude for her excellent leadership over the past three years. Dr. Fortuna's scientific and organizational skills provided a lasting legacy to the Committee. She adeptly faced the many complex and challenging issues during her term and tremendous progress has been made for the benefit of the entire Commission in meeting its science and stewardship objectives. The Chair, Head of Science, and Executive Secretary of the Commission added their thanks and congratulations to the many participants expressing their appreciation to Dr. Fortuna.

The Committee also welcomed with enthusiasm the new team of Suydam and Zerbini and looked forward to working with them over the next three years.

31. ADOPTION OF REPORT

The Committee adopted the report at 17:45 hrs on 6 May 2018, apart from the final items discussed during the last session. As is customary, these items were agreed by the Chair, rapporteurs and convenors. The Chair thanked the participants for

their scientific contributions as well as their constructive dialogue. Given the sensitivity of several agenda items, this positive approach helped ensure that all views could be presented and rigorously discussed for a productive outcome. The Chair especially thanked the convenors, rapporteurs, Head of Science, and Vice-Chair for their excellent assistance. Finally, she reiterated her thanks to the government of Slovenia and the hotel staff for the facilities and great service, which contributed greatly to the success of the meeting.

Fortuna concluded that it had been an honour to serve as the IWC Scientific Committee Chair over the past three years. She expressed her gratitude for all the support provided by so many as she led this effort. She voiced her thanks for the Secretariat, and in particular her deep appreciation for the guidance provided by the Head of Science (Donovan) without whom she could not have accomplished her work.

Suydam congratulated Fortuna for having expertly led the Scientific Committee as their Chair over the past three years. He noted that the praise and applause from the participants in the room were well very much deserved given her outstanding leadership. Suydam noted that it will be a particular challenge to follow the incredible example set by Fortuna and thanked her for her mentorship. The Executive Secretary (Lent) added to these words of gratitude and commendation on behalf of the Secretariat and wished her all the best. She also offered the full support of the Secretariat to the incoming SC Chair Suydam.

Echoing the sentiments raised under Item 30, participants thanked the Chair for her adept, fair and efficient handling of the meeting, her unflagging dedication and her great contribution to the effective working of the Committee.

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SC/67B/REP/07

Fifth Rangewide Workshop on the Status of North Pacific Gray Whales

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Fifth Rangewide Workshop on the Status of North Pacific Gray Whales[1]

1. INTRODUCTORY ITEMS

1.1 Convenors' opening remarks

The Workshop was held at the Granite Canyon Laboratory (Big Sur, California) of the Southwest Fisheries Science Center from 28-31 March 2018. The list of participants is given as Annex A. Brownell welcomed the participants and explained the history of the facility, which has been used for almost five decades to census gray whales during their southbound migration. Donovan and Punt (co-convenors) noted that the primary tasks of the workshop were to review the results of the modelling work identified at the Fourth Workshop and SC67a, to examine the new proposed Makah Management Plan (submitted by the USA – see Annex X) for gray whaling off Washington state and to update as possible (and develop a workplan for) updating the scientific components of the Conservation Management Plan (CMP) for western gray whales.

1.2 Election of Chair

Donovan and Punt were elected Chairs (Donovan chaired from the 28-30 March and Punt on 31 March.

1.3 Appointment of rapporteurs

Calambokidis, Cooke, Lang, Punt, Reeves, Scordino and Weller served as rapporteurs.

1.4 Adoption of Agenda

The Adopted agenda is given as Annex B.

1.5 Documents and data available

The documents available to the meeting are listed in Annex C. Annex D summarizes the terminology used to designate breeding stocks and feeding aggregations.

2. PROGRESS ON 'NON-MODELLING' RECOMMENDATIONS AND NEW DATA

2.1 Updated information from co-operative genetics studies

Bickham presented the results of a multi-authored study of SNPs using samples from approximately 50 whales feeding off Sakhalin Island ('western' gray whales) and approximately 100 whales from the Mexican wintering grounds (assumed 'eastern' gray whales); the full study was to be presented at SC67a. The methods used are described in DeWoody *et al.* (2017). Bickham stated that a finished version of the paper will be presented at the 2018 IWC SC meeting. The authors believe that the results will have implications for prioritising the various stock structure hypotheses being modelled in the Rangewide Review (see below).

Multiple duplicate biopsies were found within both the Sakhalin and Mexico sample sets, but none were shared between the two localities. SNP genotypes were also presented for two mitochondrial and two sex-linked loci (Zfx and Zfy). One of the sex-linked SNPs (ZFY_342) had an apparent fixed heterozygosity in the Mexican whales and thus only the second locus could be used for determining the sex of the whales. The Workshop noted that whilst there is no single explanation of this, one possibility is that there was a translocation (duplication) of the Y-linked SNP to the X or to an autosome.

Bickham also presented the results of the STRUCTURE analyses for the SNPs. In the cases with locality as a prior and without locality as a prior, $K = 2$ genomes (or populations) was the best solution; the plot with geography as a prior showed better differentiation with one predominating in the east (Mexico) and the other predominated in the west (Sakhalin). All eastern samples showed admixed ancestry (including some with predominantly the "western" genome) but the western samples showed a much higher proportion of admixture including individuals of nearly 'pure' eastern and western genomes. He also presented results for an analytical approach called Landscape and Ecological Associations (LEA)[2]. The LEA analysis also identified K = 2 genomes but with greater separation. In the Sakhalin sample set the western genome still predominated but there were both individuals with pure western and others with pure eastern genomes as well as admixed individuals. The more equal proportions

[1] Not all attendees have had a chance to comment on this final version although much of the report was agreed at the Workshop itself.

[2] http://membres-timc.imag.fr/Olivier.Francois/LEA/tutorial.htm

of western and eastern genomes in the Sakhalin samples was consistent with an Mxy estimate of genetic similarity (the Sakhalin sample set had a notably higher variance for genetic relatedness between paired samples than was observed in the Mexican sample set).

The authors of the working paper concluded that the Sakhalin population might be comprised of two types of individuals representing two breeding stocks (i.e., two different genomes), along with individuals of mixed ancestry (admixture). The proportions of the two genomes are vastly different in the two sample sets.

The Workshop **agreed** that incorporating photo-id data into the genetic results will greatly improve interpretation of stock structure and movements and **recommended** that the genetic dataset should be examined comparing whales seen only once off Sakhalin with those whales seen in multiple years.

Lang gave a brief update of her work on SNPs, using the next-generation sequencing approach ddRAD. She is analysing approximately 200 gray whales representing approximately equal sample sizes of PCFG (Pacific Coast Feeding Group), western gray whales, and Northern Feeding Group whales. She expects to present the results of at the 2019 gray whale *Implementation Review.*

The Workshop **welcomed** news from Bickham that a request to the government of Japan to obtain gray whale samples for genetics studies (including of the possible extant western breeding stock).

It was noted that the extent of mixing of gray whales in the past had probably fluctuated in response to changes in sea ice (glacial versus interglacial periods). Bickham responded that additional genome sequencing was planned and that the reconstruction of the historical demography of western and eastern gray whales is one goal of that study. Analyses may reveal associations with the climate cycles of the Pleistocene.

2.2 Updated information from photo-identification studies including consolidation of WGW catalogues

SC/MP/CMP/02 reviewed the results of long-term photo-identification studies conducted between 2002-2017 off northeast Sakhalin Island by the Joint Monitoring Program of two oil and gas companies[3]. The photo-identification catalogue resulting from this work contains 283 identified individual gray whales, including: (a) 175 whales that use the Sakhalin Island feeding area on a regular annual, (b) 27 occasionally-sighted whales (recorded at intervals greater than 3 years), and (c) 71 individuals that have been recorded only once. Forty-eight of the one-time visitors were recorded as calves, excluding the nine calves first identified in 2017. There are 29 identified mothers and 127 whales first identified as calves in the catalogue. Six mother-calf pairs were identified in 2017, along with three unpaired calves. Whale no. KOGW127 (aka "Agent"), was identified as a calf in 2005 and was first recorded as a mother in 2017 at the age of 12 years. Agent was satellite tagged in 2011 and her winter migration was tracked to the Gulf of Alaska before the transponder stopped working (Mate et al., 2015).

Drone-based photography was incorporated into the joint-programme field program in 2017. In most cases, the drone was used at an average distance of about 800 m from shore with a standard altitude of 8 meters. The range of the drone presently in use is 2.5 km from the shore. With the collection of aerial photographs from drones, a new body aspect ("back") was added to the photo-identification catalogue. Also, a new supplemental catalogue of drone-collected video was created for 35 individuals.

The catalogues of the ENL-SEIC joint programme and the Russian Gray Whale Programme (previously the Russia-US programme) were last cross-matched using data available through 2011. At that time, the two Sakhalin photo-identification catalogues contained a total of 222 whales, of which 186 were common to both. Seventeen whales were found only in the Russian Gray Whale Programme catalogue and 19 only in the ENL-SEIC catalogue (IUCN, 2013). An updated catalogue comparison, under the auspices of the IWC, is being discussed as is the concept of a common shared catalogue and database.

In discussion, the Workshop **agreed** on the importance of the long-term nature of the research programmes being conducted off Sakhalin. The concept of a common catalogue and database was welcomed and several measures to ensure data compatibility were mentioned, including the important step to standardize reporting of effort and protocols used to designate calves versus yearlings. It was further mentioned that sighting histories of whales photo-identified off Kamchatka should be evaluated to determine patterns of annual occurrence. Finally, the availability of a shared catalogue and regular updating of such was highlighted with respect to the research component of the hunt management plan proposed for the Makah hunt.

2.3 Gray whales off Korea

SC/M18/CMP/04 reported the possible occurrence of a gray whale off Korea in 2015. Video footage of what

[3] Exxon Neftegas Limited (ENL) and Sakhalin Energy Investment Company (SEIC)

appears to be a gray whale was uploaded on YouTube in 2015[4]. The whale was swimming near a port facility in Samcheok, on the east coast of Korea. While the poor quality of the video prevented positive identification to species, some features of the whale suggest that it was a gray whale. Additional information is being sought to confirm the species identification. If this sighting was indeed of a gray whale, it would be the first record from Korea since 1977. The workshop thanked D. Yasutaka Imai for alerting Kim to the existence of this video.

3. UPDATING SCIENTIFIC ASPECTS OF THE CMP

Donovan reported recent progress on the "Rangewide Review of the Status of North Pacific Gray Whales" and the 'Western Gray Whale Conservation Management Plan' (CMP). Since 2004, the IUCN and IWC have emphasized the need for a comprehensive international CMP to mitigate anthropogenic threats facing gray whales throughout their range in the western North Pacific. This CMP was initiated at an IUCN-convened international workshop in Tokyo in summer 2008 (IUCN 2009). A draft of the CMP was completed in 2010 (Brownell *et al.* 2010) and this was endorsed by both the IWC and IUCN. The first successes of the CMP included completion of a telemetry project conducted off Sakhalin and a Pacific-wide photo-identification catalogue comparison. The results of these projects showed that some of the whales sighted off Sakhalin in the summer migrate east, across the Pacific, reaching portions of the North American coast between British Columbia, Canada and the wintering lagoons off Baja California, Mexico. In light of this new information, the IWC has been engaged in the present rangewide review.

In support of the CMP initiative, in 2014 a 'Memorandum of Cooperation Concerning Conservation Measures for the Western Gray Whale Population' (the MoC), was signed by Japan, Russian Federation and the USA. In 2016, the memorandum was signed by Mexico and the Republic of Korea and Prof. Hidehiro Kato of the Tokyo University of Marine Science and Technology was appointed as coordinator of the memorandum. It is hoped that in time the other remaining range states will also sign the memorandum.

3.1 Review of existing sections

The Workshop noted that the work to complete the computing specifications, especially taking into account the new Makah Management Plan, meant that there was insufficient time to update the CMP sections, also recognising that this could best be completed after the modelling results became available, ideally at SC67b. Attention was drawn to the updated seasonal maps[5] and participants were asked to send any comments or suggestion for modification to Donovan and Reeves.

The Workshop **recommended** that the Scientific Committee considers establishing a small drafting group comprised of at least the national co-ordinators of the MoC, Reeves (IUCN) and Donovan be convened to meet intersessionally (e.g. at IUCN headquarters) to provide an updated version of the plan after SC67b.

3.2 Consideration of future stakeholder workshop

An important component of the CMP effort is the need for a stakeholder workshop (tentatively forecast to occur in 2019) that helps to finalize the CMP and develops a strategy for its implementation (IWC, 2017b). The workshop, which would be co-sponsored by IWC, IUCN and the signatories to the Memorandum of Cooperation, should be broad-based and include representatives of national and local governments, industry (e.g. oil and gas, fishing, shipping and tourism), IGOs and NGOs. Objectives of this meeting should include: (1) review and updating of the CMP taking into account any new scientific results from the rangewide workshops, (2) establish a stakeholder Steering Group to monitor CMP implementation, (3) arrange for a coordinator of the CMP and (4) establish a work plan and consider funding mechanisms to implement the actions of the plan. The IWC has a Voluntary Fund for Conservation, to which donations can be specifically directed towards the gray whale CMP and related work. It is expected, however, that after the first year of CMP implementation, range states will contribute the necessary funds to advance the conservation actions listed in the plan. The Workshop welcomed the support offered by IUCN with respect to organising the stakeholder workshop.

4 UPDATE ON MODELLING FRAMEWORK AND RUNS

4.1 Progress of modelling since SC67a including validation

[4] https://www.youtube.com/watch?v=dJ4J7luGgcE

[5] https://iwc.int/western-gray-whale-cmp

4.1.1 General progress, including validation
Punt informed the Workshop that code implementing the specifications agreed at the 4th Rangewide Workshop and modified during SC67a had been written and used to condition the reference trials based on stock hypotheses 3a, 3e and 5a, along with the sensitivity tests that implement stock hypotheses 3b and 6b.

Brandon summarized progress on validating the code implementing the operating model and the conditioning process. SC/M18/CMP/03 provides an update on code validation, including a brief overview of the code and input files, and a list of verification steps taken to date. The main focus of the validation process has been on the FORTRAN procedures necessary for the conditioning phase. Conditioning the operating model is the first and most computationally expensive phase of the Rangewide modelling effort because this code involves the bulk of calls to numerical methods to estimate parameters given model fits to the data. To this end, the conditioning code has been checked against the mathematical and statistical model specifications, to ensure that the procedures as implemented are consistent with the specifications (see Annex D for the specifications of the Rangewide model). Likewise, diagnostic output from the code has been checked against expected values. No errors in the coding were identified.

4.1.2 Modelling related to the proposed Makah management plan
Punt informed the Workshop that code implementing the Makah Management Plan (Annex X) had been developed and initial results presented to the March 2018 AWMP meeting. However, Brandon has yet to validate this code. The code implementing the Makah Management Plan needs to be validated prior to SC67b.

During the Workshop, the Makah Management Plan was clarified/updated as shown below.

(1) It was clarified that the hunt will be stopped if the PCFG 10-yr strike limit less number of PCFG-designated animals drops below 1 or if the PCFG 10-yr female strike limit less number of PCFG-designated females drops below 1. The initial implementation only stopped the hunt only when these differences were less or equal to zero.
(2) It was agreed to incorporate an 'unknown identity' component for landed whales because it may not be possible to obtain a useable photograph of landed as well as struck and lost whales (although at a lower probability).
(3) It was agreed to allowing for the fact that the amount that unidentified whales count towards the PCFG 10-year strike limit will be updated based on available data rather than always being assumed to be 0.4. The error associated with the estimate of the proportion of PCFG whales in even-year hunts needs to be accounted for (see Item 4.4.1).

4.2 Review of stock hypotheses
The Workshop reviewed how the three baseline stock hypotheses (3a, 3e and 5a) and the two stock hypotheses considered as tests of sensitivity (3b and 6b) had been implemented, noting that some of the 'limited' movements (light arrows in Annex E) had been omitted from the baseline hypotheses, but would be considered in tests of sensitivity (e.g. the PCFG in sub-area BSCS). The omission of the associated links was due to lack of mixing data to allow the links to be modelled. It was also noted that that there are no data (abundance estimates, mixing proportions, catches) for some of the sub-area (e.g. the OS sub-area), which implies that the results will be identical no matter how such regions are treated in the modelling.

The Workshop noted that the current implementation of hypothesis 5a did not include the WBS in the SKNK sub-area. This is because there was currently no basis to specify a mixing proportion for WBS vs WFG animals in the sub-area. Cooke provided abundance estimates by breeding stock / feeding group (see Item 4.3.1), which means that it is no longer necessary to specify mixing proportions for the SKNK sub-area.

The Workshop **agreed** that stock hypotheses 3a and 5a would form the references for the analyses as they appear to be most plausible, while trials would also be conducted for stock hypotheses 3b, 3c, 3e and 6b. Annex E shows the final stock hypotheses considered in the trials graphically, while Annex D, Table 2 shows the resulting mixing matrices. The γ values in Annex D, Table 2 indicate parameters that are estimated during the model fitting process.

4.2.1 Plausibility of stock hypothesis 6b
SC/M18/CMP/01 aimed to reopen discussion on the plausibility of the stock hypotheses previously considered as high priority for modelling, with special emphasis on stock hypothesis 6b. Stock hypothesis 6b assumes that the WBS has no fidelity to wintering ground and uses both wintering grounds in both Asia and Mexico. SC/M18/CMP/01 argued that this hypothesis was elevated to high priority due to discussions regarding the movements of humpback whales and the social aggregating hypothesis of Clapham and Zerbini (2015). This hypothesis involves humpback whales learning of new wintering grounds, likely through hearing other humpback whales, and temporarily immigrating. SC/M18/CMP/01 argued that this hypothesis does not apply well to gray

whales because they are much quieter than humpback whales and there is a large distance between the distribution of WBS and eastern breeding stock whales (as portrayed by hypothesis 6b) preventing communication between whales. Furthermore, humpback whales and gray whales have very different breeding behaviour, with humpback whales aggregating on modified leks (Clapham and Zerbini 2015). There does not appear to be a functional benefit for WGW to justify shifting their migration to go to wintering grounds in Mexico instead of Asia given the extra 4,000 km of travel required (Villegas-Amtmann *et al*., 2015). Furthermore, it does not appear likely that the WBS used both wintering grounds without fidelity prior to commercial whaling given that whaling occurred off Japan and Korea during a period when the whales using the Mexican wintering grounds were depleted. Bickham et al. (2013) has also presented arguments based on genetics on why hypothesis 6b has low plausibility. SC/M18/CMP/01 also suggested that hypothesis 3e has low plausibility because it assumes that WBS whales occur in their historical feeding range but do not use the Piltun Lagoon area of Sakhalin Island, which has proved to be an important feeding area since the mid-1980s. It is more likely that if the WBS exists, that this breeding stock would spend at least some time feeding near Piltun Lagoon. SC/M18/CMP/01 concluded the trials based on stock hypotheses other than 3a and 5a should be sensitivity tests.

In discussion, it was noted that gray whales that feed off Sakhalin and traditionally used wintering grounds in the western North Pacific could be driven to occasionally use migratory routes and wintering areas in the Eastern North Pacific. While the Rangewide model does not explicitly account for breeding so does not incorporate information on when or where whales breed, this hypothesis could provide an explanation for the observations of Sakhalin whales in the eastern North Pacific. There is evidence showing that whales from the same feeding groups migrate together; both Sakhalin and PCFG whales have been photographically identified in the same groups and in localized areas while on migratory routes (Weller et al. 2012, Calambokidis and Perez 2017). This could provide a mechanism by which whales that feed together, but have traditionally used different wintering areas, could learn new migratory routes.

Although the possibility that gray whales use multiple wintering grounds could not be ruled out, the Workshop **agreed** that stock hypotheses 6b would be considered as a sensitivity test. It was also **agreed** that stock hypothesis 3e would be considered a sensitivity test.

4.3 Confirm final data sets

4.3.1 Removals (direct and incidental)

IWC (2018) referenced records of gray whale deaths from entanglement/entrapment, ship strike, and unknown causes in Japan from 1982 until the present (Nakamura *et al.*, 2017). A small group (Scordino, Reeves, Brownell) met to confirm and update what had been stated previously on removals in Japan (and elsewhere), recalling that the adult that 'died off Hokkaido in 1996' was killed deliberately (Brownell, 1999).

The Workshop **endorsed** the conclusions of the small group as summarised below.

(1) Of the six gray whales reported as beached in Japan between 1990 and 2016 but with cause of death undetermined, some proportion should be assumed to have died from either entanglement/entrapment or ship strike. The under-reporting factor (usually x4 but with sensitivities of x10 and x20; Annex D, tables 8 and 9) used in the model to convert observed mortality to true mortality in the case of bycatch and ship strike would account for this.

(2) There was no reason to believe there had been any change in fishing effort (e.g. set net fishing) in Japan between 1930 and 1982. Therefore, the removal rate from 1982 to the present should be extended back to 1930 for modelling purposes.

(3) Finally, with respect to commercial set gillnet fishing in California prior to 1981, as noted last year (IWC, 2018), a seabass fishery operated in northern Mexico and southern California prior to the 1980s (e.g. landing 412,000 pounds of black seabass and 873,000 pounds of white seabass in 1953; Marine Fisheries Branch, 1956). In fact, this fishery was active and overall fishing effort 'fairly constant' from before 1930 until the early 1980s (Vojkovich and Reed, 1983). There was no observer effort in this fishery before 1981, nor was an official stranding record of cetaceans maintained in California before that time. However, a coordinated reporting system for stranding was established in the early 1960s under the auspices of the American Society of Mammalogists, and stranded gray whales were regularly reported. For example, 24 dead gray whales were reported as stranded in California between 1960 and 1968, of which seven were confirmed or suspected of having been either entangled in fishing gear or struck by a ship; Brownell, 1971). A gray whale that stranded at Ocean Beach, California, on 19 February 1953 was missing its flukes and bore 'several gashes' on the body – all suggestive of an entanglement death (Robert Orr, pers. comm. to R. Brownell, April 1964).

At last year's workshop, it was assumed that set gillnet fishing effort for halibut in California declined linearly from 1982 to no effort in 1975. To model the effect of this assumption, it was decided to assign all records of gray

whales recorded as injured or killed in halibut or other set gillnet fisheries to a single fishery and modelled separately from all other California fisheries. It was also decided to examine both a low case that assigned no deaths to set gillnet fisheries and a high case that considered all bycatch reports related to gillnet, set gillnet, net, and halibut fisheries in California as if they came from a single fishery (IWC, 2018). A recently found publication (Bureau of Commercial Fisheries, 1936) reported that both set gillnets and trammel nets were used in the 1930s in California for halibut and white seabass fishing. Based on this new information, the Workshop **agreed** to drop the assumption that fishing effort declined linearly to zero from 1982 to 1975 and therefore there was no reason to evaluate high and low scenarios as a way of accounting for bycatch in California prior to 1975.

Set gillnetting effort off California changed markedly in 1991 due to regulations passed in November 1990 intended to eliminate gillnet fishing within 3 n.miles of the mainland and within 1 n.mile of any offshore island in southern California by 1994 (Barlow *et al.*, 1994). To address this, a second set gillnet fishery was added to the model starting in 1991 and the set gillnet fishery described in the preceding paragraph was modelled as having ended in 1990.

4.3.2 Abundance estimates

There were no updates to the estimates of abundance for the PCFG or the ENP stock. New abundance estimates for western gray whales had been presented to the last WGWAP meeting (Cooke *et al.*, 2017), which will also be presented to the SC67b. Estimates for the WFG were extracted at the Workshop that would correspond to the stock structure hypotheses listed in Annex E (table 1). The larger estimates for the WFG correspond to the hypothesis that all whales visiting SE Kamchatka and/or Sakhalin belong to the WFG, while the smaller ones correspond with the hypothesis that only whales that visit Sakhalin belong to the WFG (regardless of whether these individuals also visit Kamchatka).

For the hypotheses where a proportion of the WFG belongs to the western breeding stock (WBS), this proportion is highly uncertain (and could be zero) even though the estimate for the total WFG is reasonably precise. The estimates of the numbers of WFG animals in each of the two breeding stocks are, therefore, highly negatively correlated. In these cases, the multi-stock model uses as inputs the estimate of the total WFG and the estimated proportion of this that belongs to the WBS.

4.3.3 Mixing proportions

Table 2 lists the updated mixing proportions. The mixing proportion for the EJPJ sub-area is unchanged from that specified at the 4th Rangewide Workshop because none of whales encountered recently in this sub-area had adequate photographs to allow for matching (Table 3).

New mixing proportions were calculated for PCFG whales by sub-area for the winter/spring (migrating) and summer/fall (feeding) seasons (Table 4). The sub-regions of the BCNC region used for the analysis were northern Oregon, southern Washington, and northern Washington because they were thought to have the least chance of bias in calculated mixing proportions. Updated data through 2015 based on matches to the PCFG catalogue were used. There was considerable discussion about how to calculate the mixing rate for the Oregon-Washington outer coast area due to a dramatic change in proportion of PCFG whales in northern Washington from surveys in early April 2015. Those surveys identified a large number of whales in a previously poorly sampled area that had very few PCFG whales. Identifications in spring 2015 (heavily influenced by these April surveys) reduced the overall proportion of PCFG whales based on pooled proportions through 2015 to 24% (it had been 36% based on data through 2014). To provide a value less influenced by these two days of surveys, the proportions of PCFG whales were averaged over sub-region and month to compute an overall average of 28% (an average of the eight values presented in Table 4.

The Workshop **agreed to** adopt 28% for the proportion of PCFG whales in the BCNC sub-area during the migrating season for the bulk of the trials, and that sensitivity would be evaluated to 17%. This value is obtained by restricting the analysis of mixing rates of PCFG whales during the winter/spring to just northern Washington where the hunt would occur (based on the unweighted average of the 4 months where there were at least 10 photo-IDs, table 4). Pooling all 622 photo-IDs for December to May would result in a rate of 20%, although this approach weights values towards periods with more photo-IDs.

Considering some of the uncertainty around the estimate for the portion of PCFG whales present in the spring off the Washington-Oregon coast and the variation by location, month, and year, the Workshop **agreed** the current best estimate of 28% to be +-20% (8-48%) for the true PCFG mixing rate. The rationale for the choice is that very different results would be obtained in different areas such as 1) the recently sampled zone north of Tatoosh Island in the early spring where migrating whales appear to gather in some years where recent efforts revealed almost no PCFG whales, compared to 2) areas along the Northern Washington Coast or for example in Barkley Sound

that are feeding areas for PCFG whales and where their proportion compared to migrating whales would be highest.

4.4. Confirm final trial structure and conditioning

4.4.1 Changes to the trials specifications, including stock structure

Annex D lists the specifications for the model that will form the basis for drawing final conclusions regarding the implications of alternative stock structure hypotheses and of the implementation of the Makah management plan. The specifications (see also Annex D and Table 5 and 6) reflect changes to how the stock hypotheses are implemented as well as how the abundance estimates for the western Pacific are used in conditioning. The Workshop also agreed that the following additional changes will be made the trials specifications:

(1) the base-case survival rate for animals aged 1 and older would be assumed to be 0.98, which reflects the estimates obtained by Cooke (ref) and Punt and Wade (2012); the values used in previous trials was 0.95;
(2) the SET1 and SET2 fleets (set gillnets off California in the feeding and migration seasons) would be split between 1990 and 1991 given the changes in regulations in the associated fisheries that appear to have changed bycatch rates;
(3) the survey plan for the California counts were updated to reflect the current plan (two surveys in every five-year block); and
(4) the periods used to calculate average bycatch rates to infer bycatch prior to the establish of monitoring networks into the future as generally but the earliest and most recent five years, but a longer period is specification for sub-areas (e.g. EJPJ and SI) with limited data (Annex D, table 3)

Evaluation of the Makah Management Plan requires specification of the probability of photographing a landed or struck and lost whale, as well as the probability of correctly deciding that such a whale is from the PCFG or the WFG. In addition, it is necessary to specify the probability of striking and losing a whale and assigning a sex to an animal for which a match has been made. These probabilities are specified as follows:

(1) *Probability of obtaining a photograph of sufficient quality to allow it to be matched to the catalogue*. For struck and lost whales, this probability is estimated to be a 0.6 for winter/spring and 0.8 for summer/fall (due less favourable light and weather in winter/spring compared to summer/fall). For landed whales, it is estimated to be 0.9 for all seasons.
(2) *Probability of struck and lost*. The review of the Makah whale *SLA* concluded in 2013 was based on a value for this probability of 0.5, which was informed by two strikes that occurred during the Makah 1999 hunt in which one strike resulted in a landing and the other contacted the whale but did not penetrate the skin. The Workshop agreed to retain the assumption of a 50% struck and lost rate for hunts during the winter and spring. It was decided that hunts occurring during the summer and fall were much less likely to have struck and lost due to better weather conditions and more predictive movement behaviours of whales in the normal feeding depths of PCFG whales. The Workshop therefore agreed that the struck and lost rate for summer and fall hunts would be 0.1 and that sensitivity would be explored to a value of 0.5.
(3) *False positive rate for PCFG (i.e. probability of a non-PCFG being identified as from the PCFG given a good quality photograph*). The probability that a non-PCFG whale might be falsely identified as a PCFG whale is estimated to be 0.05. Normally, there is a near 100% confidence for matches that are identified to Cascadia's PCFG catalogue because these are double checked and photographs of poorer quality where there is some ambiguity are treated as Poor Quality and not used. The value of 0.05 is based on the assumption that a slightly different set of circumstances would exist for comparison of a whale struck or landed because there would be pressure to try to match regardless of the quality of the photograph and it would be hard to justify not reporting as a match something where there was a relatively high degree of confidence (i.e. 95% confident of the match to a PCFG whale).
(4) *False negative rate for PCFG* (i.e. *i.e. probability of a PCFG whale not being identified as such given a good quality photograph*). This probability is estimated to be 0.25 for a hunt in the winter/spring, and zero for a hunt in summer since all struck whales are assumed to be of the PCFG. This value of 0.25 accounts for several factors, including whales only seen in fewer in two years in the PCFG because of a combination of being young, not being photographed, and the one year lag in available catalogue. In addition, there could be a matcher error in missing a match due to things like changed markings.
(5) *False positive rate for WFG (i.e. probability of a non-WFG being identified as from the WFG given a good quality photograph*). This probability is estimated to be 0.01 based on the WFG catalogue being smaller and more well-known. Also, it is suspected that the matcher would likely only declare a match when there was a high level of confidence given the infrequent rate of these matches.
(6) *False negative rate for WFG* (i.e. *i.e. probability of a WFG whale not being identified as such given a good quality photograph*). On the assumption that calves and lactating mothers will not be hunted, the proportion of huntable WFG whales that would not be known as WFG whales if taken during the spring

northward migration was estimated using the population model fit to the Sakhalin and Kamchatka photo-id data. An animal that has been seen off Sakhalin is assumed to be a WFG animal if seen or taken in the eastern North Pacific. An animal seen off eastern Kamchatka but not Sakhalin is not assumed to be a WFG animal, because it might be an NFG animal. The estimated proportion, averaged across the posterior distribution of the population trajectory, was 4-5% depending on the hypothesis. These estimates used data through 2011 only, that being the last season for which the catalogues were cross-matched. If only a single catalogue were used, the rate would be higher. The values used in the trials are: stock hypotheses 3a, 3c, 3e, and 6b: 0.041; stock hypothesis 3b: 0.040; stock hypothesis 5a: 0.049.

(7) *Probability of not assigning a sex to a struck and lost animal that has been identified to the PCFG.*
   a. This probability is estimated at 19% for the feeding season based on 81% of encounters of PCFG whales from June-Nov through 2015 for the Oregon and Washington outer coast having known sex. For those with known sex in this sample 58% were female and 42% male, but this could be biased by some directed sampling toward females so the sex ratio should be treated as 50:50 in the management plan.
   b. This probability is estimated at 27% for the migrating season based on 73% of encounters of PCFG whales from Dec-May through 2015 for the Oregon and Washington outer coast having known sex. For those with known sex in this sample 46% were female and 54% were male. This male-biased sex ratio is in the opposite direction of the bias from intentionally sampling females, which suggests males are actually more abundant and available in the spring off the Oregon and Washington outer coast likely as a result of females with calves migrating later and being less available in spring. Given the bias for trying to sample known females, it is likely that the sex ratio in spring is likely closer to 60:40 male:female. If hunters avoid taking mothers with calves it would further reduce the chances of taking a female.

Estimates of the proportion of PCFG whales used in the Makah management plan for assigning a struck unidentified whale in the winter/spring hunt are subject to uncertainty due to for example shifting proportions based on sampling differences and these should be considered subject to a bias (which depends on trials) that ranges from -0.1 to 0.1.

4.4.2 Base-case trials and sensitivity tests

The 4th Rangewide workshop specified a series of trials. However, it had not been possible to implement all of these trials during the intersessional period. The Workshop reviewed the set of trials and made the following changes (trial numbers relate to revised numbering system):

(1) stock hypothesis 3e is now treated as a sensitivity test as it is a variant of stock hypothesis 5a (with no WBS animals in the SI sub-area);
(2) a new sensitivity test (18C) based on stock hypothesis 3c has been added as agreed at the 4th Rangewide workshop (IWC, 2018);
(3) the sensitivity test exploring a higher proportion of WBS whales in sub-area SI (3B) involves increasing the estimates of abundance for the WBS by 50% and correspondingly reducing the estimates of abundance for the WFG;
(4) the trials involving PCFG whales in the BSCS sub-area (12A/B) are based on assuming that all PCFG whales are in the BSCS sub-area. The assumption will be conservative given that most PCFG whales are located elsewhere when the aboriginal hunt off Chukotka occurs;
(5) the trials involving WFG whales in the BSCS sub-area (13A/B) are based on assuming that all WFG whales are in the BSCS sub-area. The assumption will be conservative given that most WFG whales are located elsewhere when the aboriginal hunt off Chukotka occurs;
(6) the trials exploring the sensitivity of how the California set gillnet catches were modelled (trials 14 and 15 in Table 8 of IWC (2018)) were dropped as the approach for modelling the SET1 and SET2 fleets was modified (see Item 4.3.1);
(7) the trials with MSYR estimated and a higher pulse were dropped as these trials are unlikely to be informative (trials 14A/B and 8A/B examine these factors individually);
(8) variants of trials 5A/B and 16A/B (trials 18A/B and 19A/B) that have net immigration of 1 to the PCFG were added because the assumption of zero immigration into the PCFG is unlikely given the results of Lang and Martien (2012);
(9) trials 7A/B and 16A/B exclude the PCFG abundance estimates for 1998-2002 as a low pulse would not allow the model to mimic these data – this change in model specifications mimics the adoption in the trials used to evaluate the *SLA* for a Makah hunt by IWC (2013) of a time-varying survey bias;
(10) trials 22A/B have been added to examine the future consequences of a catastrophic events in the NFG – these events occurs randomly once in the first 50 years and randomly once in the second 50 years, with a magnitude equivalent to that of the mortality event in 1999/2000; and

(11) trials 23A/B and 24A/B have been added to explore sensitivity to the struck and lost rate for a Makah hunt in the feeding season, and the false negative rate for a Makah hunt in summer.

4.4.3 Conditioning statistics

The Workshop reviewed the diagnostic plots for evaluating the conditioning developed for the trials specified at the 4th Rangewide Workshop. The Workshop **agreed** that the following plots should be produced for each trial and provided to the Intersessional Steering Group for review:

(1) The estimates of absolute abundance (with 90% sampling intervals) and the median, 50% and 90% intervals for the time-trajectory of the model estimates of 1+ population size.
(2) The time-trajectory of the model estimates of the number of mature females.
(3) The distributions (median, 50% and 90% intervals) for the generated mixing proportions and those for the model-predicted mixing proportions.
(4) The distribution for the net immigration rate from the NFG to the PCFG and the target value (black vertical bar).
(5) The estimates of average bycatch over the period for which reporting is considered adequate [Annex D, table 3] (with 90% sampling intervals) and the median, 50% and 90% intervals for the model-estimate of the average bycatch over the period.
(6) The distributions (median, 50% and 90% intervals) for the generated survival rates for PCFG whales and those for the model-predicted survival rates for PCFG whales.
(7) The time-trajectories of removals, including the recorded removals (adjusted for under-reporting) and the bycatch inferred for the years for which reporting is not considered adequate.

4.4.4 Projection scenarios

Previous projections for the Sakhalin population (J. Cooke in Reeves *et al.*, 2005) considered a scenario in which there is future bycatch of 1.5 mature females off Japan based on inferences from bycatch at that time. The Workshop noted that observed bycatch off Japan has declined since then. The Workshop **agreed** that a projection scenario with 1 mature female taken each year in the EJPJ sub-area should to be conducted.

In addition, the Workshop **agreed** that, if possible, projections should be conducted for the current Makah *SLA*, although it was recognised this may not be feasible to achieve before 67b.

The Workshop noted that care needs to be taken to compare the results from the previous *Implementation Review* with those based on the Rangewide review because the population structure hypotheses have changed and the Rangewide review has more fully accounted for bycatch and its uncertainty.

4.4.5 Performance statistics

4.4.5.1 TIME-TRAJECTORIES OF POPULATIONS

The results of the model fits and the projections will be summarized by time-trajectories of 1+ numbers of breeding stock / feeding group and by sub-area

4.4.5.2 MAKAH MANAGEMENT PLAN

The results of the projections to evaluate the performance of the Makah management plan will be based on the standard statistics used by the Committee to evaluate the performance of Strike Limit Algorithms

(1) D1. Final depletion of 1+ and mature female numbers by breeding stock / feeding group (median, lower 5th and upper 5th percentiles)
(2) D8. Rescaled final depletion: P_T/P_0 (1+ and mature female numbers by breeding stock / feeding group; median, lower 5th and upper 5th percentiles) where P_0 is number of 1+ / mature female animals had there been no future Makah hunts.
(3) D10. Relative increase. The ratio of the 1+ and mature population size after 10 and 100 years to that at the start of the projection period by breeding stock / feeding group (median, lower 5th and upper 5th percentiles)
(4) N9. Need satisfaction. The proportion of the total number of requested strikes that were taken over the first 10 years and the entire 100-year period (median, lower 5th and upper 5th percentiles).

Results are provided for both 10 and 100 years for the D10 and N9 statistics because (a) the Makah management plan current only operates for 10 years, and (b) previous evaluations of the performance of management procedures (RMP and AWMP) have considered performance over 100 years. Population-related statistics should be also be provided for the case there is no future Makah hunt (only bycatch and hunting off Chukotka).

5. WORKPLAN

Before / during 67b

(1) Update the code for the operating model (Punt)
(2) Validate any changes to the historical (conditioning) component of the operating model (Brandon)
(3) Conduct conditioning and distribution of conditioning diagnostics to the Steering Group (Punt)
(4) Review of the conditioning results (Steering Group)
(5) Code the revised Makah management plan and the associated testing code (Punt)
(6) Validate the revised Makah management plan and the associated testing code (Brandon)
(7) Conduct the projections and assemble the projection results (Punt)

After 67b

(1) Complete drafting of the CMP.

6. ADOPTION OF REPORT

The co-chairs thanked Brownell and his colleagues for the excellent and historic facilities provided at the laboratory in the beautiful setting of Granite Canyon (complete with gray whales migrating by). The report was adopted by email.

References

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Table 1. Abundance estimates (1+) for the WFG feeding aggregation and the western breeding stock

Year	*Group*	*Hypothesis*	*Estimate*	*SD*	*CV*
1995	WFG	3a/3c/3e/6b	75.1	3.8	0.051
1995	WBS	3b	25.8	7.3	0.282
1995	WFG	3b	75.5	3.3	0.043
1995	WBS	3e	30.0*	15.0	0.500
1995	WBS	5a	26.6	6.9	0.259
1995	WFG	5a	47.8	7.7	0.160
1995	WBS+WFG	5a	74.4	3.9	0.052
1995	WBS/(WBS+WFG)	5a	0.358	0.093	0.259
2015	WFG	3a/3c/3e/6b	199.8	5.4	0.027
2015	WBS	3b	63.8	15.8	0.248
2015	WFG	3b	198.9	5.7	0.029
2015	WBS	3e	30.0*	15.0	0.500
2015	WBS	5a	64.4	14.0	0.218
2015	WFG	5a	135.6	14.1	0.104
2015	WBS+WFG	5a	200.0	5.7	0.029
2015	WBS/(WBS+WFG)	5a	0.322	0.069	0.200

* Guestimate because the WBS cannot be distinguished given the available information.

Table 2. Mixing proportions for use in the trials

Sub-area	Season	Stock / Feeding aggregation	Mixing proportion
EJPJ	All	WBS/NFG	0.33
SEA	Feeding	PCFG	0.57[1]
SEA	Migration	PCFG	0.1[2]
SEA	Migration	WGW	0.002[3]
BCNC	Feeding	PCFG	0.93
BCNC	Feeding	WGW	0
BCNC	Migration	PCFG	0.28
BCNC	Migration	WGW	0.002
CA	Feeding	PCFG	0.60
CA	Feeding	WGW	0
CA	Migration	PCFG	0.1
CA	Migration	WGW	0.002[3]

1: Not used in the conditioning as no bycatch is recorded for the SEA sub-area during the feeding season.
2: Assumed value owing to lack of data to estimate mixing proportions.
3: Set to the value calculated for BCNC by Moore and Weller 2013)

Table 3. Updated information on matches between whales encountered off Japan and those photographed off Sakhalin (D. Weller, SWFSC).

Date	Location and source	Conclusion
April 2016	Shizuoka, beached	no useable photos/no match
February 2017	Kanagawa, sighting	poor quality video only/no match
April 2017	Chiba, sighting	poor quality video only/no match
March 2017	Aogashima, sighting	no useable photos/no match
February 2018	Aogashima, sighting	no useable photos/no match

Table 4. Proportion of PCFG whales by region and Month for cells with >10 IDs through complete through 2015 for OR-WA Jan to May (no Dec data)

Region	Jan	Feb	Mar	April	May
NWA	0.09		0.09	0.10	0.41
SWA			0.38	0.21	0.33
NOR					0.63

Mean of above cells for OR to WA: **Unweighted = 28%**, Pooled = 24%
Mean of above for just N WA: Unweighted = 17%, Pooled = 20%

Table 5

Factors considered in the model scenarios. The bold values are the base-levels and the values in standard font form the basis for sensitivity analyses.

Factor	Levels
Model fitting related	
Stock hypothesis	**3a,** 3b, 3c, 3e, **5a,** 6b
$MSYR_{1+}$ (western)	As for WFG
$MSYR_{1+}$ (north)	**4.5%**, 5.5%, Estimated (common); estimate (separately)
$MSYR_{1+}$ (WFG)	**4.5%** Estimated (common); estimate (separately)
$MSYR_{1+}$ (PCFG)	2%, **4.5%**, 5.5%¸ Estimated (common); estimate (separately)
Mixing rate (migration season in BCBC	**0.28**, 0.17, 1.00
Immigration into the PCFG	0, 1, **2**, 4
Bycatches and ship strikes	Numbers dead + M/SI, **dead x 4**; dead x 10; dead x 20
Pulse migrations into the PCFG	10, **20**, 30
Projection-related	
Additional catch off Sakhalin (mature female)	0, 1
Catastrophic events	**None**, once in years 0 – 49, and once in years 50-99
Northern need in final year (from 150 in 2014)	**340**
Struck and lost rate	**(0.1; odd-years; 0.5 even years),** 0.5 all years
Future effort	**Constant**, Increase by 100% over 100 years
Probability of a photo (struck and lost whales)	**0.8; odd-years; 0.6 even years**
Probability of a photo (landed whales)	**0.9**
Probability of false positive rate PCFG	**0.05**, 0.1
Probability of false negative rate PCFG	**0.25**
Probability of false positive rate WFG	**0.01**
Probability of false negative rate WFG	**0.041 (stock hypotheses 3a, 3c, 3e, 6b);** 0.040 (stock hypothesis 3b); **0.049 (stock hypothesis 5a)**
Probability of a sex assignment given a PCFG match	**0.81**

Table 6

Final trial specifications

Trial	Description/stock hypothesis	PCFG or WFG in BSCS	$MSYR_{1+}$			PCFG		Bycatch	Conditioning
			North	PCFG	WFG	Imm.	Pulse		
Base-case trials									
0A	Reference 3a	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
0B	Reference 5a	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
Sensitivity tests									
1A	Lower MSYR PCFG 3a	No	**4.50%**	**2%**	**4.50%**	2	20	D x 4	Yes
1B	Lower MSYR PCFG 5a	No	**4.50%**	**2%**	**4.50%**	2	20	D x 4	Yes
2A	Higher MSYR PCFG and North 3a	No	**5.50%**	**5.50%**	**4.50%**	2	20	D x 4	Yes
2B	Higher MSYR PCFG and North 5a	No	**5.50%**	**5.50%**	**4.50%**	2	20	D x 4	Yes
3A	Lower WBS in Sakhalin 5a (Hyp 3e)	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
3B	Higher WBS in Sakhalin 5a	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
4A	PCFG mixing based on Northern WA only 3a	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
4B	PCFG mixing based on Northern WA only 5a	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
5A	No PCFG Immigration 3a	No	4.50%	4.50%	4.50%	**0**	20	D x 4	Yes
5B	No PCFG Immigration 5a	No	4.50%	4.50%	4.50%	**0**	20	D x 4	Yes
6A	Higher PCFG Immigration 3a	No	4.50%	4.50%	4.50%	**4**	20	D x 4	Yes
6B	Higher PCFG Immigration 5a	No	4.50%	4.50%	4.50%	**4**	20	D x 4	Yes
7A	Lower Pulse into PCFG 3a (and no 1998-2002 PCFG data)	No	4.50%	4.50%	4.50%	2	**10**	D x 4	Yes
7B	Lower Pulse into PCFG 5a (and no 1998-2002 PCFG data)	No	4.50%	4.50%	4.50%	2	**10**	D x 4	Yes
8A	Higher pulse into PCFG 3a	No	4.50%	4.50%	4.50%	2	**30**	D x 4	Yes
8B	Higher pulse into PCFG 5a	No	4.50%	4.50%	4.50%	2	**30**	D x 4	Yes
9A	Bycatch=Dead + MSI 3a	No	4.50%	4.50%	4.50%	2	20	**D + MSI**	Yes
9B	Bycatch=Dead + MSI 5a	No	4.50%	4.50%	4.50%	2	20	**D + MSI**	Yes
10A	Bycatch x 10 3a	No	4.50%	4.50%	4.50%	2	20	**D x 10**	Yes
10B	Bycatch x 10 5a	No	4.50%	4.50%	4.50%	2	20	**D x 10**	Yes
11A	Bycatch x 20 3a	No	4.50%	4.50%	4.50%	2	20	**D x 20**	Yes
11B	Bycatch x 20 5a	No	4.50%	4.50%	4.50%	2	20	**D x 20**	Yes
12A	PCFG in BSCS 3a	**PCFG**	4.50%	4.50%	4.50%	2	20	D x 4	Yes
12B	PCFG in BSCS 5a	**PCFG**	4.50%	4.50%	4.50%	2	20	D x 4	Yes
13A	WFG in BSCS 3a	**WFG**	4.50%	4.50%	4.50%	2	20	D x 4	Yes
13B	WFG in BSCS 5a	**WFG**	4.50%	4.50%	4.50%	2	20	D x 4	Yes
14A	MSYR1+ estimated (common) 3a	No		**Estimated**		2	20	D x 4	Yes
14A	MSYR1+ estimated (common) 5a	No		**Estimated**		2	20	D x 4	Yes
15A	MSYR1+ estimated (by FA) 3a	No	**Est**	**Est**	**Est**	2	20	D x 4	Yes
15B	MSYR1+ estimated (by FA) 5a	No	**Est**	**Est**	**Est**	2	20	D x 4	Yes
16A	Lower PCFG immigration and higher bycatch 3a (and no 1998-2002 PCFG data)	No	4.50%	4.50%	4.50%	**0**	20	**D x 10**	Yes
16B	Lower PCFG immigration and higher bycatch 5a (and no 1998-2002 PCFG data)	No	4.50%	4.50%	4.50%	**0**	20	**D x 10**	Yes
17A	MSYR estimated and lower pulse 3a	No	**Est**	**Est**	**Est**	2	**10**	D x 4	Yes
17B	MSYR estimated and lower pulse 5a	No	**Est**	**Est**	**Est**	2	**10**	D x 4	Yes

18A	Stock hypothesis 3b	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
18B	Stock hypothesis 6b	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
18C	Stock hypothesis 3c	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
19A	Lower PCFG Immigration 3a	No	4.50%	4.50%	4.50%	**1**	20	D x 4	Yes
19B	Lower PCFG Immigration 5a	No	4.50%	4.50%	4.50%	**1**	20	D x 4	Yes
20A	Lower PCFG immigration and higher bycatch 3a	No	4.50%	4.50%	4.50%	**1**	20	**D x 10**	Yes
20B	Lower PCFG immigration and higher bycatch 5a	No	4.50%	4.50%	4.50%	**1**	20	**D x 10**	Yes
21A	Survival = 0.95; 3a	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
21B	Survival = 0.95; 3a	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
22A	Future catastrophic events (once in each of yrs 1-50 & 51-99) - 3a	No	4.50%	4.50%	4.50%	2	20	D x 4	No, 3a
22B	Future catastrophic events (once in each of yrs 1-50 & 51-99) - 5a	No	4.50%	4.50%	4.50%	2	20	D x 4	No, 5a
23A	Summer S&L rate = 0.5 - 3a	No	4.50%	4.50%	4.50%	2	20	D x 4	No, 3a
23B	Summer S&L rate = 0.5 - 5a	No	4.50%	4.50%	4.50%	2	20	D x 4	No, 5a
24A	PCFG false negative rate = 0.1 - 3a	No	4.50%	4.50%	4.50%	2	20	D x 4	No, 3a
24B	PCFG false negative rate = 0.1 - 5a	No	4.50%	4.50%	4.50%	2	20	D x 4	No, 5a
25A	PCFG mixing based on Northern WA is 100%	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes
25B	PCFG mixing based on Northern WA is 100%	No	4.50%	4.50%	4.50%	2	20	D x 4	Yes

1 **ANNEX A**

2 # List of Participants

3

USA

J. Bickham

R.L. Brownell, Jr.

D. Darm

A. Lang

J. Scordino

D. W. Weller

N. Young

REPUBLIC OF KOREA

H.W. Kim

H. Sohn

INVITED PARTICIPANTS

J. Brandon

A. Burdin

J. Calambokidis

J. Cooke

A.E. Punt

M. Scott

R.R. Reeves

IWC

G.P. Donovan

ANNEX B

AGENDA

1. **Introductory items**
   - 1.1 **Convenor's opening remarks**
   - 1.2 **Election of Chair**
   - 1.3 **Appointment of rapporteurs**
   - 1.4 **Adoption of Agenda**
   - 1.5 **Documents and data available**
2. **Progress on 'non-modelling' recommendations and new data**
   - 2.1 **Updated information from the co-operative genetics studies**
   - 2.2 **Updated information from photo-identification studies including consolidation of WGW catalogues**
   - 2.3 **Gray whales off Korea**
3. **Updating scientific aspects of the CMP**
   - 3.1 **Review of existing sections**
   - 3.2 **Consideration of future stakeholder workshop**
   - 3.3
4. **Update on modelling framework and runs**
   - 4.1 **Progress on modelling since SC/66b, including validation**
     - 4.1.1 **General progress, including validation**
     - 4.1.2 **Modelling related to the proposal Mkah management plan**
   - 4.2 **Review of stock hypothesis**
   - 4.3 **Confirm final data sets**
     - 4.3.1 **Removals (direct and incidental)**
     - 4.3.2 **Abundance estimates**
     - 4.3.3 **Mixing proportions**
   - 4.4 **Confirm final trial structure and conditioning**
     - 4.4.1 **Changes to the trial specifications, including stock structure**
     - 4.4.2 **Base-case trials and sensitivity tests**
     - 4.4.3 **Conditioning statistics**
     - 4.4.4 **Projection scenarios**
     - 4.4.5 **Performance statistics**
5. **Work plan**
6. **Adoption of Report**

List of Documents

SC/M18/CMP

1. **Scordino, J. and Bickham, J. Plausibility of stock structure hypothesis 6b**
2. **Tyurneva, O.Y., Takovlev, Y.M., Vertyankin, V.V. van der Wolf, P. and Scott, M.J. Lomg-term photo-identification studies of gray whales (*Eschrichtius robustus*) offshore northeast Salhalin Island, Russia, 2002-2017.**
3. **Brandon, J. IWC Gray Whale Rangewide Model: Code Validation for the 2018 Workshop.**
4. **Kim, H.W. and Sohn, H. Possible occurrence of gray whale off Korea in 2015.**

Annex D

Terminology Used With Respect to Stock Structure Hypotheses

Table 1

Feeding groups or aggregations.

	Feeding groups or aggregations	Abbreviation	Definition (may vary with hypothesis)
1	**Western Feeding Group**	**WFG**	**Animals that feed regularly off Sakhalin Island* according to photo-identification data.**
2	**Pacific Coast Feeding Group**	**PCFG**	**Animals that feed regularly in the PCFG area according to photo-identification data.**
3	**North Feeding Group including**	**NFG**	**Animals found in other feeding areas (and for which there is relatively little information** photo-identification).

*May need revising with regard to southern Kamchatka animals given information in SC/A17/GW08.

Breeding stocks. There are up to two extant breeding stocks: Western (WBS) and Eastern (EBS).

Feeding groups or aggregations. There are up to three feeding groups or aggregations. There is dispersal between the Pacific Coast Feeding Group (PCFG) and North Feeding Group (NFG), but the Western Feeding Group (WFG) is demographically independent of the other two feeding groups (i.e. there is no permanent movement of animals from the NFG or PCFG to the WFG).

Sub-areas. The model includes 11 geographical sub-areas that are used to explain the movements of gray whales (breeding stocks and feeding groups) in the North Pacific and two 'latent sub-areas' used to link model predictions to observed indices of abundance.

Schematic diagrams of the hypotheses being considered are found on pp.534-536.

Table 2 Sub-areas.

Sub-area		Abbreviation
Vietnam-South China Sea		VSC
1	**Korea and western side of the Sea of Japan**	**KWJ**
2	**Eastern side of the Sea of Japan and the Pacific coast** of Japan	EJPJ
3	**Northeastern Sakhalin Island**	**SI**
4	**Southern Kamchatka and northern Kuril Islands***	**SKNK**
5	**Areas of the Okhotsk Sea not otherwise specified**	**OS**
6	**Northern Bering and Chukchi Sea**	**BSCS**
7	**Southeast Alaska**	**SEA**
8	**British Columbia to northern California**	**BCNC**
9	**California**	**CA**
10	**Mexico**	**M**
11	**Latent sub-area**	**Calif-3**
12	**Latent sub-area**	**BC-BCA-3**

*New at this Workshop – replaces the old East Kamchatka and Kuril Islands sub-area to recognise the information from telemetry and photo-identification.

ANNEX D

Trials specifications to come from André Punt

ANNEX E

Hypothesis plots – final versions to come from Aimée Lang

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Preliminary mtDNA analysis of gray whales from Japan and Russia

Naohisa Kanda[1], Mutsuo Goto[1], V. Yu Ilyashenko[2], and Luis A. Pastene[1]

[1] The Institute of Cetacean Research, Tokyo, Japan

[2] A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Science, Moscow, Russia

Contact email:kanda@cetacean.jp

ABSTRACT

Gray whales (*Eschrichtius robustus*) are divided into western and eastern populations. This study is the first to present the genetic data obtained from the gray whales migrating to or from the breeding ground of the western population along the Japanese coast. We conducted mitochondrial DNA analysis on the samples of gray whales from Japan (western, N=6) and Russia (eastern, N=7) and analyzed the generated data in comparison to those of Leduc *et al.* (2002) and Lang *et al.* (2004) to better understand the genetic characteristics of these whales at the wider geographic area. The Japanese gray whales were those either stranded on beach or bycaught on set net along the Japanese coast from 1995 to 2007, and the Russian gray whales were those legally caught during the Chukotka aboriginal subsistence whaling in 2008. All of the mtDNA haplotypes found in the Japanese (five) and Russian (six) samples matched to some of the previously reported haplotypes. The level of genetic diversity of these samples described as haplotype diversity and nucleotide diversity were surprisingly high, suggesting either gene flow between the western and eastern populations or retention of ancient polymorphism without gene flow. No statistically significant difference in haplotype frequencies was detected between the JPN and RUS samples possibly due to the small sample sizes. The phylogenetic analysis of the mtDNA haplotypes found in this study and the past studies detected no distinct cluster for the Japanese whales, supporting the past observation that the western and eastern gray whales were indistinguishable at the evolutionary time scale.

KEYWORDS: GRAY WHALES, PACIFIC OCEAN, GENETICS

INTRODUCTION

Gray whales (*Eschrichtius robustus*) distribute along the North Pacific coast from Asia and Russia to United States and Mexico and are divided into the western (Okhotsk-Korea) and eastern (Chukotka-California) populations (Rice, 1998). The eastern gray whales breed in the Baja California waters in winter and feed in the Bering and Chukchi Seas during summer, while the western gray whales breed in the coastal waters near China and feed in the Okhotsk Sea off Sakhalin Island. After severe reduction of the population size during the commercial whaling period, the eastern population recovered its abundance to near pre-exploitation level but the western one has been believed to still remain small

(IWC, 1998). Conservation and management of this species has been of concern for the range countries.

Identification of population structure is essential for effective management. Past genetic studies based on the genetic variations at mitochondrial DNA (mtDNA) and microsatellites demonstrated that the western and eastern populations were genetically distinct at the population level but not at the evolutionary level (Leduc *et al*., 2002; Lang *et al*., 2004). The population structure of the species hasn't been fully resolved yet, however, partly because the sample of what they call the western population in these past studies limited to the individuals from the narrow part of feeding ground off Sakhalin Island. These whales could have been the mixture of whales from both populations (e.g., Lang *et al*., 2004) or could have come from the eastern population (e.g., Ilyashenko, 2009). Lang *et al*. (2004) found high genetic diversity within the samples and the differences in the level of genetic differentiation between males and females, that made the authors suspect extended migration of some eastern gray whales, especially males, to the area off Sakhalin Island. Ilyashenko (2009) proposed that the current gray whale population migrating to the area off Sakhalin Island was originated from the eastern gray whales recolonized after the extinction of the species in this area during the commercial whaling period. In order to address this issue and to conduct effective management of gray whales, it is important to analyze gray whales obtained from the entire range of the species.

This study is the first to present the genetic data obtained from the gray whales migrating to or from the breeding ground of the western population along the Japanese coast (Fig. 1; Kato *et al.*, 2010). We conducted mtDNA analysis on the samples of gray whales from Japan (western, N=6) and Russia (eastern, N=7) and analyzed the generated data in comparison to those of Leduc *et al.* (2002) and Lang *et al.* (2004) to better understand the genetic characteristics of these whales at the wider geographic area.

MATERIALS AND METHODS

Samples

Three stranded gray whales on beach and three bycaught ones on set net along the Japanese coast from 1995 to 2007 were used for this study (JPN; Table 1). Detailed information on these six animals can be seen in Kato *et al*. (2010). Seven gray whales caught during the Chukotka aboriginal subsistence whaling in 2008 were also used (RUS; Table 1).

mtDNA analysis

Total DNA from each of the whales was extracted from 0.05 g of skin or muscle tissue using the protocol of Sambrook *et al*. (1989). Extracted DNA was stored in TE buffer (10 mM Tris-HCl, 1 mM EDTA, pH 8.0). The first half (486 bp) of the mtDNA control region was amplified through the polymerase chain reaction (PCR) using the following primer set: light-strand MT4 (Árnason *et al*., 1993) and heavy-strand Dlp 5R (*5′*-CCATCgAgATgTCTTATTTAAggggAAC-*3′*). PCR products were purified by MicroSpin S-400HR columns (Pharmacia Biotech). Cycle sequencing was performed with the same primers, using BigDye terminator cycle sequence Kit (Applied Biosystems, Inc). The cycle sequencing products were purified by AutoSeq G-50 spin Columns (Pharmacia Biotech). The labeled sequencing fragments were resolved by electrophoresis through a 5% denaturing polyacrylamide matrix on an ABI3100™ Automated DNA Sequencer (Applied Biosystems, Inc) following the protocols of the manufacture. For each sample both strands were sequenced.

Data analysis

Published mtDNA sequences in Leduc *et al*. (2002) were extracted from GenBank for haplotype designation and data comparison. The published data was generated from analyzing eastern gray whale sample (N=120) collected from the several locations along the coast from Chukotka to California and western gray whale sample (N=45) collected from the northeastern coast of Sakhalin Island. Because analyzed length of the sequence in our study was 37 bp shorter than that of Leduc *et al*. (2002), the haplotype G and O (hereafter, G/O), L and U (L/U), W and X (W/X) in the original paper became indistinguishable, reducing the total number of the haplotypes from 36 in the original paper to 33.

The number of haplotypes and haplotype diversity were calculated following Nei (1987). The nucleotide diversity (Nei, 1987: equation 10.5) and its standard error (se) for population sampling and stochastic processes were calculated from the pair-wise differences between the mtDNA sequences using the Kimura's 2- parameter adjustment (Kimura, 1980). The randomized chi-square test of independence (Roff and Bentzen, 1989) was used to investigate the level of genetic differentiation. In each test a total of 10,000 permutations of the original data were performed. The level of genetic differentiation expressed as H_{ST} was calculated based on Hudson *et al*. (1992).

Phylogenetic reconstruction of the mtDNA sequences was made using the neighbor-joining method implemented in the PHYLIP version 3.5c program (Felsenstein, 1993). Genetic distance among haplotypes were estimated using the program DNADIST of the PHYLIP based on Kimura's 2- parameter model (Kimura, 1980) with an observed transition:transversion ratio of 1:20. The obtained tree was visualized using TreeView PPC (Page, 1996).

RESULTS

On the basis of sequence variation at the 486 bp of control region, five different mtDNA haplotypes were found from the six Japanese gray whales, while six different haplotypes were found from the seven Russian gray whales (Table 2). These haplotypes of the JPNs matched to haplotypes A (N = 1), B (1), G/O (1), L/U (2), and Z (1) in Leduc *et al.* (2002), whereas the haplotypes of the RUSs matched to C (2), H (2), R (1), V (1), AE (1), so that total number of haplotypes found from the two studies was still 33. Haplotype diversity and nucleotide diversity within samples was 0.933 and 0.0185 (se = 0.0058) for the Japanese sample and 0.952 and 0.0163 (se = 0.0032) for the Russian sample, respectively. The level of genetic differentiation between the Japanese and Russian samples expressed as H_{ST} was 0.0316 which was not significantly different from 0 (p=0.164). Statistical test failed to detect statistically significant difference in the haplotype frequencies between the JPN and RUS (p=0.211). Because it was difficult to extract the exact number of haplotypes within the western and eastern population samples from Lang *et al.* (2004), no statistical comparison was conducted between the samples from this study and the past study.

The neighbour-joining tree was constructed for 33 haplotypes (Fig. 2). No geographically specific cluster was detected.

DISCUSSION

We analyzed the sample of the gray whales collected along the Japanese coast. Therefore, significance of this study is that these analyzed whales definitely came from the western population. We did not have

to worry about that we might have collected the individuals from the eastern population that migrated to the feeding ground of the western population.

The results of this study were very same to those of the past genetic studies (Leduc *et al.*, 2002; Lang *et al.*, 2004): the genetic diversity within each of the two samples was high and the eastern and western populations were phylogenetically indistinguishable. As already presented by the past genetic studies, the level of genetic diversity within the western population was surprisingly high as compared with a typical small population. Four possible explanations can be raised. Firstly, individual(s) from the eastern population could have been wrongly sampled as the western population. Secondly, there may be gene flow between the two populations. Thirdly, because of the long life and historically large abundance, the western population may still retains considerable amount of genetic diversity after sever, but recent, population reduction. Finally, the population size of the western population may not be as small as it has been estimated (e.g., Cooke *et al*., 2008). Among these, the first one is the most unlikely because our sample came from migratory corridor between the feeding and breeding grounds of the western population. The site fidelity of gray whales during the breeding migration has been believed strong. If all of the western gray whales feed at the area off Sakhalin Island and have been completely covered through photo-identification, the population size of the western population is indeed small as estimated (Cooke *et al*., 2008) and thus the fourth reason raised above becomes unlikely. Among the remained two, it is hard to decide. Because of the small sample size as no statistically significant genetic differentiation was detected between the Japanese and Russian samples, it was difficult to reliably estimate the level of gene flow in this study. The population reduction during the commercial whaling period was quite severe biologically but might not have been genetically, allowing the western population to retain ancient diversity. Continued population monitoring and survey is important to estimate population size and describe migration pattern of gray whales.

Five of the six individuals in the Japanese sample had the different haplotypes and those haplotypes were widespread in the phylogenetic tree. Although two (L/U and Z) of the haplotypes found in the Japanese sample were referred as the eastern population types in Leduc *et al.* (2002), the analysis of the additional individuals in Lang *et al.* (2004) detected these two in the sample collected from the area off the Sakhalin Island. Contrary to the large differences in the numbers and frequencies of the different haplotypes within the samples from the same region among the different studies (i.g., Leduc *et al.*, 2002; Lang *et al.*, 2004; this study), the total number of the different haplotypes found from these studies did not changed as much. This indicated that the inference drawn from the phylogenetic analysis in this study should reflect gray whales' evolutionary history. Sharing of quite many haplotypes between the two populations and their positions in the phylogenetic tree indicated recent divergence of the populations within the species.

During the last year's scientific committee meeting (IWC, in press), population status of the gray whales feeding at the area off Sakhalin Island, whether the whales were the member of the eastern, western or mixture of both populations, was discussed (Brownell *et al*., 2009; Ilyashenko, 2009). On the basis of the results from mtDNA and microsatellite analyses, Lang *et al*. (2004) showed that the Sakhalin gray whale sample was genetically different from the eastern gray whale sample but raised at the same time the possibility of extended migration of the eastern gray whales to the area off the Sakhalin Island.

With increase of the sample size, the newly analyzed individuals in the Sakhalin sample tended to have the haplotypes originally found only in the eastern sample but not newly discovered (see Leduc *et al.*, 2002 and Lang *et al.*, 2004). This could reflect the level of the ancient polymorphism retained in the Sakhalin sample or this could indicate that the number of the eastern gray whales migrating to the area off Sakhalin Island is more than we have anticipated. Use of our Japanese gray whales as a reference base sample is suitable to address this kind of issue. However, it is unfortunate that its sample size is small and only mtDNA data is available at this moment. We are thus planning to analyze our samples with more than ten microsatellite markers that should overcome the reluctance for population structure analysis attributable to the small sample size.

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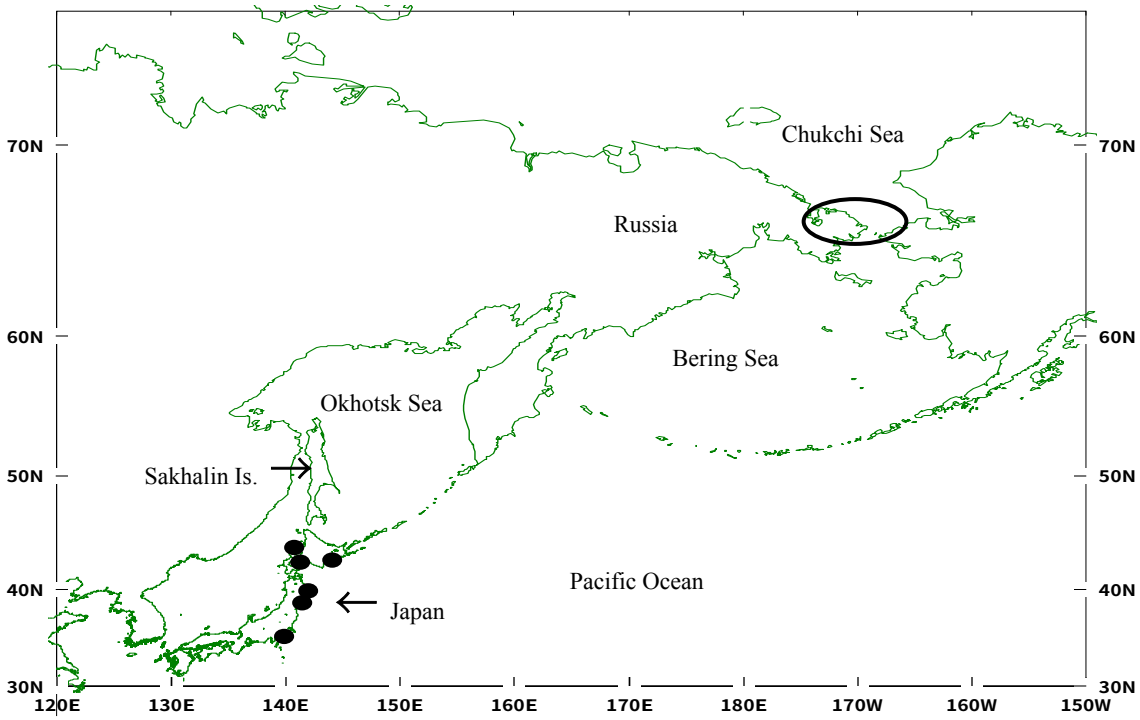

Fig. 1. Sample locations. Black dots indicate the sampling locations of the 6 Japanese gray whales, and open circle indicates the approximate area of the Chukotka aboriginal subsistence whaling colleting the 7 Russian gray whales for this study.

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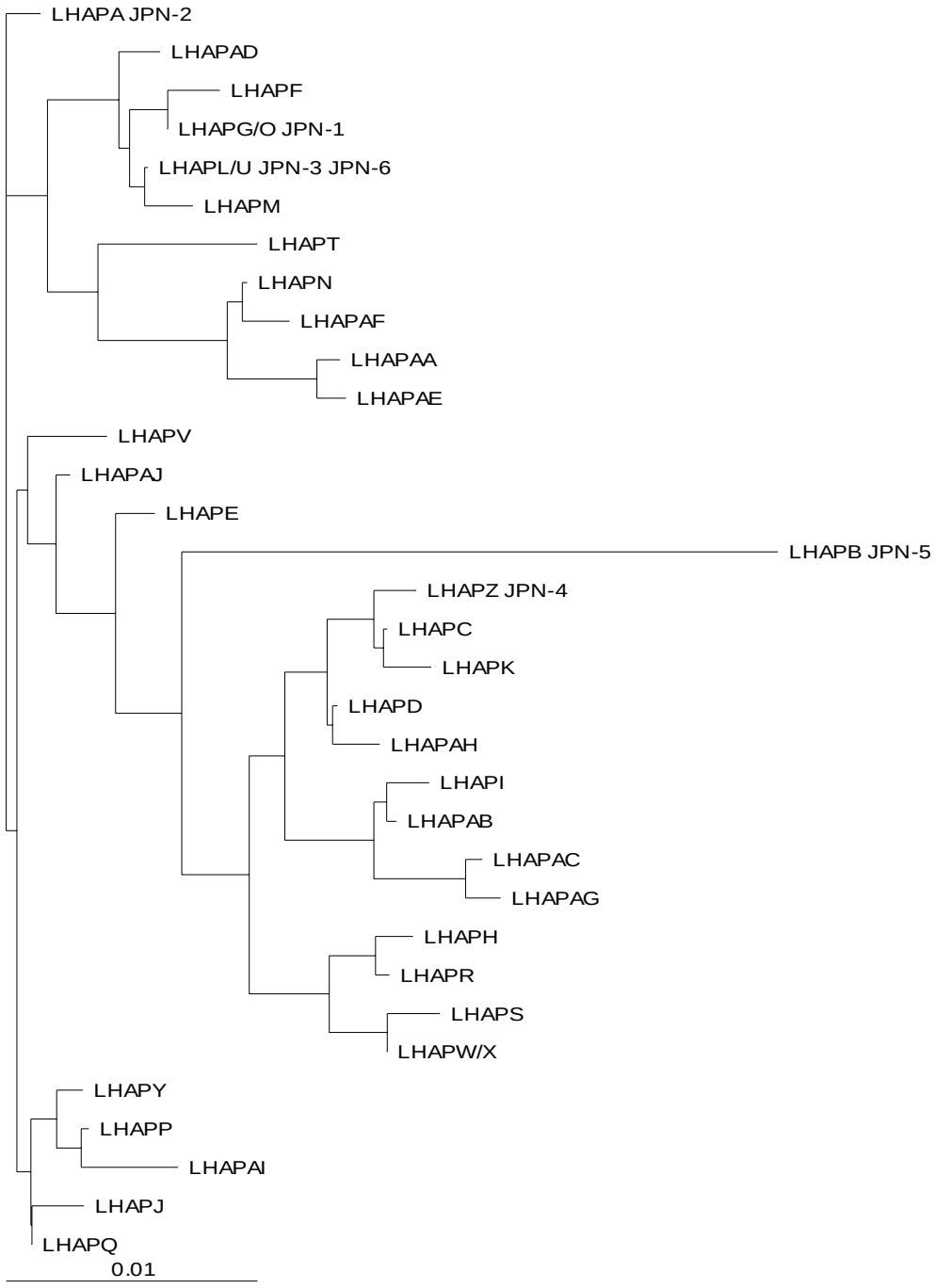

Fig. 2. Neighbour joining tree of the gray whales' mtDNA haplotypes.
LHAPs were extracted from Leduc *et al*. (2002). JPN-1 to JPN-5 was the Japanese gray whales 1 to 5 in Table 1.

Table 1. Samples analyzed in this study.

	Eastern / Western	Ocean	Area	Year	Month	Sex	Body length
Leduc-E (N=120)*	Eastern	Bering/Pacific	Chukotka - California	1990th			
Leduc-W (N=45) *	Western	Okhotsk	Sakhalin	1990th			
JPN-1	Western	Pacific	Hokkaido	1995	Apr.	F	9.5
JPN-2	Western	Sea of Japan	Hokkaido	1996	May	---	---
JPN-3	Western	Pacific	Chiba	2005	May	F	7.8
JPN-4	Western	Pacific	Miyagi	2005	Jul.	F	12.8
JPN-5	Western	Pacific	Iwate	2007	Jan.	F	9.2
JPN-6	Western	Pacific	Hokkaido	2007	Aug.	F	12.3
RUS-23	Eastern	Bering	Chukotka	2008	Jul.	M	8.2
RUS-26	Eastern	Bering	Chukotka	2008	Aug.	M	8.1
RUS-28	Eastern	Bering	Chukotka	2008	Aug.	M	8.9
RUS-37	Eastern	Bering	Chukotka	2008	Aug.	F	12.0
RUS-39	Eastern	Bering	Chukotka	2008	Sep.	M	11.1
RUS-40	Eastern	Bering	Chukotka	2008	Sep.	F	12.3
RUS-47	Eastern	Bering	Chukotka	2008	Sep.	F	13.4

* Data from Leduc *et al*. (2002): Leduc-E corresponds to their eastern population sample, while Leduc-W to their western population one.

Table 2. Haplotype distributions within the samples used in this study.

	mtDNA haplotype*																																
	A	B	C	D	E	F	G/O	H	I	J	K	L/U	M	N	P	Q	R	S	T	V	W/X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	Total
Leduc-E	13	11	12	10	2	-	8	1	-	-	4	6	6	4	3	1	3	1	8	2	2	5	2	2	2	2	2	1	1	3	1	1	1	120
Leduc-W	20	15	2	2	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45
Japan	1	1	-	-	-	-	1	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	6
Russia	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	1	-	1	-	-	-	7

*Haplotype designation was according to Leduc *et al*. (2002).

Some analyses on the modern whaling catch history of the western North Pacific stock of gray whales (*Eschrichtius robustus*), with special reference to the Ulsan whaling ground[1]

HIDEHIRO KATO* and TOSHIO KASUYA*+

Contact e-mail: katohide@affrc.go.jp

ABSTRACT

This study analysed post-1900 published and unpublished records of gray whales in the western North Pacific. Modern whaling recorded a peak annual catch of 100-200 whales in the 1910s, followed by a rapid decline in the 1920s and 1930s and a continued low level (perhaps 10-20 whales/year) for over 40 years to the l960s. Catches made during the last phase could have been the major factor suppressing recovery until recently. There are reasons to believe that this gray whale stock breeds in Hainan waters.

KEYWORDS: GRAY WHALE; MIGRATION; WHALING-MODERN

INTRODUCTION

In contrast to the recovery of the eastern North Pacific stock of gray whales (Darling, 1984), no significant sign of recovery has been detected in the 'Asian' or western North Pacific stock (e.g. IWC, 2002). The present study attempts to clarify the catch history of this stock by reviewing published and unpublished records of catches. It also considers some possible reasons for the stock's lack of recovery.

MATERIALS AND METHODS

Published and unpublished records of gray whales taken in Korean and Japanese waters were reviewed, in addition to unpublished records of sightings in the same area.

The major sources of published catch records and the periods covered are as follows: (1) 1890-1903, 1906-1945, 1948 and 1957-1966 Park (1987); (2) 1911-1945 Kasahara (1950); and 1945-1966 Brownell and Chun (1977).

Some data are common between the studies —Park (1987) cited all the statistics (1911-1945) in Kasahara (1950) and the 1957-1966 statistics in Brownell and Chun (1977).

Unpublished catch records were obtained from the private log of an ex-whaling gunner, Mr Toraichiro Emoto, covering the coastal seasons 1923/24-1933/34 and 1941/42-1944/45. They include sightings and catches by species and other information on the operation such as area and whales taken by other vessels. Between 1934 and 1941, Emoto was employed in the Antarctic fleet.

A further source of sightings data was the daily records of whale sightings recorded for the Fisheries Agency of Japan by whaling captains operating in the western North Pacific, East China Sea, Sea of Japan and Okhotsk Sea (Fig. 1). The records cover the periods 1971-1987 (large-type whaling) and 1977-1988 (small-type whaling) and are kept at the National Research Institute of Far Seas Fisheries (Far Seas Fisheries Research Laboratory).

[1] A version of this paper was originally presented as SC/A90/G19.

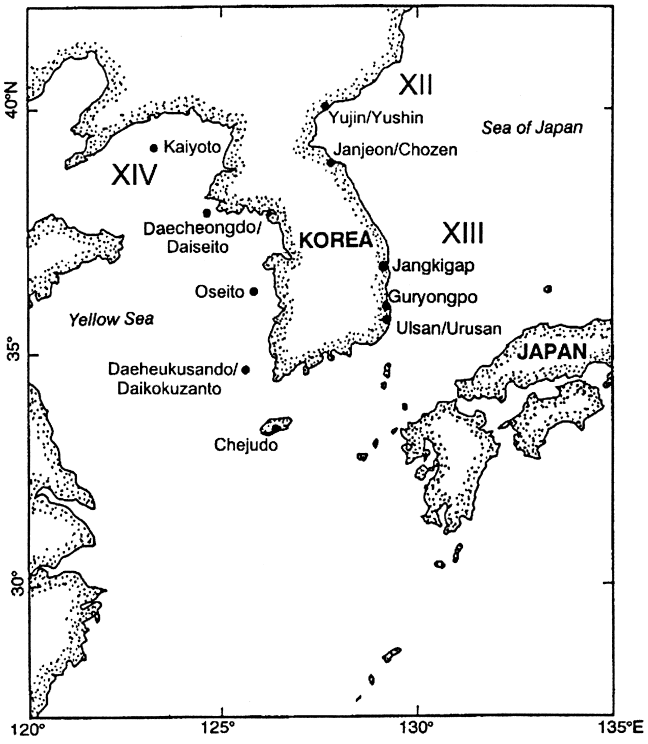

Fig. 1. Land stations (closed circle) used by modern whaling fleets in Korean waters.

Kasahara (1950) grouped the 11 pre-war Korean coastal whaling stations into three areas: (1) Area XII (the northeastern coast bordering the Sea of Japan, the Jangjeon ground of this study); (2) Area XIII (the southeastern coast bordering the Sea of Japan, the Ulsan ground); and (3) Area XIV (the Yellow Sea ground). His classification has been used in the following analysis. Some of the previous studies used Japanese geographical names in Korean waters, but in this study local names have been used as far as possible.

* *National Research Institute of Far Seas Fisheries, 5-7-I, Orido, Shimizu, Shizuoka 424-8633, Japan.*
+ Current address: *Teikyo University of Science and Technology, Uenohara, Yamanashi Prefecture, 409-0193, Japan.*

RESULTS

Catch history

A total of 1,750 gray whales (44 individuals by net whaling) were reported to have been taken from the western North Pacific stock in the 77 years from the start of modern whaling in 1891 to 1966 (Table 1): 1,704 (97.4%) were from the east coast of the Korean peninsula (Jangjeon and Ulsan ground); 3 from the west coast (Yellow Sea ground); and the remaining 43 from elsewhere. It is unclear when the exploitation of gray whales ceased in Asian waters, but it certainly lasted until 1966 (Brownell and Chun, 1977).

Just before modern whaling began off the Korean coast, Japanese net whalers took 16, 15 and 13 gray whales off Pusan (southeastern lower Korean peninsula) in 1890/1891, 1891/1892 and 1898/1899 respectively (Park, 1987). A Russian vessel, from the Pacific Whale Fishing Co., began whaling off the Korean coast in 1890 (Tonnessen and Johnsen, 1982, p.131). This marked the start of modern whaling in Asian waters. The operation continued until February 1904 and the outbreak of the Russo-Japanese war (Akaishi, 1910). Statistics are available for only three seasons in the period 1889/1900-1902/03, i.e. 116, 114 and 96 whales, respectively (Park, 1987). Catches by species are only known for the 1902/03 season, with a take of nine gray whales (about 10% of the total) off Jangjeon (Park, 1987). On the assumption that the Russian whaling fleet took about 100 whales/season and 10% of them were gray whales, the total estimated gray whale take in the 13 seasons 1891/92-1902/03 would be around 130 individuals; these are not included in Table 1, which represents the minimum estimate.

Japanese modern whaling started in Korean waters in February 1900, expanded to wider areas along the Korean and Japanese coasts after the Russo-Japanese war (Akaishi, 1910; Park, 1987) and continued in Korean waters until the end of the Second World War in 1945. Catch statistics by species are available from 1906 onwards. Although no statistics before then give the species composition, at least 37 gray whales are known to have been taken on the Jangjeon ground between 1900-1905 (Park, 1987).

High catches occurred during 1907-1918 with a maximum annual take of 193 whales in 1912. Of the total of 674, 546 (81%) were taken on the Ulsan ground. From 1920, the catch declined annually, but it is clear from the Emoto log that catches continued at a very low level on the Ulsan and Jangjeon grounds until 1945. Although the log does not cover the 1934/35-1940/41 seasons, it is a reasonable assumption that other Japanese vessels will have taken some gray whales in the area. A gray whale was reported in 1942 from a land station on Paramushiro Island in the northern Kuril Islands (Mizue, 1951) which may have originated from the Californian or eastern stock of gray whales.

There are some inconsistencies between the published statistics and the Emoto log. Emoto recorded the take of seven gray whales off the east coast of Korea in 1942/43-1944/45 (Table 1), but none are recorded in the official statistics used by Kasahara (1950) and cited in several studies. Since Emoto's records only covered about half of the total fin whales caught on the Ulsan ground during this period, the total gray whale catch there could have been higher. Additionally, if the operation off northeastern Korea (the Jangjeon ground) is taken into account, the total take of gray whales on the Korean coast could have been higher. During the war years, in the face of threats from enemy submarines, there would have been increased demands on local food sources such as gray whales.

After the Second World War, whaling resumed in the Republic of Korea in 1946 (Park, 1987) and possibly also in the Democratic Peoples Republic of Korea (North Korea). Brownell and Chun (1977) report a total of 67 gray whales taken on the Ulsan ground in the period 1948-1966. Information is not available on catches made in the Democratic Peoples Republic of Korea.

The Peoples Republic of China began modern whaling in 1964 using a catcher boat and there is a recorded catch of at least three gray whales, one each in September 1949, June 1958 and April 1960 (Wang, 1978).

Sightings of gray whales on the Ulsan ground

According to the Emoto log, the catcher boat operated up to 40 n.miles from the coast, mainly for minke and fin whales. There were no gray whale sightings beyond 10 n.miles from the coast.

Emoto recorded 17 sightings (36 individuals) of gray whales on the Ulsan ground during the winter (December and January) in the period 1923-1944. Positions are available for 11 sightings. Most occurred at a depth of $\leq$100m and between Jangkigap and Wejeulgap (Fig. 2). The Emoto log records that the majority frequented the waters off Sogi. School sizes were: 7 singles; one school each of 2 and 3 whales; and 2 schools of 4 animals. There were no records of cow and calf pairs, but it is uncertain whether such schools were either not sighted or not recorded as such.

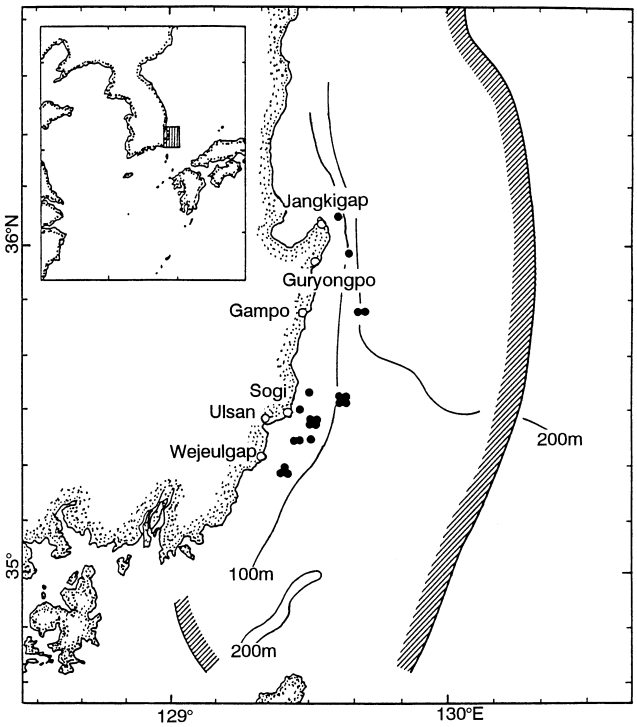

Fig. 2. Sighting positions of gray whales (closed circle) in the Emoto log (1923/1924-1933/1934; 1941/1942-1944/1945) and the ordinary daily rate of operation for fin and minke whales (inside of the shaded area).

Monthly changes in the catch

Table 2 provides monthly catch data from the Ulsan and Jangjeon grounds from published records. These occurred from November-April, with a major peak in December/January and another, smaller peak some three months later, in March/April. Although the discrepancy in magnitude of the two peaks could be due to the general operational pattern of taking fin whales in the Yellow Sea in early spring this could also be interpreted as a reflection of migratory movement south to the breeding ground.

Table 1

Catch history of the Asian stock of gray whales by modern whaling from published records and catch information from the field log by T. Emoto.

	Published records [2]						Emoto log		
Year[1]	Ulsan ground	Jangjeon ground	Yellow Sea	Others	Place unknown	Total	Ulsan	Jangjeon	Total min. catch
1890	16[3]	?	?	-	-	16+			16
1891	15[3]	?	?	-	-	15+			15
1892			No data			?			?
1893			No data			?			?
1894			No data			?			?
1895			No data			?			?
1896			No data			?			?
1897			No data			?			?
1898	13[3]	?	?	-	-	13+			13
1899			No data			?			?
1900	?	23+	?	-	-	23+			23
1901	?	?	?	-	-	?			?
1902	?	9+	?	-	5+	14+			14
1903			No data			?			?
1904			No data			?			?
1905			No data			?			?
1906	59	-	-	-	11	70			70
1907	125	-	-	-	-	125			125
1908	26	-	-	-	-	26			26
1909	?	?	?	?	?	?			?
1910	?	?	?	?	?	?			?
1911	106	13	-	2	-	121			121
1912	?	?	?	?	-	193			193
1913	?	?	?	?	-	131			131
1914	109	30	-	16	-	155			155
1915	?	?	?	9	-	139			139
1916	36	41	-	-	-	77			77
1917	53	13	2	-	-	68			68
1918	91	10	2	1	-	104			104
1919	35	11	-	-	-	46			46
1920	51	14	-	10	-	75			75
1921	23	53	-	2	-	78			78
1922	19	19	2	-	-	40			40
1923	4	23	-	-	-	27	-	-	27
1924	-	13	-	-	4	17	1	-	18
1925	10	-	-	-	-	10	2	-	10
1926	9	1	-	1	-	11	1	-	11
1927	6	3	-	1	-	10	-	-	10
1928	9	-	-	-	-	9	-	-	9
1929	11	-	1	-	-	12	2	-	12
1930	30	-	-	-	-	30	-	-	30
1931	10	-	-	-	-	10	-	-	10
1932	7	-	-	-	-	7	1	-	7
1933	1	-	-	-	-	1	1	-	1
1934	-	-	-	-	-	-	No data		?
1935	-	-	-	-	-	-	No data		?
1936	-	-	-	-	-	-	No data		?
1937	-	-	-	-	-	-	No data		?
1938	-	-	-	-	-	-	No data		?
1939	-	-	-	-	-	-	No data		?
1940	-	-	-	-	-	-	No data		?
1941	-	-	-	-	-	-	No data		?
1942	-	-	-	1	-	1	1	-	2
1943	-	-	-	-	-	-	1	-	1
1944	-	-	-	-	-	-	-	-	-
1945	-	-	-	-	-	-	-	5	5
1946	-	-	-	-	-	-			-
1947	-	-	-	-	-	-			-
1948	9	-	-	-	-	9			9
1949	4	-	1	-	-	5			5
1950	-	-	-	-	-	-			-
1951	7	-	-	-	-	7			7
1952	1	-	-	-	-	1			1
1953	7	-	-	-	-	7			7
1954	?	-	-	-	-	?			?
1955	?	-	-	-	-	?			?
1956	?	-	-	-	-	?			?

cont...

Table 1 continued.

Year[1]	Published records [2] Ulsan ground	Jangjeon ground	Yellow Sea	Others	Place unknown	Total	Emoto log Ulsan	Jangjeon	Total min. catch
1957	?	-	-	-	-	?			?
1958	7	-	1	-	-	8			8
1959	7	-	-	-	-	7			7
1960	8	-	1	-	-	9			9
1961	3	-	-	-	-	3			3
1962	-	-	-	-	-	-			-
1963	2	-	-	-	-	2			2
1964	3	-	-	-	-	3			3
1965	4	-	-	-	-	4			4
1966	5	-	-	-	-	5			5

[1] Calendar year except for 1900 and 1902 indicating 1900/01 and 1902/03 seasons respectively. [2] 1890-1908, 1948 Park,1987; 1911-45, Kasahara, 1950; 1946-66, Brownell and Chun, 1977. [3] Catch by net whaling.

Table 2
Monthly changes in the catch of gray whales in the Ulsan and Jangjeon whaling grounds.

Month	Ulsan ground 1906-1908[1]	1910-33[2]	1948[1]	1958-66[1]	Jangjeon ground 1910-33[1]	1945[3]
Nov.	3 (2, 1)	9	-	-	2	-
Dec.	112 (53, 59)	209	-	12	61	-
Jan.	90 (19, 71)	125	6	13	3	3
Feb.	1 (0, 1)	-	-	9	1	-
Mar.	4 (1, 3)	5	-	-	12	-
Apr.	- (-, -)	2	-	4	35	-
May	- (-, -)	-	-	1	13	2

[1] Park, 1987: numbers in parenthesis are catches of males and females respectively. [2] Kasahara, 1950. [3] Emoto log.

In contrast to the Ulsan ground, the Jangjeon ground recorded two distinct peaks in December and April (about four months apart) and the discrepancy in magnitude of the two peaks is less distinct. The greater time interval on the northern ground (Jangjeon) reflects the difference in timing of the gray whale migration.

Post-war records of gray whales in the northwestern North Pacific

Positions of gray and right whale sightings from Japanese catcher boats are given in Fig. 3. Japanese small-type whaling vessels operated from April-September usually within 60 n.miles of the coast; whale sightings were reported for the seasons 1977-88. Some right whales but no gray whales were recorded by those operations.

Japanese large-type whaling vessels usually operated within 300 n.miles from the coast and reported sightings of whales throughout May-March in the years 1971-87. Records included 'one like gray whale' at 34°31'N, 145°43'E (about 250 n.miles from the nearest coast). The record appears in the Japanese progress report to the International Whaling Commission (IWC) (Anon., 1981) as 'a gray whale'; however it is ignored here as the species identification may be incorrect. The large-type whalers reported nine sightings of right whales, concentrated off Sakhalin, mostly in 1974, suggesting that gray whales wintered much further to the south of the Korean peninsula possibly for breeding.

In addition to the above, there have been five sporadic records (Fig. 3) of gray whales on the Pacific coast of Japan during the period 1968-90 (one whale sighted off the Kii Peninsula; *ca.* 33°30'N-135°30'E) in June *ca.* 1959 (Nishiwaki and Kasuya, 1970); one taken off the Kii Peninsula, February 1968 (Nishiwaki and Kasuya, 1970), one sighting in Ise Bay (34°30'N-136°E), March-April 1982 (Furuta, 1984); one sighting off the Kii Peninsula (*ca.* 33°30'N-136°E), April 1985 (Kasamatsu and Ishikawa, 1990); one stranding on the coast of Sagami Bay (*ca.* 35°N-139°E), February 1990 (Kasamatsu and Ishikawa, 1990).

More recent sightings, of two individuals, were off Izu-Ohsima Island (*ca.* 34°30'N-139°30'E) in April 1993 (K. Nakamura and A. Mochizuki, pers. comm.). One animal was stranded at Suttu Town (*ca* 43°N-140°E), Hokkaido (Kato and Ishikawa, in prep.).

Information on recent sightings of this species in the waters of the Russian Federation is detailed in Weller *et al.* (1999). One juvenile was sighted off the Pacific coast of Kochi, southwest Japan (*ca.* 33°N, 133°E; Kato and Tokuhiro, 1997).

DISCUSSION

The minimum total take of gray whales by modern whaling from the Asian stock since 1891 is estimated to be 1,750 individuals, including 44 caught in net whaling in the 1890s. However, taking into account species uncertainties in the Russian records (100-200 whales) and possible under-recording during the Second World War (10 or more), a better estimate would be between 1,800 and 2,000 individuals. The rapid annual decline to 10-20 whales/season following the peak catches of 100-200 individuals/year at the turn of the century, probably reflected a decline in stock size.

Although it has generally been believed that the catch of gray whales ceased from 1933-1945 (Kasahara, 1950; Mizue, 1951; Omura, 1988), small scale exploitation continued during that period until the mid 1960s. Low level exploitation after World War II has already been documented (Brownell and Chun, 1977). Thus, this stock of gray whales was the focus of low level, but presumably significant, catches for over 60 years following earlier high catches and rapid decline; this may explain the apparent lack of recovery of this stock (and see Weller *et al.*, 2002).

Analysis of available data has identified two distinctive migration peaks along the east coast of the Korean peninsula. These peaks uphold the probability of a breeding area to the south of the Korean peninsula, the first peak in December/January due to southbound migration for winter breeding and the later March/April peak accounting for northbound migration for summer feeding. The waters

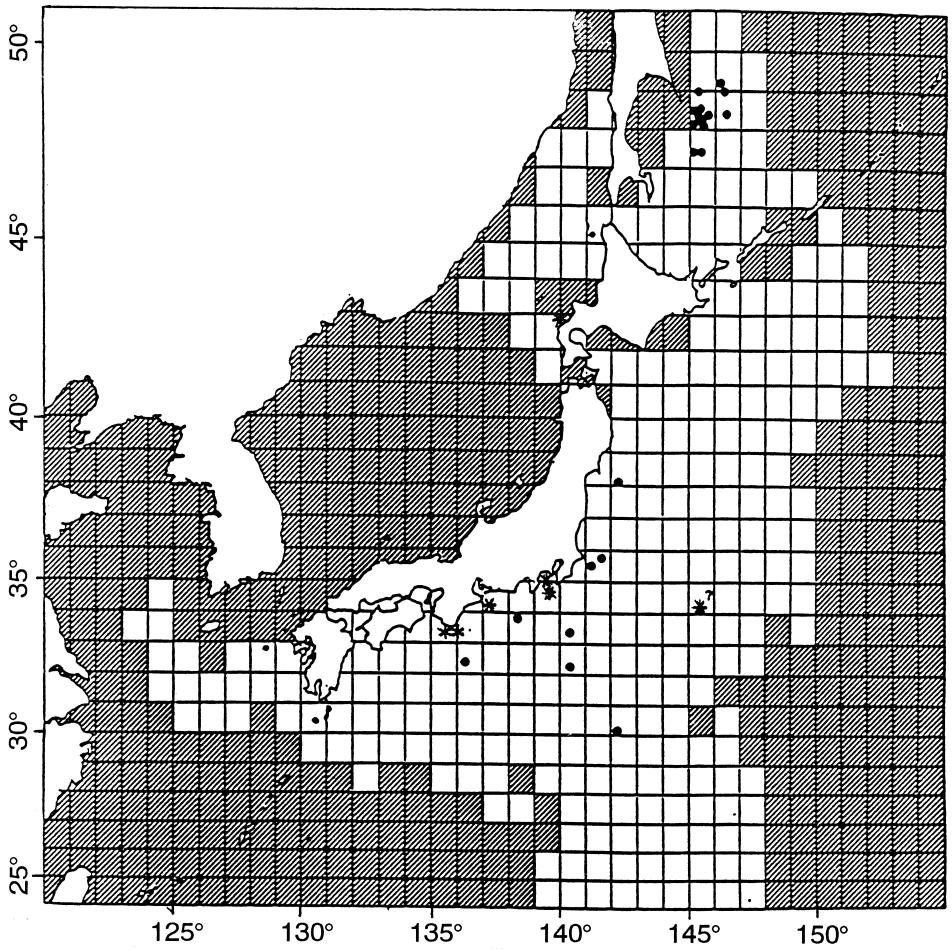

Fig. 3. Position of sightings of gray and right whales reported by Japanese coastal whaling catcher boats and some additional records of gray whales (for details see text). Species key: closed circle = right whale; star = gray whale.

around Hainan Dao island (*ca.* 20°N, 100°E) were considered by Brownell and Chun (Brownell and Chun, 1977) as the most probable breeding site for the western stock of gray whales. Comparing migration times to those of the eastern stock, the four-month period between southbound and northbound migration for the western stock upholds the possibility of Hainan Dao Island as the southern destination for the migrating whales.

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We are greatly indebted to the late T. Emoto for permission to use the 'Emoto Log' for the present study and to S. Ohsumi, Director of the National Research Institute of Far Seas Fisheries for valuable suggestions. Koo-Byong Park (National Fisheries University of Pusan, Republic of Korea) and the late K. Nasu (National Research Institute of Far Seas Fisheries) kindly reviewed the manuscript. R. Shige assisted with the artwork.

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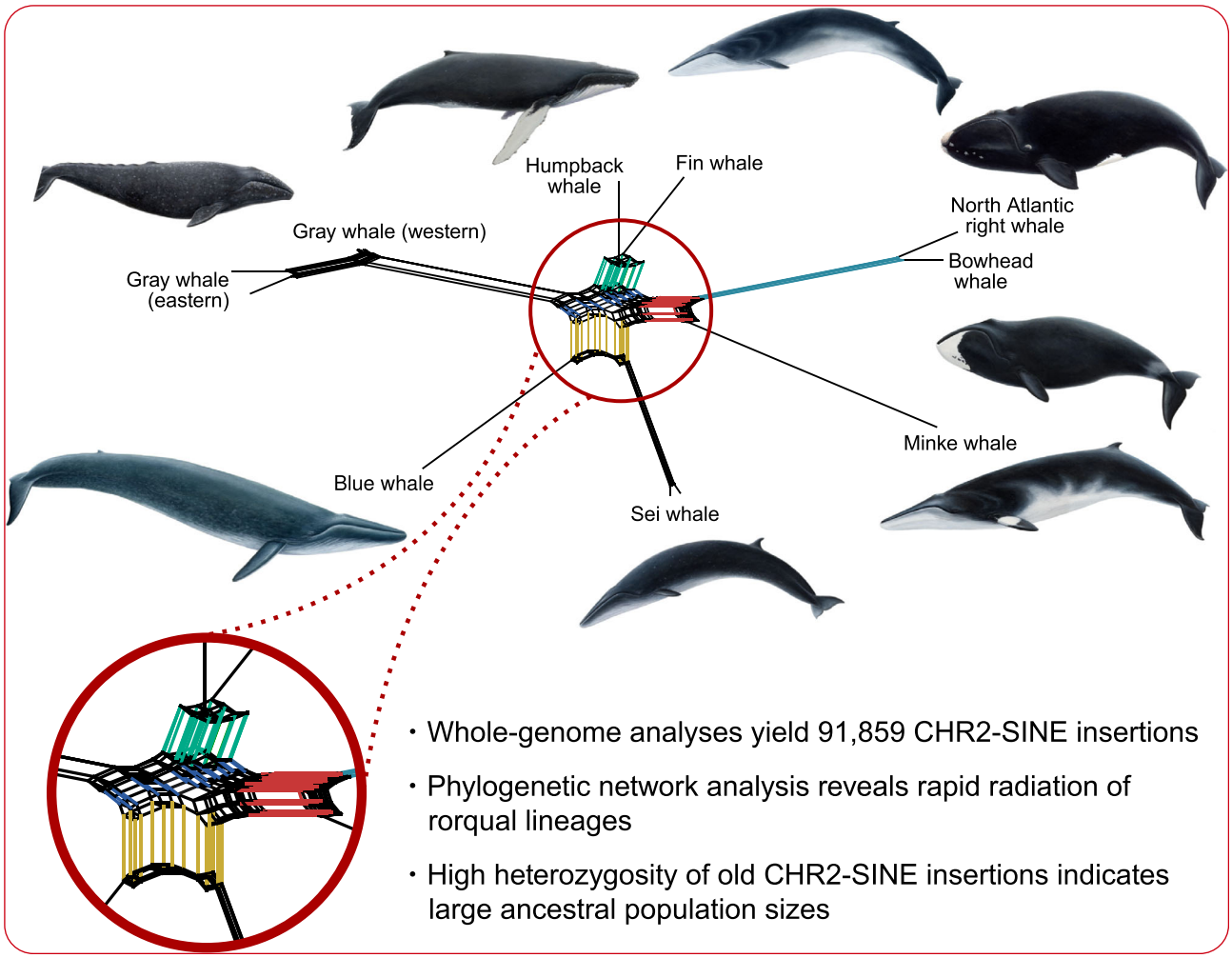
Mobile DNA



Retrophylogenomics in rorquals indicate large ancestral population sizes and a rapid radiation

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Retrophylogenomics in rorquals indicate large ancestral population sizes and a rapid radiation

Fritjof Lammers[1,2,3], Moritz Blumer[1], Cornelia Rücklé[1] and Maria A. Nilsson[1,2*]

Abstract

Background: Baleen whales (Mysticeti) are the largest animals on earth and their evolutionary history has been studied in detail, but some relationships still remain contentious. In particular, reconstructing the phylogenetic position of the gray whales (Eschrichtiidae) has been complicated by evolutionary processes such as gene flow and incomplete lineage sorting (ILS). Here, whole-genome sequencing data of the extant baleen whale radiation allowed us to identify transposable element (TE) insertions in order to perform phylogenomic analyses and measure germline insertion rates of TEs. Baleen whales exhibit the slowest nucleotide substitution rate among mammals, hence we additionally examined the evolutionary insertion rates of TE insertions across the genomes.

Results: In eleven whole-genome sequences representing the extant radiation of baleen whales, we identified 91,859 CHR-SINE insertions that were used to reconstruct the phylogeny with different approaches as well as perform evolutionary network analyses and a quantification of conflicting phylogenetic signals. Our results indicate that the radiation of rorquals and gray whales might not be bifurcating. The morphologically derived gray whales are placed inside the rorqual group, as the sister-species to humpback and fin whales. Detailed investigation of TE insertion rates confirm that a mutational slow down in the whale lineage is present but less pronounced for TEs than for nucleotide substitutions.

Conclusions: Whole genome sequencing based detection of TE insertions showed that the speciation processes in baleen whales represent a rapid radiation. Large genome-scale TE data sets in addition allow to understand retrotransposition rates in non-model organisms and show the potential for TE calling methods to study the evolutionary history of species.

Keywords: Evolution, Phylogenetics, Whales, Transposable elements, Retrotransposon

Background

The bifurcating tree of life, where at each speciation event one ancestral lineage split into two new species, is a concept deeply rooted in the field of evolutionary biology. The opposite, that several new lineages diverge from the same speciation event, a so called polytomy, is mostly regarded as an artefact of limited phylogenetic information [1]. The sequencing and analyses of complete genomes was expected to finally resolve ambiguous relationships by providing enormous amounts of data [2]. Instead of resolving long standing phylogenetic controversies, genome-scale datasets revealed a lot of natural complexity in the phylogenetic data that previously had been deemed as noise [3, 4].

The evolutionary history of baleen whales (Mysticeti) is a prominent example of a phylogeny that lacked a scientific consensus for a long time [5–8]. In particular, the relationships among rorquals (Balaenopteridae) and gray whales (Eschrichtiidae) were contentious. While some studies showed that the only extant species of gray whales (*Eschrichtius robustus*) is phylogenetically placed within rorquals [6–8], others placed the gray whale as a sister group to rorquals, which was expected given its different morphology and feeding behaviour [5, 9].

* Correspondence: maria.nilsson-janke@senckenberg.de
[1]Senckenberg Biodiversity and Climate Research Centre, Senckenberg Gesellschaft für Naturforschung, Senckenberganlage 25, 60325 Frankfurt am Main, Germany
[2]LOEWE Centre for Translational Biodiversity Genomics (LOEWE-TBG), Senckenberganlage 25, 60325 Frankfurt am Main, Germany
Full list of author information is available at the end of the article

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Recently, whole-genome sequencing (WGS) of nearly all extant baleen whale species suggested that the rapid radiation of rorquals might represent a hard polytomy [10]. To further explore if the baleen whale phylogeny contains a polytomy, we use transposable element (TE) insertions. TEs are a robust and independent type of phylogenetic markers, that overcomes many limitations of sequence based phylogenetics, i.e. based on single nucleotide variants (SNV) [11]. Furthermore, TEs evolve neutrally and occur interspersed throughout the genome. Hence, they avoid potentially biased phylogenetic signals from gene tree error or linkage disequilibrium that can occur in sequence-based multi-locus analyses [12]. In addition, TE insertions are virtually homoplasy-free because parallel insertions in the large genomic space are very rare [11]. Also, they are less prone to reversals or mutational saturation that can affect SNV-based phylogenetic inference [11].

In baleen whale genomes, the most abundant TEs are short and long interspersed nuclear elements (SINEs and LINEs), covering 24.5% of the bowhead whale genome [10, 13]. The most abundant SINE family in baleen whales are CHR2 elements, which are named after their presence in **C**etacea, **H**ippopotamidae and **R**uminants [14] and emerged at least 56 million years ago (Mya). Like most other SINEs, the non-autonomous CHR2 elements are derived from a tRNA sequence. They are mobilized by the enzymatic machinery of LINE1 elements via an RNA intermediate that is reverse transcribed to cDNA and reintegrated into the genome. Compared to LINEs, their relatively high insertion frequencies make SINEs ideally suited for phylogenetic inference in mammalian genomes [11]. TEs have a long history of being used as phylogenetic markers for different cetacean groups [15–17].

Due to advances in genome sequencing and software development thousands of TE insertions can be inferred from multiple genomes across species and individuals [18, 19]. Thus, genome-scale TE detection was successfully applied to analyze retrotransposition in several vertebrate clades outside humans [20–23]. Furthermore, WGS based approaches proved extremely valuable in phylogenetic inference because they can increase the number of discovered TE insertions a thousand-fold, providing enhanced statistical power and the possibility to detect processes of reticulate evolution [23]. By contrast, PCR-based approaches have relied on tedious and time-consuming experimental work to find a few dozens of phylogenetically informative TE insertions from hundreds to thousands of candidate loci [24, 25]. Selection of candidate loci using an experimental approach was often based on a single genome sequence, introducing an ascertainment bias in the phylogenetic signal [17, 26, 27] that can be avoided by the use of large scale WGS sequencing and bioinformatic pipelines.

Here, we identified 91,859 CHR2 insertions in the available baleen whale genomes. This dataset was used to reconstruct the rorqual species tree and allowed us to quantify evolutionary conflict originating from their rapid radiation that took place approximately 8 Mya, coinciding with the onset of modern global oceanic circulation.

Results

WGS mapping and TE variation discovery

We mapped 11 WGS datasets from baleen whales with a coverage depth between 7 and 30 X to the bowhead whale (*Balaena mysticetus*) genome sequence [13] (Additional file 1: Table S1). From the mapped data, the Mobile Element Locator Tool (MELT) [19] called 488,373 non-reference (i.e. absent from the bowhead whale genome) CHR2 insertions, of which 327,488 (67.1%) passed stringent quality filtering. The bowhead whale is a natural outgroup to rorquals and gray whales, hence we focused on calling non-reference insertions in the 11 baleen whales to obtain an ascertainment bias free marker set for rorquals and gray whales. The total number of extracted CHR2 insertion calls per species ranged between 27,994 and 38,182, except for the North Atlantic right whale (*Eubaleana glacialis*), for which 6608 were found (Table 1). The North Atlantic right whale diverged from the bowhead whale about 4.4 Mya, hence fewer variable CHR2 loci reflect a closer genetic distance. In comparison, the divergence time of right whales and the bowhead whale to rorquals and gray whales is ~ 28 Ma. For clarity, we follow the nomenclature by ref. 10 to include the gray whale within rorquals sensu lato (Balaenopteridae + Eschrichtiidae).

Table 1 Numbers of all CHR2 insertion calls, as well as the amount of heterozygous insertions (Het) in baleen whale genomes compared to the bowhead whale genome

Sample	No CHR2 calls	Het
Blue whale	37,133	26,942
Fin whale	27,994	13,712
Gray whale (eastern) A	36,064	14,648
Gray whale (eastern) B	38,182	17,449
Gray whale (western) A	32,057	24,922
Gray whale (western) B	32,735	22,544
Humpback whale	28,618	14,622
Minke whale	28,606	12,089
North Atlantic right whale	6608	4221
Sei whale A	29,874	11,242
Sei whale B	29,617	11,079
Total	327,488	173,470

Extensive simulations to test the performance of MELT on our dataset showed that a sequencing depth of 5 X or higher is sufficient to reach true positive rates (TPR) of 99% for CHR2 insertions (Additional file 1: Figure S1A). Similarly, 92% of called CHR2 insertions were correctly recognized as homozygous indicating a high genotype accuracy on our dataset (Additional file 1: Figure S1B). MELTs internal filtering reduced sensitivity slightly (Additional file 1: Figure S1C, D), however, our simulations showed that the most effective filters affected all mapped genomes equally because they were based on properties of the reference genome, e.g. the presence of low-complexity regions (Additional file 1: Figure S2). Hence, these filters are not expected to create biases between samples that would influence phylogenetic inference. Furthermore, MELT-Split, which jointly genotypes all genomes, highly improved the detection of orthologous insertions compared to analyzing each genome individually and later combining the results. In summary, the simulations showed that our approach generated a dataset of high-quality baleen whale TE insertions with the corresponding orthology information that are suitable for evolutionary analyses.

TE phylogenomics recovers rorqual speciation history

By creating a presence-absence matrix from 327,488 genotyped CHR2 insertion sites in all genomes, 91,859 orthologous integration events were identified that took place during the evolution of baleen whales. Based on the presence-absence matrix, phylogenetic trees were reconstructed using Dollo parsimony, Bayesian inference (BI), and Neighbor-Joining (NJ) methods. The three reconstruction methods indicated a common monophyletic origin of Balaenopteridae and Eschrichtiidae (Fig. 1a, Additional file 1: Figure S3) and placed the gray whale as the sister species to the fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeangliae*) clade. The minke whale (*Balaenoptera acutorostrata*) was reconstructed as the most basal rorqual species. In the NJ and BI trees, blue whale (*Balaenoptera musculus*) and sei

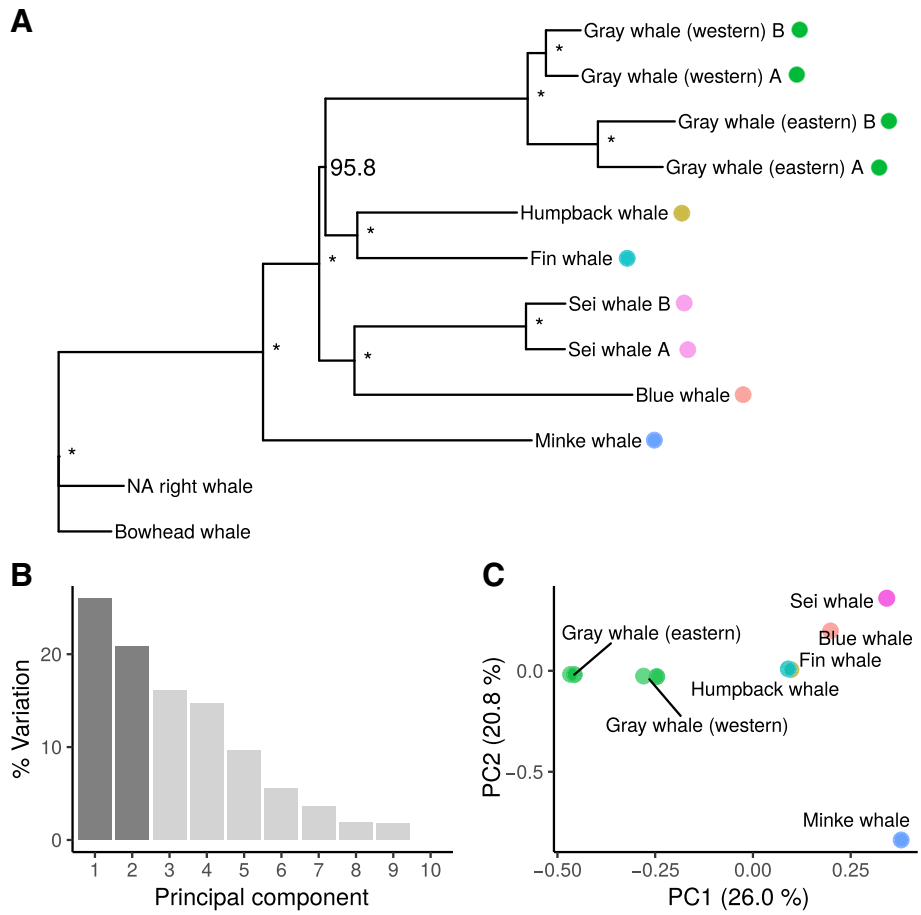

Fig. 1 Phylogenetic signal calculated from 91,859 CHR2 insertions in baleen whales. **a** Neighbor-Joining tree based on CHR2 insertions. All nodes received bootstrap values of 95% or higher (100% shown as asterisk). **b** Percentage of variation explained by principal components 1–10 in the PCA. **c** Scatterplot of the first two principal components (PC1 and PC2) among baleen whale genomes

whales (*Balaenoptera borealis*) formed a monophyletic clade as a sister group to the fin, humpback and gray whales. The CHR2 Dollo parsimony tree differed slightly from this topology because it reconstructed blue and sei whale as two separate lineages outside the fin, humpback and gray whale clade (Additional file 1: Figure S3 A). All trees received high node support with bootstrap values > 0.95 (Dollo parsimony, NJ) and 100% posterior probabilities (BI).

Although these tree reconstruction methods can by design only yield bifurcating topologies and cannot take conflicting genomic signals into account, considerable amount of phylogenetic conflict is indicated by low consistency indices (CI) (ranging between 0.629 and 0.646). The CI is a measure for tree support that indicates the fraction of minimum character changes compared to the observed number of changes, i.e. the tree length. If all character changes are consistent with the reconstructed tree, the CI is 1.0.

Analyzing the phylogenetic signal from CHR2 insertions among rorquals sensu lato using a principal component analysis (PCA) resulted in only the minke whale being clearly separated from the other species in the first two components, which together explained more than 50% of the variance in the dataset (Fig. 1b and c). While most species were found to be distinct along the first component, gray, fin and humpback whale were nearly indistinguishable on the second component. Furthermore, on the second component, the intraspecific differentiation between the two gray whale populations was as high as between other species pairs (Fig. 1c).

Network analysis reveals phylogenetic conflict

The low CIs of the phylogenetic trees indicate considerable amounts of phylogenetic conflict in the baleen whale genomes. To further explore these evolutionary signals, a median-joining network was calculated in order to uncover signals that otherwise remain hidden by traditional bifurcating tree-reconstruction algorithms. The phylogenetic network of CHR2 insertions showed a star-like web in the center of Balaenoptera and Eschrichtiidae (rorquals sensu lato) (Fig. 2a). Edges in the network that cluster the

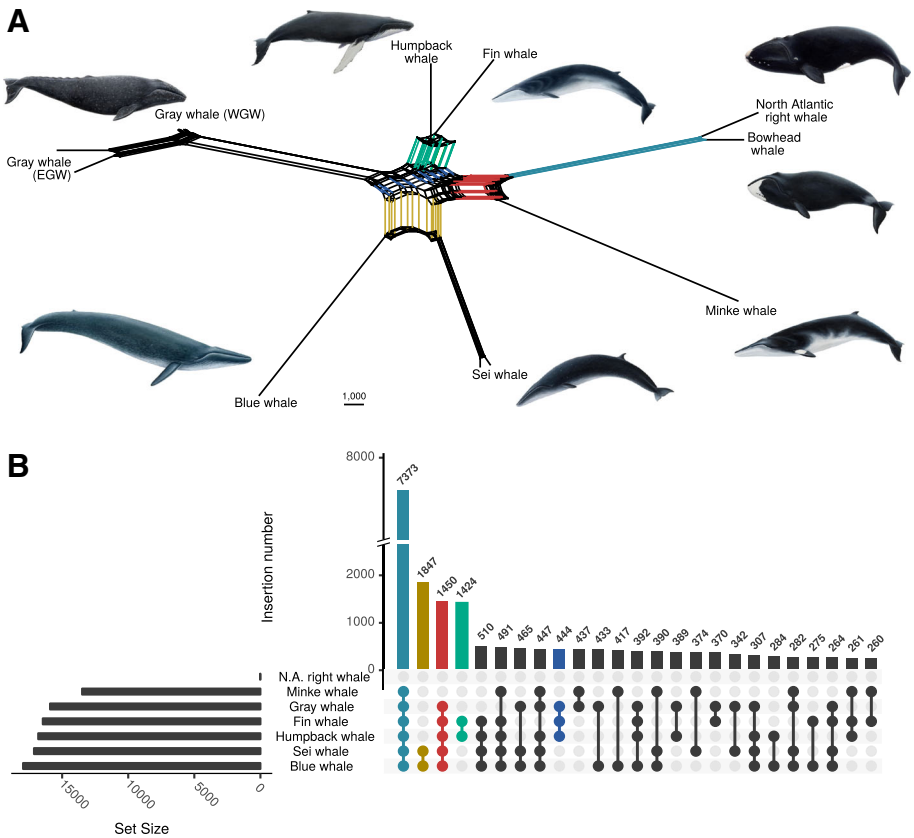

Fig. 2 Phylogenetic conflict among baleen whales inferred from CHR2 insertions. **a** Phylogenetic median-joining network based on 91,859 CHR2 insertions. **b** Distribution of phylogenetic signals in the dataset. Each synapomorphic CHR2 insertion is considered a phylogenetic signal for the common ancestry for the taxa carrying the insertions. The x-axis shows synapomorphic CHR2 insertions between species listed on the left-hand side. Bars on the y-axis show the number of insertions for the respective synapomorphies. The set sizes on the left-hand side show the total number of insertions present per species. Whale paintings are by Jon Baldur Hildberg (www.fauna.is)

gray whale with either the blue and sei whales and/or fin and humpback whales had similar lengths, thus indicating equally strong phylogenetic signal for both topologies.

A quantification of shared CHR2 insertions in baleen whales showed that the four strongest phylogenetic signals support the NJ tree (Fig. 2b) and are in agreement with the evolutionary history of rorquals inferred from genomic sequence analyses [10]. For example, the strongest signal consisted of 7373 synapomorphic CHR2 insertions shared by all rorquals sensu lato and supports a common ancestry of this clade. Within rorquals, 1450 insertions support that the gray whale diverged after the minke whale, confirming the paraphyly of rorquals sensu stricto. The monophyly of blue and sei whale as well as of fin and humpback whale was supported by 1847 and 1424 insertions, respectively. These strong signals match the well supported nodes in the reconstructed phylogenetic tree (Fig. 1a): the minke whale is clearly distinct from the other rorquals, and the sister group relationships of blue and sei whale as well as of fin and humpback whale are strongly supported. In contrast to other phylogenetic signals incongruent to the species tree, the numbers of TE insertions for the different phylogenetic positions of the gray whale among rorquals are highly similar and make a differentiation between evolutionary scenarios difficult. A ratio of 510:465:444 CHR2 insertions place the gray whale outside a fin, humpback, blue and sei whale clade (510), as sister clade to blue and sei whale (465) or as sister clade to fin and humpback whale (444), respectively (Additional file 1: Figure S4). Hence, this speciation event in the phylogenetic tree appears intuitively as unresolved and in fact a polytomy was only marginally rejected by the KKSC bifurcation test (p = 0.0204) [26]. In addition, a plethora of alternative phylogenetic signals of similar strengths illustrate the star-like radiation of Balaenopteridae and Eschrichtiidae. For example, the gray whale shares 433, 374 and 370 CHR2 insertions exclusively with the blue, humpback and fin whale, respectively. With regard to the previously established species tree, these insertions appear to be signals for ILS, however, they can not be considered by the KKSC test [26]. The KKSC test updates the statistical framework introduced by Waddell et al. [28] to test for the significance of conflicting phylogenetic signals from TE insertions to distinguish between ILS and introgression scenarios.

TE insertion dynamics

To explore the insertion dynamics of CHR2 in baleen whales, we investigated the genetic diversity and the insertion rates across time. We mapped the insertion points of all 91,859 CHR2 insertions on the baleen whale species tree [10] and calculated the frequency of heterozygous insertions on basis of the genotyping information provided by MELT. This allowed us to track how many insertions from each ancestral branch were fixed over time. Not surprisingly, several terminal branches exhibit high rates of heterozygous CHR2 insertions such as the two gray and sei whale populations and the blue whale (Additional file 1: Figure S5). High rates of heterozygous insertions originate also from the ancestral branches that led to the ancestor of gray, fin, humpback, sei and blue whales as well as from the ancestral branch to the fin, humpback and gray whale clade. The genomic heterozygosity of CHR2 insertions was lower in the sei whale branch and the fin and humpback whale clades, branches that exhibit less phylogenetic conflict (Fig. 2).

CHR2 insertion rates were calculated by mapping the insertion numbers on the species tree and using previously estimated divergence times [10] and an average generation time of 24.4 years for extant baleen whales [29]. The estimated insertion rates were relatively stable across the evolutionary lineages and ranged between 0.013–0.138 CHR2 insertions per generation (Additional file 1: Figure S6). The insertion rates at the terminal and shallow branches were relatively low and varied between 0.013 and 0.035. For the ancestral branch to gray, fin, humpback, blue and sei whale a ~ 10-fold increase in insertion rate was observed compared to other branches. The majority of CHR2 insertions that occured on this branch are incongruent to the bifurcating species tree. Repeat landscapes of minke and bowhead whale genome assemblies illustrate the evolution of TE sequences over time, by plotting the frequencies of sequence divergence to the TE consensus sequences. Both whale species show an increase in frequency of low-divergent SINEs (5–10% CpG-adjusted divergence), that could indicate an amplification burst of these elements (Additional file 1: Figure S7). The presence of a similar peak in both species at the same divergence indicate it must have occurred before their divergence at ~ 28 Mya.

Discussion

Here we have performed the first genome-scale analysis of TE insertions in whales based on next-generation sequencing technology. The included dataset, consisting of 91,859 insertion events across eight baleen whale species, exceeds the dataset size from a previous experimental approach by several magnitudes [16]. Our dataset made it possible to reconstruct the baleen whale evolutionary history and a detailed quantification of phylogenetic conflict.

Many previous studies have attempted to resolve the phylogeny of baleen whales and to clarify the evolutionary origin of the gray whale (family Eschrichtiidae). The gray whale is ecomorphologically derived from the family Balaenopteridae [5, 9] because it is the only bottom-feeding species within a clade of strictly lunge-feeding species [30] leading to confusion about its taxonomic position among baleen whales. Using TEs as virtually homoplasy-free and independent phylogenetic markers overcomes limitations from single-nucleotide based phylogenies [11] and should

provide a more detailed understanding about the evolution of baleen whales. Thus, we expected that a detailed analysis of TE insertions would finally settle the baleen whale relationships and also add additional information about the rate of retrotransposition in the slowest evolving mammals.

An evolutionary network analysis together with a detailed analysis of phylogenetically incongruent CHR2 insertions suggests that the speciation of rorquals represents a divergence that might not be entirely dichotomous. This is in spite that the TE based phylogenies were well supported and highly identical to the multi-locus coalescent tree generated from 34,192 sequence based gene trees [10] and a supermatrix tree [7]. However, careful interpretation is warranted given that bootstrap support and posterior probability were designed to assess sampling error of single genes, not genome-scale datasets and might lead to wrong conclusions about the species relationships [31]. Using bootstrap replicates and Bayesian probabilities to infer branch support is common practice, however, well-supported branches might merely be the result of an oversimplified evolutionary model if the dataset is large and the phylogenetic signal is not tree-like. Our in-depth analysis of conflicting synapomorphic TE insertions in baleen whale genomes show that the high statistical support in the phylogenetic trees is based on marginal numeric differences. Unfortunately, methods and models to reconstruct phylogenies from genome-scale multi-locus TE insertion datasets are not as developed as for nucleotide substitutions.

The presence of several equally strong conflicting phylogenetic signals in the CHR2 dataset can be caused by a) insufficient character sampling leading to an unresolved divergence (soft polytomy), b) near-instantaneous speciation and subsequent incomplete lineage sorting (ILS), or c) speciation under genetic exchange. Given the data presented here, it is highly unlikely that the divergence of the gray whale and its sister lineages represent a soft polytomy (a), as our extensive dataset of 91,859 CHR2 insertions is distributed across the near complete 2.3 Gb genome sequence of baleen whales and each node in the phylogeny is supported by several hundred insertions (Fig. 2b). In addition, a confounding effect from incorrect phylogenetic signal is marginal because SINE insertions are virtually free from homoplasy.

ILS (b) is the persistence of ancient polymorphisms across speciation events and has been observed in several TE-based phylogenomic studies [32–34], including a study investigating baleen whale relationships [16]. Several factors, such as a rapid radiation, large or expanding ancestral effective population sizes (N_e) and consequently a slow evolutionary fixation rate favor the occurrence of ILS [33]. The gray whale and the ancestors of the blue- plus sei whales and fin- plus humpback whales rapidly diverged from each other within less than one million years, as is evident from the star-like phylogenetic network (Fig. 2a) and previous divergence time estimates [10, 35]. In addition, a large ancestral N_e is suggested by the high number of species-tree incongruent CHR2 insertions and the large fraction of evolutionary old and still unfixed, heterozygous insertions that integrated on the ancestral branches with the highest degree of ILS (Additional file 1: Figure S5, and S6). The genome-wide analysis of CHR2 insertion thus strongly indicates that the ancestral rorqual population exhibited large population sizes and radiated rapidly. Also, explicit modeling of the demographic histories of baleen whales based on genomic data indicates large ancestral population sizes of whales [10]. However, these estimates do not reach back enough in time to cover the timeframe of the radiation.

Whales are the largest living animals and known for their slow physiological and evolutionary rate [36]. They exhibit the slowest nucleotide substitution rate among mammals, estimated to be 10 times slower than among primates [37]. Our estimates indicate that the rate of SINE insertions is about 50% slower than in humans, for which a mean rate of 0.046 Alu insertions per generation per genome was estimated [38]. However, we also observe a 10-fold increased CHR2 insertion rate on the branch to the fin, humpback, gray, blue and sei whale clade. Similar strong fluctuations in SINE insertion rates across evolutionary time, like estimated within baleen whales, were also reported for great apes [20].

Finally, a potential third cause for a conflicting phylogenetic signal (c) is that the emerging whale species might have exchanged genetic material for a long time because vicariance is more difficult to maintain in the marine than in the terrestrial environment. Hence, also speciation with genetic exchange of baleen whales might have caused trans-species polymorphisms [10, 39]. Whether the resulting genomic mosaicism is a result of speciation with genetic exchange or from ILS is however not possible to determine [40] and both processes are plausible for baleen whales. Either process or a combination of both could have created the observed phylogenetic signals that are incompatible with a strictly bifurcating tree. More detailed investigation of these processes require new methods that examine patterns of phylogenetic signals from TE insertions with respect to speciation processes and gene flow.

Conclusions

This study demonstrates the suitability of WGS datasets to infer TE insertions, one of the largest contributor to genomic variation in mammals [41]. Thus, TE insertions are a highly valuable source for

comparative genomics and for reconstructing phylogenies. In line with the first application of TE-based phylogeny of baleen whales [16] and a recent nucleotide-based study [10], the radiation of rorquals sensu lato appears to represent a hard polytomy when depicted as a phylogenetic tree because alternative phylogenetic scenarios are equally well supported. Therefore, a better representation of the rorquals' evolutionary history would be to represent the divergences in a phylogenetic network [10], allowing for the incorporation of ILS and genetic exchange between species as horizontal reticulations. We anticipate that a population-wide sampling of baleen whales might illuminate the divergence processes in more detail.

Materials and methods

WGS mapping

Whole-genome sequencing data from ref. 10 plus additional samples of two gray whales and a fin whale [42, 43] were quality-checked with FastQC (https://www.bioinformatics.babraham.ac.uk/projects/fastqc/), trimmed if necessary with Trimmomatic [44] and mapped to the bowhead whale genome with BWA [45] (Additional file 1: Table S1). The bowhead whale (*Balaena mysticetus*) genome assembly [13] was chosen for reference mapping over the more continuous minke whale genome because it is a natural outgroup to the rorqual species and thus eliminates TE detection bias between samples [23].

TE detection

The Mobile Element Locator Tool (MELT) [19] was run in the Split mode on all scaffolds larger than 100 kb. A consensus file for TE detection was created according to the MELT manual. We chose the general consensus sequence of the CHR2 SINE family, that was active during the evolution of Cetacea [46]. Seven different subfamilies of CHR2 have been described for cetaceans [47], that contain indels compared to the general CHR2 consensus sequence. Using the full length general consensus of CHR2 [14] and allowing for 10% mismatches makes a broader detection of CHR2 insertions in MELT possible. To annotate all copies of the CHR SINE family elements in the bowhead whale genome, the genome sequence was repeat-masked (http://www.repeatmasker.org/) with the Cetartiodactyla repeat library. BEDOPS [48] converted the RepeatMasker output into BED format.

Simulation and sensitivity analysis

Prior to TE calling, we performed a sensitivity and specificity analysis using our custom-made TE calling assessment pipeline ESAT (Element Simulation Analysis Tool) using sequences and parameters matching our whale dataset. We selected the longest scaffold (5 Mb) from the bowhead whale assembly to serve as a sample genome for our sensitivity analysis. We randomly integrated 200 CHR2 SINEs in the sample genome sequence and simulated paired-end Illumina reads from the resulting sequence with SimSeq (https://github.com/jstjohn/SimSeq) at sequencing coverage levels ranging from 1 to 30 X coverage. For read simulation we generated an error-profile typical for our whale resequencing datasets. Reads were mapped to the sample genome with BWA [45] as described above and MELT was used to call the CHR2 SINE insertions from our simulated genome. We generated 10 replicates per simulation. To analyze the performance of MELT, we assessed if the detected non-reference TE insertions matched the simulated TE locations using BEDtools [49]. The detection rate (DETR) reflects the sensitivity of MELT to successfully identify a TE insertion. True positive rate (TPR), false positive rate (FPR) and false negative rates (FNR) were calculated from the detected TEs to estimate MELT's accuracy on the whale dataset. Finally, the proportion of correctly genotyped insertions among the detected variants was recorded. We made ESAT publicly available on https://github.com/crueckle/ESAT.

Phylogenomic analysis

Orthologous TE insertion calls across the taxon sampling were identified using the GroupAnalysis and Genotype algorithms in MELT. TE insertion calls passing internal MELT filters were extracted with bcftools filter (www.htslib.org). A NEXUS-formatted presence absence matrix of orthologous TE insertions was created with a modified version of vcf2phylip [50]. Phylogenies were reconstructed using Neighbor-Joining and Dollo Parsimony in PAUP* [51]. Under Dollo Parsimony, only character state changes from absence to presence (0 to 1) are allowed, thus matching the evolutionary model of TE insertions. Heuristic tree search was conducted with random addition of sequences and 100 repetitions using Tree Bisection and Reconnection (TBR) as branch swap algorithms. Bootstrap support values were calculated from 1000 replicates. Likelihood scores for each tree were calculated using the 'lscores' command. A Bayesian inference tree was calculated in MrBayes v.3.2.6 [52] using "irreversible" character type (ctype irreversible:all) with 10e7 generations and sampling every 1000th generations, 25% of the samples were discarded as burn-in. Principal component analysis (PCA) for the filtered CHR2 datasets were conducted with the SNPRelate package for R. Phylogenetic median joining networks were generated in SplitsTree4 [53]. The intersection diagram was created with UpSetR [54]. For gray and sei whales, only TE insertions present in all individuals of the respective species were considered.

Insertion rates

Per-branch insertion rates were calculated from the number of CHR2 insertions that we had mapped to the species tree from ref. 10. This tree was used because it is the best available bifurcating representation of the baleen whales evolutionary history and is congruent with other recent studies on baleen whale phylogeny [7]. Species-tree incongruent CHR2 insertions were assumed to be the result of ILS and accordingly mapped to the most recent ancestral branch leading to the affected species. The insertion rate was calculated by the equation $\mu = \eta_{CHR2}{}^{*}b/24.4$ with n_{CHR2} for the number of CHR2 insertions and b as the branch length in years. The mean generation time of 24.4 years was calculated for from recent generation time estimates of the studied species [29].

Additional files

Additional file 1: Table S1. List of samples with accession numbers and sequencing properties. **Figure S1.** Simulation results for CHR2 detection with MELT at varying depth of coverage using dataset specific parameters. **Figure S2** Frequency of filters applied by MELT to exclude low-quality CHR2 calls. **Figure S3** Phylogenetic trees of baleen whales reconstructed with CHR2 insertions. A) Dollo-Parsimony tree reconstructed in PAUP*. Asteriks indicate 100 % bootstrap support (500 replicates), lower bootstrap support is given as numbers. B) Bayesian inference tree with posterior probability given for nodes. **Figure S4** Three alternative relationships in the rorqual radiation and the number of CHR2 insertion that support them. **Figure S5** Phylogenetic tree of rorquals with frequency of heterozygous insertions per branch. **Figure S6** CHR2 insertion rates per generation. **Figure S7** Repeat landscapes of minke whale and bowhead whale based on available assemblies. (PDF 475 kb)

Additional file 2: Data S1: VCF file with filtered CHR2 variants in baleen whales called by MELT. (ZIP 10547 kb)

Additional file 3: Data S2: NEXUS file with the presence-absence matrix of CHR2 insertions in baleen whales encoded as 1 (presence) and 0 (absence). (ZIP 159 kb)

Abbreviations

BI: Bayesian inference; CI: Consistency index; DETR: Detection rate; ESAT: Element simulation analysis tool; FNR: False negative rate; FPR: False positive rate; ILS: Incomplete lineage sorting; MELT: Mobile element locator tool; Mya: Million years ago; N_e: Effective population size; NJ: Neighbor-Joining; PCA: Principal component analysis; SNV: Single nucleotide variant; TBR: Tree bisection and reconnection; TE: Transposable element; TPR: True positive rate; WGS: Whole genome sequencing

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Availability of data and materials

All sequencing data is accessible from the respective accession numbers listed in Additional file 1: Table S1. The presence absence data (Additional file 3: Data S2) and the insertion calls (Additional file 2: Data S1) are provided in Additional file 1: Table S1, respectively. The modified version of vcf2phylip is available at https://github.com/mobilegenome/vcf2phylip.

Authors' contributions

FL and MN conceived the study. MB and FL performed the analyses. CR wrote the simulation pipeline (ESAT). FL, MB and MN interpreted the results. FL wrote the manuscript with input from MN. All authors read, gave comments and helped to revise the final version of the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

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Author details

[1]Senckenberg Biodiversity and Climate Research Centre, Senckenberg Gesellschaft für Naturforschung, Senckenberganlage 25, 60325 Frankfurt am Main, Germany. [2]LOEWE Centre for Translational Biodiversity Genomics (LOEWE-TBG), Senckenberganlage 25, 60325 Frankfurt am Main, Germany. [3]Institute for Ecology, Evolution and Diversity, Goethe University Frankfurt, Biologicum, Max-von-Laue-Straße 13, 60439 Frankfurt am Main, Germany.

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A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy

in

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by

Aimée R. Lang

Committee in Charge:

Professor William F. Perrin, Co-Chair
Professor Ronald S. Burton, Co-Chair
Professor John A. Hildebrand
Professor Rick G. LeDuc
Professor David W. Weller
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The material found in Chapter Two is being prepared for submission for publication. I was the primary researcher and author. The co-authors D. Weller and A. Burdin supervised the field effort through which the genetic samples were collected. The co-authors D. Weller, R. LeDuc, and R. L. Brownell, Jr. supervised the research.

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VITA

1996	Bachelor of Science, Auburn University
2002	Master of Science, San Diego State University
2010	Doctor of Philosophy, University of California San Diego

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ABSTRACT OF THE DISSERTATION

The population genetics of gray whales (*Eschrichtius robustus*) in the North Pacific

By

Aimée R. Lang

Doctor of Philosophy in Marine Biology

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Professor William F. Perrin, Co-Chair

Professor Ronald S. Burton, Co-Chair

Within the North Pacific, gray whales (*Eschrichtius robustus*) are recognized as distinct eastern and western populations. Although both populations were severely reduced by whaling, the eastern population is generally considered to have recovered while the western population has remained highly depleted. This study expanded on previous work supporting differentiation between eastern and western populations using mtDNA and utilized a panel of 13 microsatellite loci to provide additional insight into the population structure of gray whales. Comparison of microsatellite allele frequencies indicated that

eastern and western populations are genetically distinct. Although highly statistically significant, the level of nuclear differentiation between the two populations was relatively low, and the results of sex-specific analyses and assignment testing suggested that some degree of male-biased dispersal may occur between populations. Within the set of samples collected from animals on the primary western feeding ground, relatedness analyses revealed that, consistent with field observations, the fidelity of females and their offspring to this area have been important in shaping the structure of the population. Furthermore, analysis of the paternity of animals first identified as calves, with known and sampled mothers, in the western population between 1995 and 2007 identified 18 males as putative fathers, providing evidence that many of the animals identified on the Sakhalin feeding ground interbreed with each other, presumably while sharing a common migratory route. However, the success of the paternity assignment was lower than expected given the high proportion of sampled animals in this population, suggesting that some males which are contributing to reproduction may not use the primary western feeding ground on a regular basis. The combination of these results suggests that the population structure of gray whales in the North Pacific is more complex than previously thought, and that some movements between the eastern and western populations may take place. However, the maintenance of genetic differences between the two populations supports their recognition as separate eastern and western populations. Future efforts should focus on elucidating the nature and extent of any dispersal which is occurring in order to better understand factors potentially influencing the recovery of the small western population.

I. INTRODUCTION

The overall objective of this dissertation is to utilize molecular approaches to elucidate factors shaping the population structure of gray whales (*Eschrichtius robustus*) in the North Pacific. Any genetic patterns that may be delineated, however, must be put into the context of what is known about the distribution, history of exploitation, and current status of the gray whales on both sides of the North Pacific. As such, a general review of the current understanding of these topics, as well as a summary of findings from previous genetic studies, is provided below. Following this review, the rationale behind the current study is described in more detail and the specific objectives of each chapter are outlined.

Distribution

Although gray whales were first described based on subfossil remains from the coasts of England and Sweden (Lilljeborg 1861, 1867; Gray 1865), the population in that ocean basin is thought to have gone extinct by the early 18th century (Mead and Mitchell 1984). The current distribution of the species is limited to the eastern and western margins of the North Pacific (*Figure 1-1*), where two populations are recognized.

Eastern population

The population in the eastern North Pacific spends its summers feeding in the northern Bering and southern Chukchi Seas (Moore and Ljungblad 1984), although sightings in the eastern Beaufort Sea (Rugh and Fraker 1981) and as far west as the East Siberian Sea (Miller *et al.* 1985) have been recorded. In addition, a small number of animals, referred to as the Pacific Coast Feeding Aggregation (PCFA) of gray whales,

show fidelity to more southern feeding grounds located in the coastal waters between northern California and southeastern Alaska (Gilmore 1960, Pike 1962, Hatler and Darling 1974, Patten and Samaras 1977, Darling 1984, Calambokidis *et al*. 2002). Starting in November (Rugh 1984), animals migrate south along the west coast of North America. The primary wintering grounds for this population are located in the lagoons and coastal waters of Baja Mexico (Gilmore 1960, Swartz 1986, Urban *et al.* 2003), with some animals sighted in the Gulf of California (Findley and Vidal 2002). Animals return to the Arctic feeding grounds between May and June.

Western population

Although whaling logbook records indicate that gray whales once had a fairly extensive summer distribution within the Okhotsk Sea (Reeves *et al.* 2008), the majority of recent sightings of gray whales in the western Pacific during summer months have been confined to waters off the northeastern coast of Sakhalin Island, Russia (Weller *et al.* 1999, 2008). The primary feeding ground for the population is located in the shallow waters (<20 m depth) adjacent to the channel connecting Piltun Lagoon to the Okhotsk Sea (*Figure 1-2*; Weller *et al.* 1999, 2008). Animals have also been documented feeding in an area further offshore during some years (Miyashita *et al.* 2001, Burdin *et al.* 2002), and sporadic sightings of western gray whales have been made in other areas of the Okhotsk Sea and western Bering Sea (Weller *et al.* 2002, 2003). More recently, the occurrence of gray whales, some of which are known to have utilized the primary feeding ground off Sakhalin, has also been documented off the southeastern coast of Kamchatka (Tyurneva *et al.* 2009).

Understanding of the current distribution of western gray whales outside of their summertime range is limited. Some records of sightings, strandings, and entrapments of gray whales off Japan exist (Kato *et al.* 2007), suggesting that these regions may be used by migrating whales. The majority of these records are derived from the Pacific coast, although a few (n=4) have been recorded from the Sea of Japan coast (Kato *et al.* 2007). At least one of the whales entrapped off the Pacific coast of Japan has been matched photographically to an animal known to utilize the primary Sakhalin feeding ground (Weller *et al.* 2008b), providing a link between these two areas. Although no gray whales have been sighted off Korea since 1968 (Brownell and Chun 1977), peaks in the whaling catch records indicate that Korean waters were utilized by gray whales as part of both their northbound and southbound migratory routes (Kato and Kasuya 2002). The wintering grounds for this population have yet to be confirmed, but a limited number of sightings, strandings, and catches between 1933 and 1996 have suggested that western gray whales may overwinter in the coastal waters of southern China, including around Hainan Island (Wang 1984, Henderson 1990, Zhu 1998).

Temporal Changes

Although the distribution of the eastern and western populations are generally considered to be geographically separate, past Arctic environmental changes may have played a role in influencing patterns of mixing and separation between eastern and western animals, as has been proposed for bowheads in the Canadian Arctic (Dyke *et al.* 1996, SaVelle *et al.* 2000). Sea ice expansion during the Neoglacial (~4700 to 2500 years ago) may have limited access to parts of the Bering Sea and has been hypothesized to

have altered the distribution of North Pacific pinnipeds and cetaceans (Crockford and Frederick 2007). Most recently, the "Little Ice Age" (~400 – 750 years ago), which caused Arctic-wide cooling and widespread glaciation (Overpeck *et al.* 1997), may have shifted the distribution of sea ice further south and potentially facilitated mixing between the two populations during that time. It is also possible, however, that increases in sea ice cover could have led to population declines by limiting the extent of shallow water habitat available for feeding.

There are several indications that the distribution and habitat use patterns of eastern gray whales may have changed over the last few decades as a result of the increasing size of the population and/or habitat alterations associated with sea ice reduction and warming in the Arctic. Limited surveys conducted in 2002 found that the density of whales utilizing the Chirikov Basin, once considered a primary foraging habitat, was markedly lower than the densities recorded in the early to mid-1980s (Moore *et al.* 2003). Declines in abundance of ampeliscid amphipods, generally considered a preferred prey species for gray whales, were also documented within this region over that time period (Coyle *et al.* 2007). Given that the reduced density of whales utilizing the Chirikov Basin occurred while the eastern population was still growing, it is likely that these changes were reflected in an expanded foraging range for the population (Moore *et al.* 2003). Several other observations further suggest that some combination of environmental changes and the increased abundance of whales may be influencing foraging patterns of eastern gray whales. These observations (reviewed in Moore *et al.* 2008) include 1) median migration dates of southbound whales are approximately one week later than those observed prior to 1980, suggesting a potential redistribution of

whales on the feeding grounds (Rugh *et al.* 2001), 2) the number of calves born north of Mexico has increased over the last several decades (Sheldon *et al.* 2004), and 3) a positive correlation has been found between reproduction in the eastern population and the amount of time primary feeding areas are free of ice in the preceding year (Perryman *et al.* 2002). In addition, although similar behaviors may have been difficult to detect in the past when the population size was smaller and research efforts were more limited, gray whales have been observed foraging on atypical prey (cumaceans) off Kodiak Island, an area formerly considered part of the migratory route, since 1999 (Moore *et al.* 2007), and some gray whales are known to have remained at high latitudes in the western Beaufort Sea during winter months in 2003-2004 (Stafford *et al.* 2007).

These observations suggest that in the face of population recovery and a changing environment, gray whales may respond by shifting patterns of habitat use on their feeding grounds. Such shifts could be reflected in increased opportunities for mixing between the eastern and western populations. Importantly, however, mixing on the feeding ground does not necessarily denote gene flow. Studies of eastern gray whales have indicated that breeding occurs primarily while animals are on the migratory route, with females coming into estrous during a three week period extending from late November to early December, which coincides with the initiation of the southward migration from summer feeding areas (Rice and Wolman 1971). Females which fail to conceive during this first phase of mating may experience a second estrous approximately 40 days later, when whales would be at or near the wintering areas.

History of exploitation

Eastern population

Aboriginal harvesting of gray whales in the eastern Pacific has been occurring since at least the 16th century (Krupnik 1984). Commercial hunts for eastern gray whales on the population's wintering grounds, which began in 1845, peaked between the 1854/1855 and the 1864/1865 seasons, with an average of 486 whales taken per year (Henderson 1984). The number of whales killed per year declined over the next decade, averaging 214 per year until 1873/1874, after which whaling in lagoons largely ended due to the low number of remaining whales (Henderson 1984).These hunts were particularly devastating to the population due to the large number of females killed in lagoons, which greatly reduced the reproductive potential of the population. During the latter half of the 19th century, gray whales were also being taken via shore whaling from stations along the coast of California (Sayers 1984). By the turn of the century, the small number of remaining whales had made whaling no longer commercially viable (Henderson 1984).

Modern "industrialized" whaling for eastern gray whales was limited to a relatively short time period between 1914 and 1946, during which a total of 940 takes were recorded (Reeves 1984). The signing of the International Agreement for the Regulation of Whaling in 1937 provided protection of gray whales from commercial takes by at least some countries. In 1946, the International Convention for the Regulation of Whaling was established and banned commercial whaling by nations which were members of the International Whaling Commission (IWC). Since Russia (then the USSR) was a member of the IWC, eastern gray whales then received protection from commercial

whaling throughout their range. However, aboriginal subsistence whaling of eastern gray whales by the native people of Chukotka (Russia) and Washington State is allowed under the agreement. The current aboriginal catch limits allow for the take of 620 whales between 2008 and 2012, with a maximum of 140 permitted in a given year (www.iwcoffice.org).

Western population

Aboriginal whaling in the western North Pacific, which was active during the 18th century and probably began much earlier, was conducted by Koryak natives in the northern Okhotsk Sea and likely took some gray whales in that area (Krupnik 1984). Although the species taken were not well-documented, gray whales may also have been taken via hand harpoon by the Japanese as early as the 16th century (Omura 1984). By at least the late 17th century, gray whales were being taken by Japanese net whaling, which continued through the late 19th centuries (Omura 1984). Yankee-type whaling by American and European fleets in the Okhotsk Sea took gray whales from the late 1840s through at least the 1880s; the number of whales taken was estimated to be similar to those recorded for the Bering Sea and the Arctic, which numbered in the several hundreds (Henderson 1984).

Japanese net whaling continued to take some gray whales between 1890 and 1899 (Park 1987, Kato and Kasuya 2002), and modern-type commercial whaling for gray whales, most of which occurred off the Korean Peninsula, began in 1891 (Kato and Kasuya 2002). Although large numbers of gray whales were taken as early as 1907, catches peaked between 1911 and 1919, when up to 193 whales were taken in a single

year (Kato and Kasuya 2002). The mean annual catch dropped to 29 whales/year in the 1920s, and only 48 whales were taken between 1930 and 1933 (Kato and Kasuya 2002). The lack of recorded takes between the mid- to late-1930s indicates that the population had reached commercial extinction, and it was considered by some to have been extirpated by that time (Mizue 1951, Bowen 1974). However, the probable existence of the population was later described based on records of additional catches off the Korean coast between 1948 and 1966 (Brownell and Chun 1977), as well as the sighting of a small number of gray whales in the western Okhotsk Sea in 1967 (Berzin 1974, described in Brownell and Chun 1977) and a mother-calf pair in Korean waters in 1968 (Brownell and Chun 1977). The estimated total catch of western gray whales between 1890 and 1966, including both net whaling and modern-type whaling, was 1800-2000 animals (Kato and Kasuya 2002).

As aforementioned, gray whales first received protection from commercial whaling in 1937; however, none of the countries which border the western population's range were signatories to that agreement, resulting in much more recent exploitation of gray whales in the western North Pacific compared with that of whales in the eastern North Pacific. Some protection was afforded the western population in 1946, as Russia was a member of the IWC at that time. Japan joined the IWC in 1951, although South Korea and China did not join the IWC until 1978 and 1980, respectively. North Korea is not currently a member.

Abundance, current status, and potential threats

Eastern population

Shore-based counts of the eastern North Pacific population of gray whales have been conducted by the National Marine Fisheries Service since 1967/1968. Based on the population's abundance and trends in the population growth rate (Buckland *et al.* 1993), the eastern North Pacific stock of gray whales was removed from the List of Endangered and Threatened Wildlife and Plants in 1994. As required under the Endangered Species Act, the population was monitored over the next five years, after which a comprehensive status review was conducted (Rugh *et al.* 1999). Based on the population's continued growth and the lack of evidence indicating that eastern North Pacific gray whales were facing imminent threats, this review supported the continued classification of eastern North Pacific gray whales as non-threatened, although continued monitoring of the population's abundance was recommended (Rugh *et al.* 1999). The current size of the population is estimated at approximately 22,000 animals (Rugh *et al.* 2008, Wade and Punt 2010).

In 1999 and 2000, however, the eastern North Pacific population of gray whales experienced an "unusual mortality event", during which the number of animals stranding in each of those years (n = 283 and n = 368, respectively) was greater by an order of magnitude than those recorded in previous years (mean = 41 strandings/year between 1995 and 1998; Gulland *et al.* 2005). Although the cause of this mortality event remains in question, the emaciated condition of many of the stranded whales suggested that starvation may have been a contributing factor (LeBouef *et al.* 2000, Gulland *et al.* 2005) and led to speculation that the eastern North Pacific gray whale population may have

reached carrying capacity (Moore *et al.* 2001). However, several factors have indicated that the high mortality rate observed during these two years represented a short-term, acute event rather than a chronic trend (Rugh *et al.* 2005), including the return of stranding rates to levels observed prior to the event (Gulland *et al.* 2005) and calf counts which, a year after the event ended, were similar to the averages for previous years (Perryman *et al.* 2004).

Debate over the delisted status of the eastern population has also been derived from recent molecular estimates of historic abundance, which suggested that prior to exploitation gray whales in the North Pacific numbered ~96,000 animals (Alter *et al.* 2007). Given that the current abundance is approximately 20% of the genetically derived estimate, the authors recommended that the eastern gray whale population should be listed as "depleted" under the Marine Mammal Protection Act. Considerable debate over the interpretation of genetic estimates of historic abundance exists (*e.g.*, Palsboll *et al.* 2007). In addition, given that the contemporary carrying capacity of the environment may not be representative of the carrying capacity during the time period(s) for which these historic estimates are valid, the relevance of using such genetic estimates in determining the current status of populations has been questioned (Angliss and Allen 2008).

In part because of their largely coastal distribution, eastern gray whales may be subject to a variety of threats, including but not limited to vessel collisions, entanglement in fishing gear, habitat degradation, disturbance from anthropogenic noise, and disturbance from whale-watching (Angliss and Allen 2008). As well, in recent years Chukotkan subsistence hunters have noted that some whales (i.e., "stinky whales") have a strong medicinal odor. The cause of this phenomenon is not well understood, although it

has been hypothesized that changes in the whales' metabolism (potentially correlated with changes in prey) or contamination by bacteria, fungi, or biotoxins may be responsible (Rowles and Ilyashenko 2007, Rosa *et al.* 2009).

Western Population

The western population of gray whales was likely never as large as its eastern counterpart. Although reliable estimates of pre-exploitation size of the population are not available, back-calculation of population size using whaling catch records suggest that by 1900, after the population may have already been reduced by centuries of pre-modern whaling, approximately 1000-1200 individuals remained (Bradford 2003). Mark-recapture models have estimated that the population's abundance in 2003 was 99 animals (95% CI = 90-109), and population assessment using an individual-based model and data collected through 2007 predicted that the median non-calf population size in 2008 would be 130 animals (confidence limits 120-142; Cooke *et al.* 2008). These estimates indicate that the current size of the population is approximately 10% of that at the turn of the century. The population is currently listed as Endangered under the Endangered Species Act and Depleted under the Marine Mammal Protection Act. Internationally, it is listed as Critically Endangered by the International Union for Conservation of Nature (IUCN, Hilton-Taylor 2000, Baillie *et al.* 2004).

The small size of the western gray whale population leaves it vulnerable to numerous threats. Of particular concern for this population is the low number of reproductive females which have been documented (n=24 between 1995 and 2007, Weller *et al.* 2008a), some of which appeared to be experiencing longer-than-normal

intervals between successive calvings, particularly during the early years of the study (Weller *et al.* 2009). A male-biased sex ratio has also been identified among animals sampled on the western feeding ground (58.5% males) in the population; this sex-ratio is particularly pronounced among calves, approximately 66% of which are male (Weller *et al.* 2009). Given that the growth of the population is restricted by the rate at which calves are produced by females, this male-biased sex ratio could be a limiting factor in the population's recovery.

The onset of large-scale oil and gas development in waters proximate to the primary feeding ground in the mid-1990s has raised concern for the western gray whale population's survival (Weller *et al.* 2002, Reeves *et al.* 2005, IISG 2006). Activities associated with this development put western gray whales at risk for behavioral disturbance due to noise, ship strikes or collisions due to increased boat traffic in the area, disturbance to the benthic environment, and exposure to oil and other chemicals (reviewed in Reeves *et al.* 2005, IISG 2006).

Incidental catches in coastal net fisheries along the whales' migratory routes pose another significant threat to the population's survival (Weller *et al.* 2002; Brownell *et al.* 2007, Weller *et al.* 2008). This threat was highlighted by the loss of four whales, all females, to entrapment in nets off Japan between 2005 and 2007 (Brownell *et al.* 2007, Kato *et al.* 2007, Weller *et al.* 2008). Recent population assessment models have shown that if this rate of mortality continues, the population has a high probability of becoming extinct (Cooke *et al.* 2008). Photographic examination of scarring patterns indicate that at least 18.7% of whales identified between 1995 and 2005 showed scars consistent with

entanglement in fishing gear (Bradford *et al.* 2009), emphasizing the risk this threat poses to the population.

The limited information available on the areas used as migratory routes or wintering areas for western gray whales restricts understanding of the threats western gray whales face on other parts of their range. However, it is likely that whales are exposed to hazards associated with nearshore industrialization, shipping congestion, and pollution in these areas (Weller *et al.* 2002).

Previous genetic work

Most of the genetic work that has been conducted thus far on gray whales has focused on examining the potential for sub-structuring within the eastern gray whale population. These studies have indicated that fidelity to natal lagoons may create some degree of structuring within the eastern population, with small but significant mtDNA differentiation detected between cows (mothers with calves) utilizing two of the primary calving lagoons and females sampled in other areas (Goerlitz *et al.* 2003). An additional study, utilizing both mtDNA and microsatellites with samples collected from all three of the primary calving lagoons, also identified small but significant departure from panmixia between two of the lagoons using the nuclear data, although no significant differences were identified using mtDNA (Alter *et al.* 2009).

Sub-structuring within the eastern population could also be generated by fidelity of whales to particular feeding regions. Feeding ground fidelity has been observed in individuals belonging to the PCFA, which utilize coastal waters between northern California and southeast Alaska to feed during summer months (Darling 1984,

Calambokidis *et al.* 2002). Within these waters, photo-identification research, which commenced in the early 1970s, has identified some whales which demonstrate annual return to specific areas within this larger region, although movements between areas within the region also occur regularly (Hatler and Darling 1974, Darling 1984, Calambokidis *et al.* 2002, 2004). Recent estimates of the annual abundance of animals utilizing this region range from ~250 to ~300 animals (Calambokidis *et al.* 2004, Calambokidis 2007). Concern for this group of animals has stemmed in part from the resumption of subsistence whaling by the Makah tribe in northern Washington, an area used by both migrating and feeding whales. Genetic studies of the PCFA whales have focused on determining whether fidelity to this area is derived matrilineally, as internal recruitment of animals into this aggregation would require separate management to ensure that local extirpation would not result in a loss of part of the natural range. Initial work utilizing a simulations-based approach indicated that if the PCFA of whales was derived from a single colonization event in the past 40 to 100 years, detectable mtDNA genetic differentiation would be generated (Ramakrishnan and Taylor 2000). Subsequent empirical analysis, however, failed to detect such a signal when comparing 16 samples collected from known residents utilizing Clayoquot Sound, British Columbia, with samples (n=41) collected from animals presumably feeding in more northern areas (Steeves *et al.* 2001). Additional genetic analysis utilizing an extended set of samples (n=45) collected from whales within the range of the PCFA indicated that the level of genetic diversity and the number of mtDNA haplotypes identified were inconsistent with measures which would be expected if the aggregation was an exclusive maternal isolate (Ramakrishnan *et al.* 2001). However, both studies focused on evaluating only the

hypothesis of founding by a single colonization event and recognized that alternative scenarios, such as limited dispersal of whales from other areas into the PCFA, could also require separate management (Ramakrishnan and Taylor 2000, Ramakrishnan *et al.* 2001).

In addition, differentiation between the eastern and western populations has been explored using mtDNA (LeDuc *et al.* 2002). This study utilized 45 biopsy samples collected between 1995 and 1999 from animals utilizing the primary western feeding ground located in the coastal waters of northeastern Sakhalin Island, Russia, as well as 120 samples collected primarily from animals which stranded along migratory routes in the eastern Pacific. Significant differences in mtDNA nucleotide diversities and haplotype frequencies were identified ($\varphi_{st} = 0.117$, $p < 0.001$; $F_{st} = 0.087$, $p < 0.001$), supporting recognition of the eastern and western populations as separate stocks. MtDNA haplotype diversity was substantially reduced in the western population (h=0.70) when compared to the eastern population (h=0.95). This reduction was derived from differences in the distribution of haplotypes between the two populations. While the 33 haplotypes identified in the eastern population were distributed relatively evenly, the distribution of haplotypes in the western population was highly skewed, with two haplotypes found in very high frequencies (44.4% and 33.3%) and the eight remaining haplotypes found in only one or two individuals.

The number of mtDNA haplotypes (n=10) found among western gray whales was surprisingly high given what is known about this population's small size and history of exploitation. This finding was inconsistent with a scenario in which the western gray whale population, then estimated to contain approximately 100 individuals, had been

growing at the expected rate over the past 30+ years, and raised the possibility that little to no growth occurred in the population between the end of whaling in 1966 and the time of the study (LeDuc *et al.* 2002). However, the occurrence of some degree of male-biased dispersal could also explain the high number of haplotypes found in the western population (LeDuc *et al.* 2002). Given the maternal inheritance patterns of mtDNA, such dispersal could occur without having a substantial impact on the extent of mitochondrial genetic differentiation observed. Some support for this possibility was derived from examination of the distribution of mtDNA haplotypes among the sexes. Of the eight western haplotypes which were found in only one or two individuals, six were found only in males. Given the greater number and diversity of haplotypes found in the eastern population, any animals dispersing from the east into the western population would be likely to carry a haplotype not previously found in the west, suggesting that some of those males which carry haplotypes found in only low frequencies in the western population could represent possible dispersers between the two populations (LeDuc *et al.* 2002).

Objectives

The overall objective of this study is to utilize information from genetic markers to add to our understanding of factors shaping the structure of gray whale populations in the North Pacific. Although the previous genetic study identified significant levels of genetic differentiation between eastern and western gray whale populations, it also raised questions about potential movements of some males between the two populations (LeDuc *et al.* 2002). Additional insight into these questions may be provided by integrating information obtained from nuclear bi-parentally inherited markers with that provided by

mtDNA. In Chapter Two, a panel of 13 microsatellite markers is used to determine if significant nuclear genetic differentiation can be detected between the eastern and western populations. Sex-specific comparisons are used to specifically address the possibility that some male-biased dispersal is occurring. This chapter also compares levels of genetic diversity that have been maintained in the two populations, to determine if a substantial amount of genetic diversity has been lost in the much smaller western population.

The use of microsatellites has the additional advantage of facilitating genetic discrimination between individuals, allowing patterns of relatedness between individuals to be assessed. In the third chapter, the microsatellite data are used to conduct a paternity analysis for animals first identified as calves on the western feeding ground. The results of this analysis are used to determine the number of males contributing to reproduction in the western population, as well as to assess the distribution of reproductive success among those males. Given that this is the first study examining patterns of male reproductive success among gray whales, the results are evaluated in terms of our overall understanding of the mating system of mysticetes. The patterns identified are also discussed in light of their implications for the size and the extent of isolation of the western population.

The goal of the fourth chapter is to assess the role that intermixing between eastern and western populations may play in creating genetic heterogeneity among animals sampled on the western feeding ground. The potential for within population processes, such as differential reproductive success among females, to create substructuring within the feeding ground is also explored.

The fifth chapter discusses the incidental identification of two pairs of samples which are genetically identical using the markers utilized in this study. In both cases, one sample of each pair was collected in the eastern Pacific while the other sample was collected in the western Pacific, suggesting the potential for genetic detection of movements of individuals between the two populations. The caveats of using such methods to identify movements are discussed, as well as the implications for population connectivity that might be derived from assuming such movements are real.

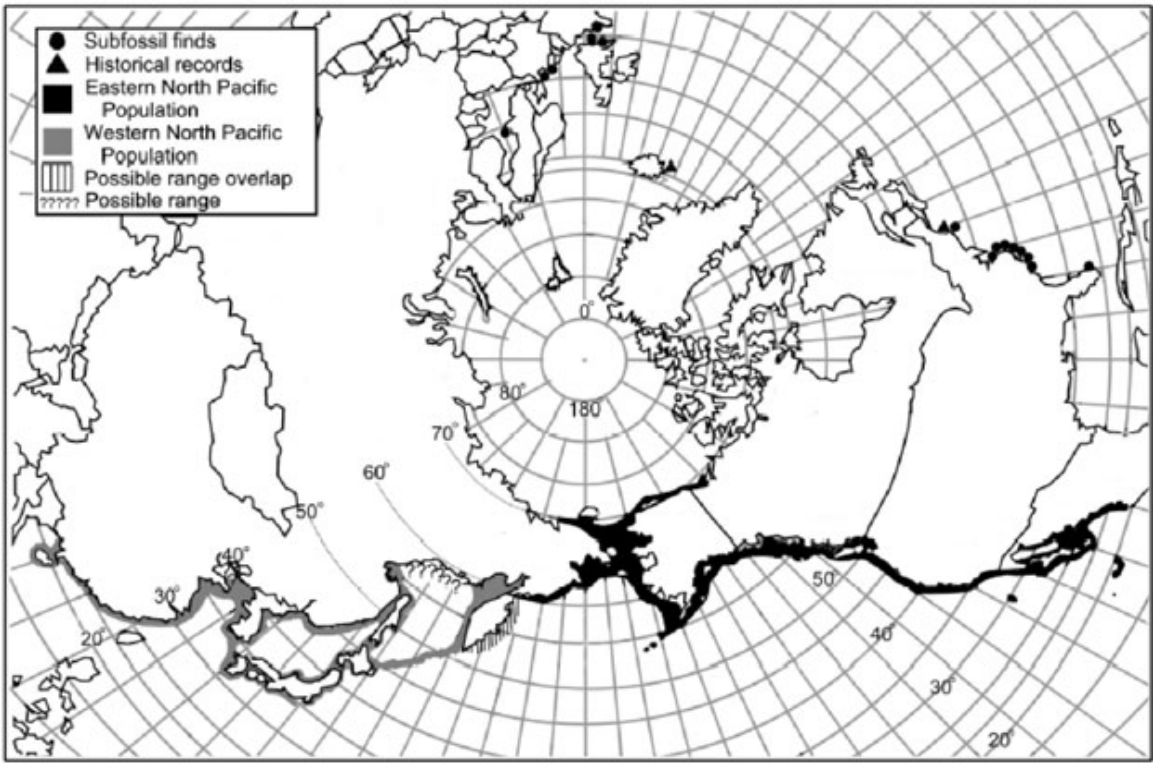

Figure 1-1. The range of the gray whale. Reproduced from Swartz *et al.* 2006

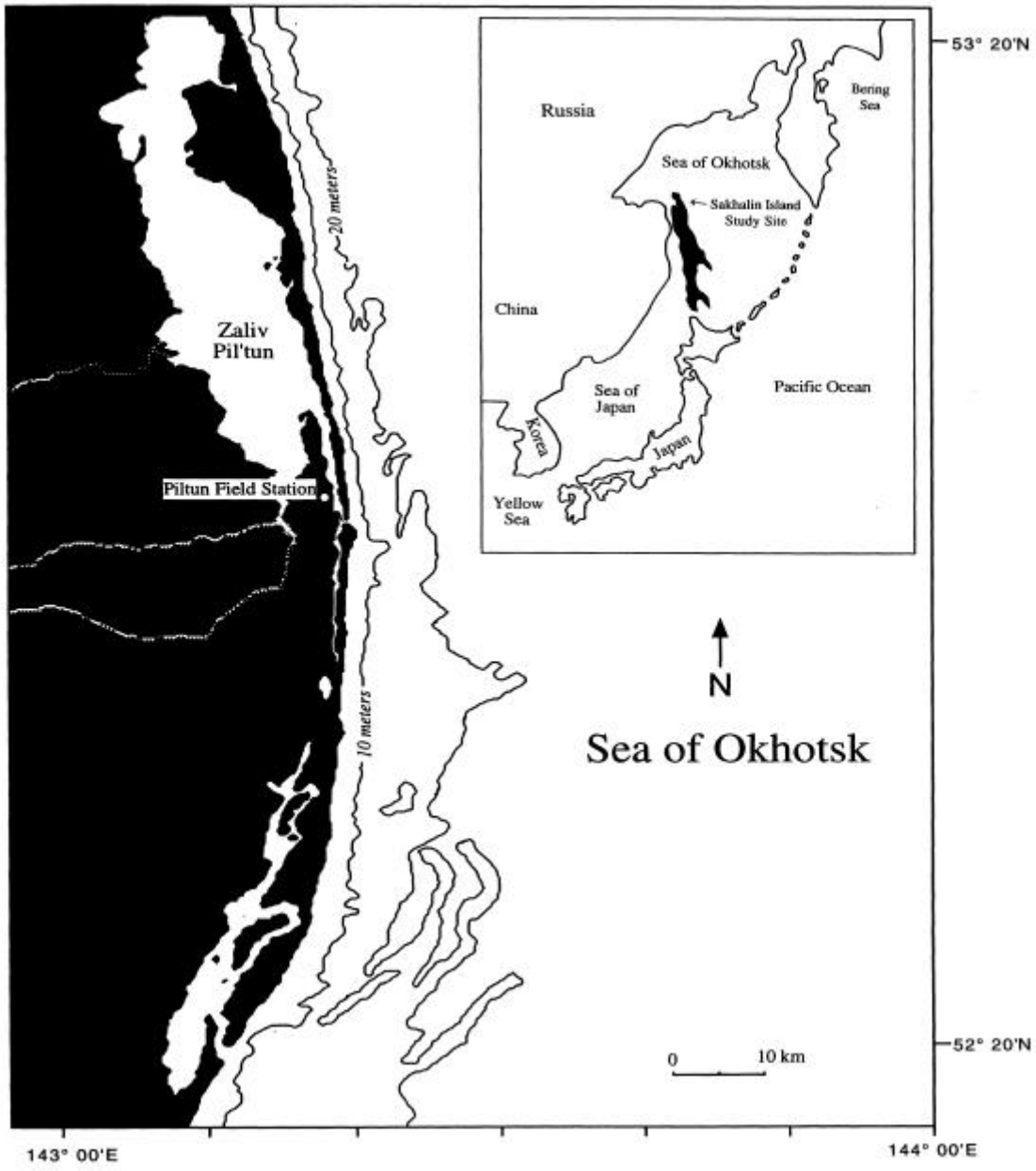

Figure 1-2. Map of the Piltun study area. Inset shows relative location of Sakhalin Island in the Okhotsk Sea.

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II. CHAPTER TWO

Genetic differentiation between the western and eastern gray whale (*Eschrichtius robustus*) populations using microsatellite markers

ABSTRACT

Within the North Pacific, gray whales (*Eschrichtius robustus*) are recognized as distinct eastern and western populations. Although both populations were severely reduced by whaling, the eastern population is generally considered to have recovered while the western population has remained highly depleted. Previous studies have documented genetic differentiation between the two populations on the basis of mtDNA haplotype frequencies. Since mtDNA represents only maternal inheritance patterns, the present study used bi-parentally inherited microsatellite markers (n=13) to measure differentiation between populations as well as to compare levels of nuclear genetic diversity retained in each. Mean levels of genetic diversity, as measured by the microsatellites, were similar between the eastern and western populations, indicating that the western population has retained relatively high levels of nuclear genetic diversity despite its small size. Comparison of microsatellite allele frequencies confirmed that eastern and western populations are genetically distinct. Although highly statistically significant, the level of differentiation between the two populations is relatively low, and sex-specific analyses suggest that some amount of male-biased dispersal may occur between populations. While these results suggest some movements between the eastern and western populations may take place, the maintenance of genetic differences between the two populations supports their recognition as separate eastern and western populations. Future efforts should focus on elucidating the nature and extent of any dispersal which is occurring in order to better understand factors potentially influencing the recovery of the small western population.

INTRODUCTION

Although gray whales (*Eschrichtius robustus*) once inhabited the North Atlantic Ocean (Mead and Mitchell 1984), the current distribution of the species is limited to the eastern and western margins of the North Pacific (Rice and Wolman 1971). Within this region, gray whales are recognized as having distinct eastern and western populations. Eastern gray whales winter in the lagoons and adjacent waters of Baja California, Mexico and then migrate north along the west coast of North America to feed in the Bering and Chukchi Seas during summer (Rice and Wolman 1971), with small numbers remaining in more southern waters between northern California and southeastern Alaska during summer months (Darling 1984, Calambokidis *et al.* 2002). For western gray whales, the primary feeding ground is in the coastal waters off northeastern Sakhalin Island, Russia (Weller *et al.* 1999, 2002). The location of the wintering ground(s) for this population remains unknown, but limited information from sightings, strandings, and catches shows that some animals winter in the coastal waters of southern China (Wang 1984, Henderson 1990, Zhu 1998).

Both gray whale populations were greatly reduced by intensive commercial whaling during parts of the 19th and 20th centuries, but the two populations have exhibited different trajectories in abundance following exploitation. Commercial whaling for eastern gray whales ceased in 1936 (Brownell and Swartz 2006), and the population's size has increased since that time (Rugh *et al.* 2005). Eastern gray whales were removed from the U.S. List of Endangered and Threatened Wildlife and Plants in 1994, and recent abundance estimates indicate that the population contains approximately 22,000 animals (Rugh *et al.* 2008, Punt and Wade 2010). In the western population, however, hunting

continued through at least 1966 (Brownell and Chun 1977). Although likely never as large as its eastern counterpart, this population was reduced to a much smaller size than the eastern population and was considered by some to be extinct as recently as the 1970s (Bowen 1974). Today western gray whales exist only as a small remnant population. Recent population assessment utilizing a Bayesian individually-based stage-structure model and photo-identification data collected between 1994 and 2007 projected a median non-calf population size of 130 individuals in 2008, assuming current demographic and population trends continue (Cooke *et al.* 2008). This population was listed as Critically Endangered by the IUCN in 2000 (Weller *et al.* 2002, Baillie *et al.* 2004), and its continued survival is jeopardized by problems associated with small population size (reviewed in Clapham *et al.* 1999), as well as by a wide range of potential anthropogenic threats, including the rapid expansion of oil and gas development on its summer feeding ground off Sakhalin Island, Russia (Weller *et al.* 2002, Reeves *et al.* 2005, IISG 2006) and mortality due to net entrapment while on the migratory route off Japan (Brownell *et al*. 2007, Weller *et al.* 2008b).

Concern for the conservation status of the western population led to the initiation of a joint Russia-U.S. research program in 1995. This program is based on the summer feeding ground off Sakhalin Island, Russia and has incorporated both photo-identification studies and biopsy sampling (Weller *et al.* 1999, 2002). Photo-identification research has shown that most whales demonstrate high rates of annual return and pronounced seasonal site fidelity to the Sakhalin feeding ground (Weller *et al.* 1999, 2002). The majority (83% of identified whales (n=169) have also been genetically sampled, allowing a male bias (58% males) to be documented among sampled individuals (Weller *et al.* 2002, 2008).

This male bias is particularly pronounced in individuals first identified as calves, of which 66% are males (Weller *et al.* 2008).

Biopsy samples collected between 1995 and 1999 have been used to show that the eastern and western populations are genetically distinct based on mitochondrial DNA (mtDNA) haplotype frequencies (LeDuc *et al.* 2002). This study found that western gray whales have retained a relatively high number of mtDNA haplotypes for such a small population. Genetic differentiation between the eastern and western populations was based on differences in the frequency distributions of haplotypes within each population. While haplotypes were apportioned relatively evenly among the eastern gray whale samples, the haplotype distribution found within the western gray whale samples was highly skewed, with two haplotypes found in very high frequencies and the remaining haplotypes identified in only one or two individuals (LeDuc *et al.* 2002).

The work presented here used thirteen microsatellite markers to further examine population structure of gray whales. Unlike mtDNA, which is maternally inherited and provides information about historic gene flow of females only, microsatellites are nuclear bi-parentally inherited markers and reflect gene flow of both males and females. The primary goal of this study was to examine genetic differentiation between eastern and western populations using microsatellites, as well as to assess factors which might contribute to that differentiation. Secondarily, levels of nuclear genetic diversity were compared between the two populations to determine if substantial genetic variability has been lost in the much smaller western population and could thus be affecting its ability to recover. Finally, since additional western gray whale samples have been collected since

the LeDuc *et al.* (2002) study, further analysis of population structure and genetic diversity using mtDNA was also conducted.

METHODS

Sample collection and DNA extraction

One hundred forty-two western gray whale samples were collected between 1995 and 2007 via biopsy darting of free-ranging whales on the population's feeding ground off Sakhalin Island, Russia. All except for one of the western gray whale samples are linked to a photographically identified animal, and this sample set represents 83.4% of all animals (n=169) identified on the western feeding ground through 2007. One hundred thirty-seven eastern gray whale samples obtained from the archive at the Southwest Fisheries Science Center were used for comparison to the western population. These samples were taken primarily from stranded animals (n=105), with some samples obtained from directed subsistence takes (n=12), fisheries bycatch (n=3), and biopsies (n=17) from free ranging whales. Collection locations ranged from southern California north to the Chukotka Peninsula in Russia.

DNA had been previously extracted for 120 of the eastern gray whale samples and 45 of the 142 western gray whale samples (those collected between 1995 and 1999) for use in an earlier study (LeDuc *et al.* 2002). For the remaining samples, whole genomic DNA was extracted using either the QIAGEN DNeasy™ tissue kit or the Corbett Robotics X-tractor Gene robot with the recommended protocols.

Molecular sexing and mtDNA control region sequencing

For those samples (n=114) not analyzed in the prior study by LeDuc *et al.* (2002), molecular sexing and mtDNA control region sequencing were conducted. For all of the eastern gray whale samples as well as the western gray whale samples which were collected prior to the 2006 season (n=94), a polymerase chain reaction (PCR) was used to determine sex utilizing primers described in Fain and Lemay (1995) and following the methods described in Gilson *et al.* (1998). For western gray whale samples collected in 2006 and 2007 (n=20), the protocol described in Morin *et al.* (2005) was used to determine the sex of individuals.

PCR was used to amplify a 523-base-pair fragment from the mtDNA control region using the primers 5'-TACCAAATGTATGAAACCTCAG-3' (H00034, Rosel *et al.* 1995) and 5'-CCTCCCTAAGACTCAAGGAAG-3' (L15812, Escorza-Trevino *et al.* 2005). Amplification products were cleaned through purification columns (QIAquick, Qiagen) and then sequenced using standard protocols with ABI-PRISM® Dye-DeoxyTerminator Big Dye™ v3.1 (Applied Biosystems) and the same primers. Following ethanol precipitation, sequenced products were run on an ABI 3100 or ABI3130 capillary sequencer. Consensus sequences for both strands were generated using ABI SEQSCAPE v2.5 software.

Microsatellite genotyping

Thirteen microsatellite loci isolated from other cetacean species were used to genotype the samples (*Table 2-1*). Reactions were performed in 25-uL volumes containing approximately 100 ng of genomic DNA and 2.5 uL of 2.0 mM $MgCl_2$ buffer,

1.5 uL of 10 mM dNTPs, 0.75 uL of each primer (at 10uM concentrations, with the forward primer of each pair fluorescently labeled), and 0.25 uL Taq. The thermal cycling profile included an initial hot start of 94°C for 2 min followed by 35 cycles of 94°C for 45 s, 1 min at the annealing temperature (see *Table 2-1*), and 1.5 min at 72°C, with a final 5-min extension at 72°C. Amplified products were mixed with a size standard and loaded onto an ABI 3100 or ABI 3130 sequencer. Sizing and binning of allele fragments using ABI GENESCAN and GENOTYPER analysis software were automated and relied on the use of internal lane standards, with subsequent manual evaluation of all labeled peaks.

Microsatellite scoring errors and identification of replicate samples

Prior to inclusion in this study, photo-identification data collected during biopsy sampling were used to identify and remove any duplicate samples (*i.e.,* samples taken from the same individual) from the western population sample set. Genotypic data were used to search for duplicates within the eastern gray whale sample set using MS Excel Toolkit v3.1 (Park 2001); one duplicate was identified and removed prior to analyses, leaving a total of 136 eastern gray whale samples. Microsatellite data were also examined for signs of large-allele dropout and null alleles using MICRO-CHECKER v2.2.1 (van Oosterhout *et al.* 2004).

Genetic variability within populations

ARLEQUIN v3.01 (Excoffier *et al.* 2005) was used with the mitochondrial control region data to calculate standard indices of genetic variation (nucleotide diversity,π, and haplotype diversity, h; Nei 1987) for each population. Genetic diversity

at the nuclear level was characterized by generating the number of alleles, observed heterozygosity, and expected heterozygosity for each microsatellite locus in each population using ARLEQUIN. Within each sample set, a Markov-chain approximation of an exact test, as implemented in GENEPOP v3.4 (Raymond and Rousset 1995a), was used to test for departures from Hardy Weinberg expectations and for linkage disequilibrium between all pairs of loci.

Bottleneck analyses

Populations which have undergone recent bottlenecks are expected to exhibit genetic signatures characteristic of a reduction in effective population size (Cornuet and Luikart 1996, Luikart and Cornuet 1998, Luikart et al. 1998, Garza and Williamson 2001). One such signature is a transient excess of heterozygosity (H_e) relative to that expected in a population of constant size, which results from the rapid loss of rare alleles contributing little to overall heterozygosity (Cornuet and Luikart 1996). Here we utilized the program BOTTLENECK v1.2 (Piry *et al.* 1999) to determine if the gray whale microsatellite data demonstrated evidence of population bottlenecks. As recommended (Piry *et al.* 1999), a two-phase model assuming 95% single-step mutations and 5% multiple-step mutations was employed, with the variance among multiple steps set to 12. The distribution of gene diversity at equilibrium was estimated using a coalescent process with 10,000 simulations, and a one-tailed Wilcoxon test was used to determine if an excess of heterozygosity, relative to that expected in populations at equilibrium, was present (Cornuet and Luikart 1996).

The loss of rare alleles during a population bottleneck may also result in gaps in the size distribution of microsatellite alleles. This can be measured as the mean ratio (*M*) of the number of alleles to the allele size range across all loci (Garza and Williamson 2001); bottlenecked populations demonstrate reduced *M* values. Here we used ARLEQUIN to calculate *M* for both gray whale populations and then compared our values to those reported for reduced and stable populations by Garza and Williamson (2001).

Genetic differentiation among populations

Two approaches were used to assess the degree of genetic differentiation between the two sampling regions. In the first approach, samples were divided *a priori* into populations based on the geographic location in which they were collected. The extent of genetic differentiation between populations was then examined using both mtDNA sequences and microsatellite data. For mtDNA data, an analysis of molecular variance (AMOVA, Weir and Cockerham 1984, Excoffier *et al.* 1992) was used to generate frequency-based (F_{ST}) estimates of differentiation using the program ARLEQUIN (20,000 permutations were used to test for significance). For microsatellite loci, genetic differentiation was examined using an AMOVA (ARLEQUIN) and allelic frequencies (with 20,000 permutations to test for significance) to generate F_{ST} values (Weir and Cockerham 1984). Modified exact tests based on genotype counts, as implemented in GENEPOP v3.4 (Raymond and Rousset 1995b), were also utilized to measure levels of differentiation. Significance was tested using 10,000 permutations. Since the western gray whale sample set included 57 mother-calf pairings, analyses of genetic

differentiation were repeated after removal of the sample representing the calf in each pair, in order to avoid biasing the results by including known first-degree relatives.

As an alternative to *a priori* stratification of samples by geographic location, population structure was also explored using a Bayesian model-based clustering approach (STRUCTURE v2.2, Pritchard *et al.* 2000) with the microsatellite data. STRUCTURE assumes that within a set of samples there are K populations, each of which is characterized by allele frequencies at each locus. The program then divides all samples into K genetically distinct clusters by assigning individuals to putative populations such that deviations from Hardy-Weinberg and linkage equilibrium are minimized within each group. Five independent runs of K=1-5 were performed with a burn-in period of 50,000 iterations followed by 100,000 Markov-chain Monte Carlo repetitions, using a model based on admixture with correlated allele frequencies (Falush *et al.* 2003). After averaging across runs, the log probability of the data given K (Ln P(X|K) was used as the criterion to infer the number of clusters (K) most compatible with the our data.

Detection of sex-biased dispersal

The potential for sex-biased dispersal between populations was investigated using the microsatellite data with the methods described by Goudet *et al.* (2002) and implemented in FSTAT v2.9 (Goudet 2001). Since the signal of sex-biased dispersal disappears with mating (Goudet *et al.* 2002), animals first sampled as calves in the western population were omitted prior to analysis. This program generates a number of statistics aimed at identifying patterns of sex-biased dispersal. The statistics utilized here were 1) F_{st}, the proportion of genetic variation among populations; 2) the mean corrected

assignment index (mAIc) and 3) the variance around the assignment index (vAIc) (Favre *et al.* 1997, Mossman and Waser 1999). The p values were estimated using 10,000 randomizations, and a one-tailed test was utilized based on the expectation that, as in most mammals, dispersal is biased toward males. F_{st} and mAIc are expected to be higher in the more philopatric sex, while vAIc should be lower (Goudet *et al.* 2002).

To further explore the potential for sex-biased dispersal between populations, sex-specific estimates of genetic differentiation were generated using the methods outlined above with both the mtDNA and microsatellite data. In addition, values of cluster membership (Q) produced by the STRUCTURE model assuming K=2 clusters were compared between males and females.

RESULTS

Genetic diversity

Forty haplotypes defined by 39 variable sites were identified from the 278 gray whale samples. Thirty-five haplotypes were found among the eastern gray whale samples, while 22 haplotypes were found in the western gray whale sample set. Seventeen haplotypes were shared between the two populations. The frequency of haplotypes in each population is shown in *Table 2-2*. When all samples were combined, nucleotide diversity (π) was 0.018 (SD=0.0092), while haplotypic diversity (h) was 0.89 (SD=0.012). When subdivided by population, nucleotide diversity was relatively similar in both populations (π=0.016 ±0.0081SD, eastern population; π=0.018 ±0.0093SD, western population), while measures of haplotype diversity were higher in the eastern (h=0.95 ±0.006SD) than the western (h=0.77±0.025SD) population (*Table 2-3*). Sex-

specific diversity measures indicated that although haplotypic diversity was similar between the male (*h*=0.96) and female (*h*=0.95) subsets of the eastern population, lower levels of haplotype diversity were found among the western female subset (*h*=0.77) when compared to the western male subset (*h*=0.83).

No signal of large-allele dropout or null alleles was identified by MICROCHECKER for any locus in either of the two populations. No deviation from Hardy-Weinberg Equilibrium was detected in either population after controlling for the False Discovery Rate (FDR, Benjamini and Hochberg 1995). After correcting for the FDR, only one loci combination was found to be in significant linkage disequilibrium in the eastern population. However, significant linkage disequilibrium was detected for eight loci combinations in the western population. Given that the same loci pairs were not in disequilibrium in both populations, it is unlikely that this result was derived from physical linkage. Linkage disequilibrium can result from inclusion of related individuals within a sample set. Therefore, known relatives were removed and the tests were rerun on the remaining genotypes. Six loci combinations remained in linkage disequilibrium after controlling for the FDR.

After averaging across loci, measures of microsatellite diversity were higher in the eastern population (H_o=0.74, H_e=0.74, K=9.8) than in the western population (H_o=0.71; H_e=0.70, A=8.8); however, these differences were relatively small (*Table 2-4*). A total of 18 private alleles were observed in the eastern population, while only 5 private alleles were found in the western population.

Statistical analysis of the microsatellite allele frequency data using the program BOTTLENECK did not detect evidence of a recent (2-4N_e generations) bottleneck in

either population. Under the model utilized, heterozygosity excess was not observed in the eastern (Wilcoxon test, *P*=0.989) or the western population (Wilcoxon test, *P*=0.999). In addition, the calculated *M* values (0.823±0.15and 0.808±0.17) in the eastern and western populations, respectively) were more consistent with those described for stable populations and were considerably higher than the upper bound (0.70) that Garza and Williamson (2001) derived for reduced populations.

Genetic differentiation among populations

Significant genetic structuring between eastern and western populations on the basis of both mtDNA haplotypes and microsatellite allele frequencies was observed (*Table 2-5*). Similar results were also observed for the microsatellite data when genetic differentiation was assessed using the exact test; the overall results were significant ($p \leq 0.001$), with 11 of the 13 loci showing significant differences when analyzed independently (data not shown). These comparisons remained significant ($P \leq 0.001$) after known relatives (n = 57 calves which had sampled mothers) were removed from the analysis (*Table 2-5*); however, only three of the thirteen loci showed significant differences when analyzed independently.

STRUCTURE analyses (Pritchard *et al.* 2000, Falush *et al.* 2003) supported the presence of two populations (P ~1.0), with a clear increase in the log-likelihood of the data for K = 2 when compared to that for other numbers of clusters (*Table 2-6*). The probability that the data contained only one cluster was < 0.001, suggesting that eastern and western populations are not panmictic. When Q values, which represent the proportion of each individual's genotype that can be attributed to each of the clusters,

were used to assign individuals into clusters, 80% (n = 109 of 136) of animals sampled in the east were grouped into the same cluster while 65% (n = 92 of 142) of animals sampled in the west were grouped into a cluster (*Figure 1*). However, average source population Q values were relatively low for both populations; they averaged 0.69 (± 0.209SD) for animals sampled in the east and 0.60 (± 0.296SD) for animals sampled in the west.

Sex-specific comparisons

Sex-specific estimates of differentiation were much more marked among females than among males. Using mtDNA haplotype frequencies (*Table 2-5*), both the male and female comparisons were highly significant, although the F_{st} value estimated for females (F_{st} = 0.078) was more than twice as high as that estimated for males (F_{st} = 0.033). Interestingly, while the male-specific comparisons remained significant (P = 0.029) in the microsatellite exact test, F_{st} estimates based on microsatellite allele frequencies suggested no significant differences between eastern and western males. The sex-biased dispersal tests in FSTAT also supported greater philopatry among females when compared to males. While difference in males and females were not significant for the mean assignment index (*P* = 0.365) or the variance in the mean assignment index (*P* = 0.9262), females demonstrated significantly higher F_{st} values (*P* = 0.0176).

Results of the STRUCTURE analysis provided further evidence that male-biased dispersal may be occurring. After removing animals first identified as calves, average Q values were similar between eastern males (Q_{EM} = 0.70 ± 0.211SD) and females (Q_{EF} = 0.67 ± 0.208SD, *P* = 0.26, t-test); 80% and 87% of males and females were assigned to

their source population. In contrast, average Q values were lower for western males (Q_{WM} = 0.47 ± 0.339SD) than for western females (Q_{WF} = 0.63 ± 0.250; P = 0.010, t-test). Only 40% of western males had Q ≥ 0.50 for the cluster representing the western population, in contrast to 75% of western females.

DISCUSSION

Genetic variability

Populations reduced to small sizes can suffer from a loss of genetic diversity, which in turn may compromise their ability to respond to changing environmental conditions (Willi *et al.* 2006) and negatively influence long-term viability (Spielman *et al.* 2004, Frankham 2005). Although little is known about the level of genetic diversity maintained in the western gray whale population prior to its depletion by commercial whaling, comparison of the levels of diversity found in this small population with those maintained in the much larger population in the eastern Pacific can provide some insight into whether reduced genetic diversity may influence its recovery. Previous studies utilizing mtDNA indicated that although the western gray whale population had retained a relatively high number of mtDNA haplotypes and levels of nucleotide diversity which were similar to those found in the eastern population, the population had reduced haplotype diversity when compared to its eastern counterpart (LeDuc *et al.* 2002). Our results, using an extended sample set that included ~83% of photographically identified western gray whales, support these earlier findings. As previously noted, the reduced haplotype diversity found in the western population was not a reflection of the number of haplotypes present but rather of the skewed distribution of those haplotypes (LeDuc *et al.*

2002). This skew was even more marked with the added samples. While the frequencies of the two most common haplotypes changed little, new low frequency haplotypes were added, with 14 of the 22 western gray whale haplotypes being found in only one or two animals.

While approximately half (49%) of the mtDNA haplotypes identified in the eastern population were shared with animals sampled in the western North Pacific, a much larger proportion (77%) of the mtDNA haplotypes found in the western population were also identified in eastern animals. Given the relatively thorough sampling of animals on the western feeding ground, it is likely that most if not all haplotypes present in that area have been identified, indicating that the mtDNA haplotypes found only in the eastern Pacific are likely to be unique to that population. In contrast, the low proportion of animals sampled in the eastern population suggests that those haplotypes currently identified only among western animals (n=5) might also be discovered in the eastern population with additional sampling.

Although the relationship between population size and mtDNA diversity is not straightforward (Bazin *et al.* 2006; Nabholz *et al*. 2008), the number of haplotypes (n=22) found in the western gray whale population is surprising given its small size and history of exploitation. In a similar study of endangered North Atlantic right whales (*Eubalaena glacialis*), which are thought to number approximately 400 individuals, only five haplotypes have been documented (n = 180 samples, Malik *et al.* 2000). While sampling in other populations has been less comprehensive, similar patterns have been found in other small mysticete populations, including the Okhotsk Sea bowhead whale population (*Balaena mysticetus*), in which only four different haplotypes were found (n = 25

samples, LeDuc *et al.* 2005), as well as the Sea of Cortez fin whales (*Balaenoptera physalus*), in which three haplotypes have been identified (n = 56 samples, Berube *et al.* 2002).

Although the number of haplotypes currently found in the western population is higher than might be expected, this pattern may not persist into the future. Eleven of the 14 haplotypes found in low frequencies have been identified only in a single male. Although little specific information is available on gray whale longevity, they are generally thought to live for approximately 40 to 60 years. It is possible that some of these "rare haplotype" males could be animals that escaped being killed by whalers which hunted gray whales until at least 1966. Given the maternal inheritance pattern of mtDNA, and assuming that these males are indeed the only animals in the population with these haplotypes, the eventual loss of these individuals has the potential to substantially decrease levels of mtDNA diversity in the future.

The level of nuclear genetic diversity found in the western population was slightly lower than, but similar to, that found in the much larger eastern population. The number of microsatellite alleles found exclusively in the eastern population, however, was markedly higher than the number found in the western population. Given that the western population has been relatively thoroughly sampled, these results suggest that the western population's depletion and continued small size may have resulted in the loss of rare alleles from the population. No genetic signature of a bottleneck was detected in the western population using the microsatellite data. However, simulations have shown that detection of bottlenecks using genetic methods is dependent on a wide range of conditions, including duration of the bottleneck, mutation rate, pre-bottleneck size, and

post-bottleneck recovery (Williamson-Natesan 2005), and many studies have failed to detect the genetic signature of a bottleneck even when demographic data indicate population size collapse (*e.g.*, Queney *et al.* 2000, Spong and Hellborg 2002).

Overall, the western population appears to have retained relatively high genetic diversity despite its history of exploitation and continued small population size. In other populations, the maintenance of genetic diversity in the face of population decline has been attributed to long generation times (Dinerstein and McCracken 1990, Hailer *et al.* 2006, Lippe *et al*. 2006), which are characteristic of baleen whales and may have buffered the population against the rapid loss of variation. However, the relatively high level of genetic diversity that appears to have been maintained in the western population could also be the result of dispersal of eastern animals onto the western feeding ground. Even at low levels, dispersal has been shown to obscure bottleneck signatures (*e.g.,* Kellar *et al.* 2001, Busch *et al.* 2007) and genetically "rescue" populations from the loss of genetic diversity (Vila *et al.* 2003). Further exploration of this possibility is detailed below.

Population structure

The inclusion of additional samples to analyses employing mtDNA supported the previous conclusion that the two populations are genetically distinct (LeDuc *et al.* 2002). Nuclear differentiation estimates further confirm differences between the two populations and indicate that genetic separation between populations is not derived solely from female philopatry. These measures of differentiation remained significant after known first degree relatives (*i.e*., the calf from sampled mother-calf pairs) were removed from

the dataset, suggesting that such differences are not solely an artifact of the inclusion of highly related individuals in the analysis.

Although highly significant, the degree of nuclear differentiation, as measured by F_{ST} values, between the two populations is relatively small. This pattern of differentiation is similar to that found in North Pacific bowhead whale populations, which also demonstrate a significant but small degree of differentiation between a smaller western population inhabiting the Okhotsk Sea and a much larger eastern population in the Bering-Chukchi-Beaufort Seas (LeDuc *et al.* 2005). The relatively small but highly significant genetic differences observed in gray whales, particularly when combined with the similar pattern observed in North Pacific bowhead populations, suggests that past Arctic environmental changes may have played a role in influencing patterns of historic mixing and separation of eastern and western animals. Both stranding records and radio-carbon dating of remains have indicated that changes in sea ice distribution may have mediated bowhead whale distribution in the Canadian Arctic (Dyke *et al.* 1996, SaVelle *et al.* 2000). Within the North Pacific, Arctic-wide cooling and glaciation brought on by the "Little Ice Age" (~400-750 years ago) may have resulted in a southern shift in sea ice distribution and reduced sea level (Overpeck *et al.* 1997), potentially facilitating mixing between eastern and western whales. Sea ice expansion during the Neoglacial (~4700 to 2500 years ago) may also have limited access to parts of the Bering Sea and has been hypothesized to have altered the distribution of North Pacific pinnipeds and cetaceans (Crockford and Frederick 2007).

A second explanation for the low level of differentiation is that some limited gene flow could be occurring between the two populations. At equilibrium, the amount of

neutral genetic divergence, as measured by F_{st}, maintained between populations is dependent on the absolute number of migrants exchanged between populations, a measure which is the product of the effective size of the populations and the migration rate (N_em, Wright 1931). Thus the amount of differentiation maintained between two populations is a balance between the differences generated by genetic drift and the homogenizing effects of migration; given the small size of the western population, genetic drift could be acting to counteract some degree of genetic interchange between the two populations.

A third scenario which might also explain our results involves dispersal of whales between feeding areas without genetic exchange. Since breeding in gray whales is thought to primarily occur along migratory corridors (Rice and Wolman 1971), movement between feeding regions does not necessarily imply gene flow between the populations. Given that all of the western gray whale samples were obtained on the feeding ground, low differentiation levels could potentially be generated by a small number of eastern gray whales traveling to the western gray whale feeding ground during summer months and consequently being sampled while mixed with members of the western population. If these eastern dispersers visit the western feeding ground but return to the eastern Pacific to breed, such extralimital movements would act to reduce measured levels of genetic differentiation between populations in the absence of significant gene flow.

Some support for a limited degree of dispersal and/or gene flow between populations can be derived from the results of the sex-specific comparisons. If the observed low level of differentiation were due to recent divergence, similar patterns of

differences should be observed for males and females. Contrary to this expectation, all measures of differentiation were at least twice as high for female-only versus male-only comparisons. In addition, although comparisons between males remained significant for mtDNA, the F_{st}-based comparison of microsatellite allele frequencies did not identify significant differences among males, suggesting that some degree of male-biased dispersal may be occurring between populations. Such a pattern could also provide an explanation for the large proportion of mtDNA haplotypes (11 of 22) in the western population which are represented only by a single male. Given the higher diversity and number of mtDNA haplotypes found in the eastern population, any dispersers from the east would have a relatively high probability of carrying haplotypes considered "rare' in the west (LeDuc *et al.* 2002). Eight of the eleven haplotypes carried by only a single male in the west were also found in the east; given the low proportion of sampled animals in the east, it is plausible that the other three haplotypes would also be identified among eastern animals with additional sampling.

Although the analyses summarized here are not able to discriminate between gene flow and feeding ground dispersal, a combination of genetic assignment tests and parentage analysis in the future may be useful to distinguish between these two possibilities. In addition, simulation modeling could be utilized in the future to determine the degree of gene flow or feeding-ground dispersal which could occur under non-equilibrium conditions while still allowing the two populations to maintain genetic distinctiveness.

Conclusions and conservation implications

The results presented here support past work indicating that eastern and western populations are genetically distinct, further highlighting the need for continued conservation and expanded protection of the critically endangered western gray whale population. Although highly statistically significant, the level of differentiation between the two populations is relatively low, which may reflect recent divergence of the two populations, perhaps mitigated by past environmental changes, but could also suggest that some limited degree of dispersal and/or gene flow may occur between the two populations. Discrimination between these proposed explanations is important, given that each scenario could have different effects on the recovery of the critically endangered western population. If a restricted amount of gene flow is taking place, that interchange could be important in providing "genetic rescue" for the western population, helping to maintain relatively high levels of genetic diversity in a small population which would otherwise likely suffer from inbreeding and a subsequent loss of fitness. However, if dispersal between feeding grounds without any gene flow is occurring, then any eastern dispersers are not contributing to the gene pool but could be artificially inflating our estimates of both genetic diversity and population size, which would suggest that the western population is even more vulnerable than currently thought. Given the wide range of threats, including entrapment in fishing nets as well as expanding oil and gas development, which challenge the recovery of the western gray whale population, further exploration of possible mechanisms of intermixing is needed to better understand the dynamics of this critically endangered population.

The material found in Chapter Two will be submitted for publication. I was the primary researcher. The co-authors D. Weller and A. Burdin supervised the field effort through which the genetic samples were collected. The co-authors D. Weller, R. LeDuc, and R. L. Brownell, Jr. supervised the research.

Table 2-1. Microsatellite loci used in the study. Includes the species for which primers were initially designed, size of repeats, annealing temperature (T_a), size range, and reference listing primer sequences.

Locus	Source Species	Repeat Size (bp)	T_a (°C)	Size Range (bp)	Reference
DlrFCB17t*	*Delphinaptera leuca*	2	54	183-213	Buchanan *et al.* 1996
EV14t*	*Megaptera novaeangliae*	2	55	138-156	Valsecchi and Amos 1996
EV37	*Megaptera novaeangliae*	2	55	183-231	Valsecchi and Amos 1996
EV94t*	*Megaptera novaeangliae*	2	52	209-237	Valsecchi and Amos 1996
Gata028	*Megaptera novaeangliae*	4	54	159-187	Palsboll *et al.* 1997
Gata098	*Megaptera novaeangliae*	4	54	67-103	Palsboll *et al.* 1997
Gata417	*Megaptera novaeangliae*	4	54	198-222	Palsboll *et al.* 1997
Gt023	*Megaptera novaeangliae*	2	54	94-116	Palsboll *et al.* 1997
RW31	*Eubalaena glacialis*	2	54	114-136	Waldick *et al.* 1999
RW48	*Eubalaena glacialis*	2	55	112-124	Waldick *et al.* 1999
SW10t*	*Physeter macrocephalus*	2	55	119-151	Richard *et al.* 1996
SW13t*	*Physeter macrocephalus*	2	55	168-196	Richard *et al.* 1996
SW19t*	*Physeter macrocephalus*	2	55	122-142	Richard *et al.* 1996

* The sequence has been modified from the original design by placing the sequence GTTTCTT on the 5' end of the reverse primer (Brownstein *et al.* 1996)

Table 2-2. Frequency of mtDNA haplotypes in each population.

	# of Individuals	
Haplotype	**East**	**West**
A	15	51
B	10	44
C	13	9
D	7	5
E	4	3
F		1
G	9	2
H	1	2
I		1
J		1
K	5	
L	6	1
M	6	2
N	5	1
O	1	
P	2	
Q	1	1
R	7	
S	1	
T	7	1
U	3	
V	3	1
W	1	
X	6	
Y	3	1
Z	2	1
27	2	
28	2	3
29	2	
30	3	
31	1	
32	1	
33	1	1
34	1	
35		7
36	2	
37	1	
38		3
41	1	
42	1	
Total	136	142

Table 2-3. Genetic diversity estimates based on mtDNA control region sequences. Includes number of individuals (n), number of haplotypes (k), haplotype diversity (h) and percent nucleotide diversity (π). For haplotype diversity and nucleotide diversity, standard deviations are included in parentheses.

Population		n	k	h	π (%)
East	All	136	35	0.95 (±0.006)	1.57(±0.810)
	Females	49	23	0.95 (±0.014)	1.41 (±0.744)
	Males	87	30	0.96 (±0.008)	1.66 (±0.856)
West	All	142	22	0.77 (±0.025)	1.82 (±0.932)
	No known relatives	84	22	0.82 (±0.030)	1.83(±0.937)
	Females*	36	10	0.77 (±0.050)	1.89 (±0.984)
	Males*	42	15	0.83 (±0.041)	1.82 (±0.944)
Both		278	40	0.89 (±0.012)	1.81 (±0.922)

* Excludes animals first identified as calves

Table 2-4. Microsatellite data for gray whales. Includes number of alleles per loci (k), expected heterozygosities (H_e), observed heterozygosities (H_o), and number of private alleles (K_p). The overall results include averaged values over all loci for k, H_e, and H_o, and the sum of all private alleles for K_p.

	East				West			
Locus	**K**	**H_e**	**H_o**	**K_p**	**K**	**H_e**	**H_o**	**K_p**
D17t	15	0.89	0.90	1	15	0.88	0.85	1
EV14t	9	0.81	0.78	1	9	0.76	0.74	1
EV37	17	0.88	0.89	1	17	0.85	0.91	1
EV94t	11	0.79	0.74	2	9	0.75	0.75	0
Gata028	8	0.78	0.82	3	5	0.75	0.78	0
Gata098	10	0.65	0.65	3	7	0.63	0.61	0
Gata417	7	0.71	0.71	0	7	0.63	0.65	0
Gt023	9	0.72	0.76	1	8	0.68	0.68	0
RW31	10	0.82	0.83	1	9	0.82	0.85	0
RW48	5	0.40	0.42	0	5	0.36	0.34	0
SW10t	9	0.77	0.76	1	9	0.75	0.77	1
SW13t	8	0.63	0.67	1	8	0.67	0.68	1
SW19t	10	0.71	0.67	3	7	0.64	0.67	0
Overall	9.8	0.74	0.74	18†	8.8	0.70	0.71	5†

Table 2-5. Analysis of molecular variance (AMOVA) and pairwise comparisons among gray whale populations from microsatellites and mtDNA control region sequences. Significant P values (<0.05) are shown in bold. Comparisons using only females and only males did not include known relatives.

Comparison	**Microsatellites**			**mtDNA**	
	Genotype frequency			**Haplotype frequency**	
	F_{ST}	F_{ST} probability	Exact test probability	F_{ST}	F_{ST} probability
All individuals	0.009	**≤ 0.001**	**≤ 0.001**	0.068	**≤ 0.001**
No known relatives	0.005	**≤ 0.001**	**≤ 0.001**	0.045	**≤ 0.001**
Females	0.013	**≤ 0.001**	**≤ 0.001**	0.078	**≤ 0.001**
Males	0.002	0.117	**0.039**	0.033	**≤ 0.001**

Table 2-6. Results of STRUCTURE analyis using a model incorporating admixture with correlated allele frequencies. Includes the inferred number of genetic clusters (K), the estimated log likelihood value (after averaging across runs) for the data given K (Ln P(X|K)), and the posterior probability of K (Pr (K|X)). The value of K with the highest posterior probability is shown in bold. Details about the parameters incorporated in each model are described in the text.

K	Ln P (X|K)	Pr (K|X)
1	-11612.18	~0
2	**-11469.22**	**~1**
3	-11682.32	~0
4	-11808.74	~0
5	-12214.70	~0

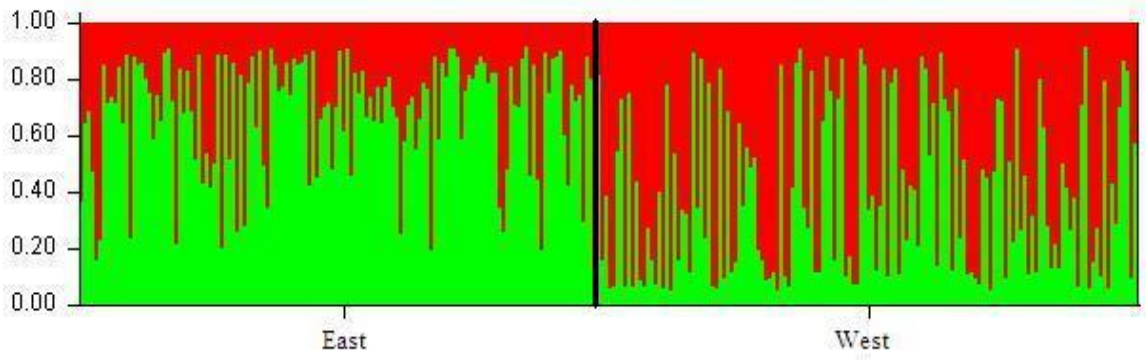

Figure 2-1. STRUCTURE barplot for K=2 using a model based on admixture with correlated allele frequencies. Individuals are represented by vertical bars, and the different colors of the bars represent the proportion of admixture (*Q*), or ancestry, from a each inferred genetic cluster. Individuals are grouped according to the population in which they were sampled, and the black line denotes the boundary between animals sampled in the eastern and western Pacific.

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III. CHAPTER THREE

Delineating patterns of male reproductive success in the western gray whale (*Eschrichtius robustus*) population

ABSTRACT

Monitoring of the critically endangered western gray whale population on its primary feeding ground off Sakhalin Island, Russia, has led to the collection of genetic samples from 83% of animals photographically identified from this area. The high proportion of sampled animals provides a rare opportunity to learn more about the mating system of a baleen whale species as well as to identify factors potentially influencing this small population's recovery. Utilizing a panel of 13 microsatellite loci, paternity analysis was conducted to identify breeding males and assess the distribution of male reproductive success. Using biopsy samples from 57 mother-calf pairs and 42 candidate males, putative fathers were identified for 46 to 53% of calves sampled in the population between 1995 and 2007. Although most males were assigned paternity of only one calf, a mild skew in the distribution of reproductive success was identified, with some males siring three to four calves over the 12 seasons of the study. Eighteen putative fathers were identified, and analysis of relatedness patterns among those calves which were not assigned a father suggested that an additional 15 males may be contributing to reproduction in the population. The relatively low success rate of the paternity analysis, in comparison to expectations derived from the percentage of photographically identified animals which have been sampled, indicates that some reproductive males may not use the Sakhalin feeding area on a regular basis. While the high percentage of "missing fathers" in this small population is puzzling, these results provide evidence that many of the animals identified on the Sakhalin feeding ground interbreed, presumably while sharing a common migratory route.

INTRODUCTION

Little is known about the mating systems of most species of baleen whales. Differences in the reproductive cycles of males and females suggest that mysticetes, like the majority of mammals, are polygynous (Clutton-Brock 1989, Mesnick and Ralls 2009). In most baleen whale species, females are restricted to producing a calf every two to three years due to the energetic constraints imposed by gestation and lactation, while males have potential reproductive rates that are much higher. These differences result in a skew in the number of reproductively available females relative to reproductively active males (*i.e*., the operational sex ratio), increasing the extent to which males must compete for females and permitting variance in male reproductive success to develop. As has been proposed for aquatically mating pinnipeds (Bartholomew 1970), however, the degree of polygyny which can be established in baleen whales is likely limited by the marine environment in which they breed, as females are highly mobile and resources are difficult to defend.

Much of the information available on mysticete mating systems has been derived from behavioral observations and the collection of physiological data. In humpback whales (*Megaptera novaeangliae*), the use of alternative mating tactics by males, including physical competition for access to females as well as "escorting" of females (Pack *et al.* 1998, Clapham 1996), has been documented and suggests a mechanism by which differential reproductive success might be generated in this species. In North Atlantic right whales (*Eubalaena glacialis*), males aggregate in large active groups and appear to compete for access to a female (Kraus and Hatch 2001). In addition, right whales, along with bowhead and gray whales, have high testes-to-body weight ratios,

indicating that sperm competition is an important strategy utilized by males (Brownell and Ralls 1986). The existence of both pre- and post-copulatory competition for fertilization in this species suggest that male reproductive success may not be evenly distributed across individuals.

While these studies have proven valuable in elucidating male mating strategies, they do not provide information on which males in a population successfully breed or how male reproductive success is allocated among individuals, which can have important implications for the maintenance of genetic diversity in small populations. The effective size of a population is determined not only by the number of animals contributing to successive generations, but also by the distribution of reproductive success among those individuals. High variance in reproductive success acts to decrease the effective size of the population (Hedrick 2005), thereby increasing the rate at which genetic diversity is lost. In addition, identifying reproductive pairs within populations can increase our understanding of the role that mate choice may play in inbreeding avoidance (*e.g.,* Archie *et al.* 2007) as well as of the relationship between offspring fitness and parental relatedness (*e.g.,* Amos *et al.* 2001).

Genetic analysis of paternity has the potential to provide detailed information on the reproductive success of individual males. In baleen whales, these analyses have thus far been limited to humpback (Clapham and Palsboll 1997, Nielsen *et al.* 2001, Cerchio *et al.* 2005) and North Atlantic right whales (Frasier *et al.* 2007). In studies of both species, the genetic results contributed valuable insight into patterns of reproduction which were not readily apparent based on previous studies. In humpback whales, the distribution of male reproductive success deviated from that predicted under random

mating, but the variation was lower than expected given the apparent skew in the operational sex ratio and the degree of male competition observed (Cerchio *et al.* 2005). In North Atlantic right whales, males demonstrated high variance in reproductive success when compared to other aquatically-mating marine mammals, although the variance was low relative to those breeding terrestrially (Frasier *et al.* 2007). These results support the idea that sperm competition creates differential reproductive success among males, but that the lack of control over resources and mates in the aquatic environment limits the degree of polygyny which could develop (Frasier *et al.* 2007). Results from this study also suggested that the low level of genetic variability in this species may be influencing reproductive success. Calves for which both parents were identified had significantly higher levels of genetic diversity, as measured by microsatellite markers, than expected under random mating, indicating that successful mating only occurs between individuals that are genetically dissimilar (Frasier 2005).

In gray whales, behavioral observations of multiple males mating with a female suggest a polygynous or promiscuous mating system (Jones and Swartz 1984). While mating behavior has been observed in all seasons, fertilization is thought to primarily occur during the southbound migration (Rice and Wolman 1971). Information from fetal growth rates suggests that females come into estrus during an approximately three-week period extending from late November to early December at the start of the southbound migration. Most females are thought to conceive during this period, although some females may ovulate approximately 40 days later when on or near the wintering grounds. Increased testes weight and the larger seminiferous tubules of males on the southbound

migration, as compared to those of northbound and summer feeding males, also support a peak in spermatogenic activity in late autumn to early winter (Rice and Wolman 1971).

As aforementioned, the high testes weight to body weight ratios found in gray whales suggest that this species utilizes sperm competition as a strategy for males to obtain successful fertilizations (Brownell and Ralls 1986), raising the possibility that, like North Atlantic right whales, some variance in male reproductive success may exist. Genetic paternity analysis would provide information valuable in assessing this possibility. Such a study would be difficult to conduct in the eastern gray whale population, given its large size and the relatively small proportion of animals which have been sampled. However, the population of gray whales found in the western North Pacific, which is both small and well-sampled, presents a valuable opportunity to conduct such an analysis. This population of whales was nearly extirpated by commercial whaling, which continued through at least 1966 (Brownell and Chun 1977, Weller *et al.* 2002). Unlike its eastern counterpart, which currently numbers approximately 20,000 to 22,000 animals (Rugh *et al.* 2008, Punt and Wade 2010), the western population has remained severely depleted and is estimated to contain approximately 130 individuals of one year or older (Cooke *et al.* 2008). Western gray whales are listed as Critically Endangered by the IUCN (Baillie *et al.* 2004). Anthropogenic threats potentially jeopardizing the population's recovery include extensive oil and gas development on the population's primary feeding area (Weller *et al.* 2002, Reeves *et al.* 2005) and mortality of whales associated with entrapment in fishing gear during their migration past Japan (Brownell *et al.* 2007).

Much of what is known about this small population of whales has been derived from long-term studies on their primary feeding ground located in the coastal waters of northeastern Sakhalin Island, Russia. Following a pilot study in the summer of 1995, a monitoring program was initiated in 1997 and continues to date. Extensive photo-identification records collected as part of this effort have shown that western gray whales exhibit a high degree of seasonal site fidelity to the Sakhalin feeding area (Weller *et al.* 1999, 2008a). This site fidelity, in combination with the population's small size, has facilitated the collection of genetic samples from a high percentage (~83%) of animals identified on the feeding ground. Analysis of these samples using both mitochondrial DNA (mtDNA) and a panel of microsatellite markers has shown that the western population is genetically distinct from the much larger eastern gray whale population (LeDuc *et al.* 2002, Chapter Two).

Given the high percentage of sampled animals and the availability of extensive sighting records for most individuals, genetic analysis of paternity in the western gray whale population will not only contribute to our understanding of mysticete mating systems but may also provide information important in assessing factors influencing the population's recovery. The low number of known reproductive females (n=24 between 1995 and 2007) has raised concern for the population's capacity for growth and recovery (Weller *et al.* 2002, 2008a). Little is known, however, about the number of breeding males in the population, or how reproductive success is distributed among these animals. Although previous studies have suggested that the western gray whale population has retained relatively high levels of genetic diversity (Chapter Two), information about

factors potentially influencing the effective size of the population may provide insight into the past and future maintenance of genetic diversity in this population.

In addition, limited information is available about the movements of western gray whales outside of their feeding range. The wintering ground(s) for this population is suspected to be off the southern coast of China, but the location has yet to be confirmed. Sightings, strandings, and entrapments suggest that gray whales migrate along both the eastern and western coasts of Japan, as well as along mainland Asia (Brownell *et al.* 2008). Although photo-identification records have identified one of the animals entrapped off the Pacific coast of Japan as an animal known to utilize the Sakhalin feeding ground (Weller *et al.* 2008b), thus far this is the only established link between a feeding area and a migratory pathway. Given that mating is thought to occur primarily while on migratory routes, the use of paternity analysis to identify pairs of interbreeding animals will provide information on which animals have utilized the same areas for migration and potentially overwintering.

Finally, questions have been raised about the isolation of this small population. Although the eastern and western populations have traditionally been considered geographically separate, in recent years gray whales have been sighted in feeding areas located off the eastern coast of Kamchatka. Some of these whales are known to have visited the Sakhalin feeding area, while others are of unknown origin (Tyurneva *et al.* 2009). These sightings have raised speculation about possible overlap among feeding regions for the eastern and western populations. In addition, although genetic studies have confirmed that eastern and western gray whale populations are distinct, the level of nuclear differentiation between the two populations is relatively low, suggesting that

some intermixing of eastern and western animals could be occurring (Chapter Two). Such intermixing could entail the use of the Sakhalin feeding area by eastern whales which then return to the eastern Pacific, or it might include some limited amount of interbreeding between the two populations. Although the lack of extensive sampling of the eastern population limits comparisons across populations, the proportion of reproduction that can be attributed to animals sampled off Sakhalin will provide some insight into the extent and nature of any interbreeding which may be occurring.

Between 1995 and 2007, 57 mother-calf pairs and 42 males of unknown age were sampled on the feeding ground off Sakhalin. These samples represent 90% of identified mother-calf pairs, and 83% (n=142) of all animals identified on the Sakhalin feeding ground during the study period. Using these samples and a suite of 13 microsatellite markers, a genetic paternity assessment was conducted for this population. The primary objectives of this work were to identify the number of males contributing to reproduction in the western population and to evaluate the distribution of reproductive success among these males. The results of the assessment not only expand our knowledge of mating systems of baleen whales, but also increase our understanding of factors potentially affecting the recovery of the western gray whale.

METHODS

Sample collection

Following a Russian-American pilot effort in 1995, a collaborative Russia-U.S. research program was established in 1997 which focuses on individual monitoring of western gray whales using photo-identification and genetic sampling (Weller *et al*., 1999,

2002). Field studies are carried out annually during summer months on the primary feeding ground off the northeastern coast of Sakhalin Island, Russia. Surveys (n=337) of this area have led to the photographic identification of 169 whales; genetic samples for 141 (83.4%) of the identified whales have been collected through biopsy-darting (Weller *et al.* 2008).

The genetic sample set includes samples collected from 57 animals which were first identified as calves (approximately 6-8 months of age) on the feeding ground and which are linked to known and genetically sampled mothers. Animals were identified as calves based on their small body size (approximately one third that of an adult), and, in most cases, their constant affiliation with a particular adult whale (Weller *et al.* 1999). For 54 of the calves, identification of the mother was first established via behavioral observations and confirmed by genetic analysis. Three calves were already separated from their mothers when first identified; in these cases the mother was identified using genetic parentage analysis alone.

The sex of all animals was determined using molecular methods (detailed in Chapter Two). Forty-two animals were identified as males of unknown age and were included as candidate fathers in the analysis. Males first identified as calves which may have reached sexual maturity during the study period were also included as potential candidate males. Although it is not known at what age male western gray whales first reproduce, the earliest estimates of age at sexual maturity in eastern gray whales is five years (IWC, 1993). Therefore, male calves were included as potential candidates for those years in which they would have been at least five years of age and potentially capable of reproduction in the preceding season when fertilization would have occurred.

To incorporate the changing number of candidates as calves from earlier years of the study became potentially sexually mature, paternity analysis was run separately for each year of the study.

Analysis

Samples utilized in the study had been genotyped at 13 microsatellite loci for use in the previous study; the protocols used to produce this data are detailed in Chapter Two. Paternity was assessed using the likelihood-based approach as implemented in CERVUS v3.0 (Marshall *et al.* 1998, Kalinowski *et al.* 2007). The objective of this analysis was to identify the candidate father which was statistically the most likely to be the true parent of the calf. The likelihood for each candidate was calculated using information on the allele frequencies in the population, such that a candidate male which shared a rare allele at a given locus with the calf was considered to be more likely to be the true father than a candidate sharing a common allele with the calf. The number of mismatches between the genotype of the father and the genotype of the calf (after removal of the maternal contribution to the calf's genotype) was also utilized in the likelihood analysis.

Simulations were used to generate critical values allowing confidence in the assignments to be evaluated. These simulations used the allele frequency data from the population being analyzed to generate simulated genotypes for parent-offspring pairs and unrelated individuals. The simulated data were then used to calculate the likelihood of parentage for the true parent as well as for each of the unrelated candidate parents for the simulated offspring. For each candidate identified as the most likely parent (whether or not it represented the true parent), the difference in likelihood scores between that

individual and the next most likely individual, referred to as Δ , was recorded. The distribution of Δ scores where the identified parent was the true parent with the distribution of scores where the identified parent was an unrelated individual was then compared to determine a critical value, such that the identified Δ was sufficiently large to distinguish true parents from unrelated parents at a specified (e.g. 95%) level of confidence.

One of the strengths of the CERVUS analysis is that it is able to account for potential errors in the dataset. Genotyping errors, mutations, or null alleles may create mismatches between the genotypes of candidate fathers and offspring, such that the true father might be falsely excluded when such factors are not taken into account. By incorporating an estimated error rate into the simulations run by CERVUS, the potential for such false exclusions is reduced. Here we ran the CERVUS analysis utilizing two different error rates. The first analysis assumed that no errors were present in the dataset, but this differs from a strict exclusionary approach in that likelihood scores were used to differentiate between candidate parents when more than one male had genotypes which matched that of the mother-calf dyad at all loci. The second analysis utilized an error rate of 0.01, allowing candidates to be assigned as putative fathers which had genotypes mismatching that of the mother-calf dyad at up to two loci. Additional parameters used in the simulations included 1) the number of simulated genotypes = 10,000, 2) proportion of loci typed = 0.99 (the true proportion), 3) minimum number of loci typed = 12, and 4) proportion of candidate males sampled=0.50. Given that the error rate and the proportion of sampled males are not known, additional simulations to explore the effects that these parameters may have had on the results are described in the Supplementary Information.

Results were evaluated at both the strict (95%) and relaxed (80%) levels of statistical confidence. The allele frequencies utilized for the likelihood calculations and simulations incorporated only the genotypes of non-calves, to avoid skewing the allele frequency distribution by inclusion of known relatives.

The pool of candidate males changed during some years of the study, as males first identified as calves and known to be ≥ 5 years of age became incorporated in the analysis. As such, the simulations used to calculate critical values were run separately for years with different pools of candidate males, such that while the proportion of candidate males sampled (0.50) was held constant throughout the study, the number of candidates was updated to reflect the changing number of sampled males. The total number of candidate males used in the CERVUS simulation was set by multiplying the number of sampled males by two in accordance with the assumption that 50% of candidates had been sampled.

To provide insight into the reproductive success of unsampled males, the program DADSHARE (http://www.zoo.cam.ac.uk/zoostaff/amos, see Hoffman *et al.* 2003) was used to estimate the number of putative sires for the calves for which all sampled candidates were excluded. This program inferred paternal sibships by calculating pairwise paternal relatedness coefficients among unassigned offspring using the relatedness coefficient of Queller and Goodnight (1989). A clustering algorithm (UPGMA) was then used to produce a dendrogram linking the most closely related individuals and sorting offspring into groups compatible with having a single father (e.g. paternal half-siblings). In addition, Monte Carlo simulations were used to explore the pattern which would be produced if 1 to K fathers sired the offspring, with K representing

the total number of offspring being assigned (e.g., the pattern produced if each offspring had a different father). The average r-values and standard deviations generated in the simulated scenarios were compared with the observed average r-values presented in the dendrogram. In order to evaluate how this method compares with direct parentage assignment, DADSHARE was run both with a dataset containing only those calves which were not assigned a putative father by the paternity assessment analysis as well as with a dataset including only those calves which were assigned putative fathers in the previous analyses.

A simulation-based approach, similar to that employed in previous parentage analyses conducted for mysticetes (Cerchio *et al.* 2005, Frasier *et al.* 2007), was used to evaluate how the observed patterns of male reproductive success compared with those expected if all candidate males had an equal probability of fathering calves within a year (e.g., if mating were random). To make the results of the simulation comparable to those generated in the CERVUS analysis, simulations were based on the number of sampled candidate males included in each year of the analysis as well as the number of paternities which were assigned for those years. For each year of the analysis, candidate males were randomized, and then fathers were selected with replacement for the number of calves which were assigned paternity in that year. This process was repeated for each year of the study, and the number of calves fathered by each male was summed across years to generate the expected distribution of reproductive success for the study period under the expectation of random mating. This process was repeated 1000 times to generate the mean expected number of sampled males which were assigned paternity of zero, one, two, three, four or more calves under random mating.

To facilitate comparisons of male reproductive success with other species, the standardized variance (SV = variance/mean) in reproductive success was calculated as implemented in previous studies (e.g., Coltman *et al.* 1998, Frasier *et al.* 2007) and using both the results of the paternity analysis and results from the simulations based on random mating. This measure was based only on the reproductive success of males which were assigned as putative fathers of at least one calf during the study. The standardized variance in reproductive success is considered to be zero in truly monogamous species and to increase with the extent of polygyny (Boness *et al.* 1993).

Results

Genetic profiling

Summary statistics for the microsatellite loci used in the study are shown in *Table 3-1*. The total exclusionary probability of the multilocus genotypes used in the paternity analysis, as calculated by CERVUS when one parent is known, was high at 0.9999. The probability of identity (P_{ID}, Paetkau and Strobeck 1994) was estimated to be $2.83x10^{-13}$, indicating that the loci utilized in the study provided high power to resolve relationships between individuals. The more conservative $P_{ID\text{-}sib}$ (Evett and Weir 1998) was also calculated to account for the possible presence of related individuals within the dataset. This estimate was low ($1.38x10^{-5}$), suggesting that the data would be able to distinguish between any full siblings included as candidates. Rechecking of ~20% of all genotypes did not identify a substantial source of error.

Paternity assignment

When no mismatches were allowed between the genotype of candidate males and that of the mother-calf dyad (hereafter referred to as the "stringent criterion"), paternities were assigned for 26 (45.6%) of the 57 calves. All paternities were assigned at the 95% confidence level. One calf had a genotype which matched that of two candidate males; for the remaining 25 calves only one possible match was identified. No putative fathers were identified for the remaining 31 calves.

Incorporating an error rate of 0.01 (later referred to as the "relaxed" criterion), the CERVUS analysis supported all of the assignments previously made and identified putative fathers for an additional four calves, such that paternity was resolved for 52.6% of calves in the study. The four additional assignments included putative fathers with one (n=2) to two (n=2) mismatches with the genotypes of the mother-calf dyads. All CERVUS assignments were supported at the 95% confidence level, with the exception of the one calf whose genotype matched that of two candidate males with no errors, which was assigned at 80% confidence. Those calves which were not assigned putative fathers by the CERVUS analysis mismatched all potential candidates at ≥ 2 loci; for the majority (79%) of these calves, mismatches for ≥ 3 loci were present with all candidates.

The success of the paternity assignment varied greatly across the 12 years of the study (*Table 3-2*). Excluding years in which only one calf was sampled, the proportion of paternities assigned per year ranged from one year in which no paternities were assigned to years (n=3 using the relaxed criterion) in which putative fathers were assigned to two thirds of sampled calves.

The paternity assignment also varied greatly across the reproductive females included in the study (*Table 3-3*). Excluding females which only had one offspring during the study, the average proportion of calves with assigned fathers per female was 0.54 (relaxed criterion) and assignment success ranged from having no calves assigned putative fathers (n=3 females) to having all calves born during the study assigned putative fathers (n=5 females).

Male reproductive success

When no errors were allowed, 17 males were assigned paternity of the 26 calves, for an average of 1.5 (±0.72SD) calves per male (*Table 3-4*). Average reproductive success was slightly higher when calculated from analysis incorporating error, with 18 males assigned paternity for 30 calves and an average of 1.7 (±0.91SD) calves per male. In both cases, the majority of males (59% and 65% of assigned males for the stringent and relaxed analyses, respectively) were assigned paternity of only one calf each, although a small number of males were assigned paternity of 3-4 calves during the 12 seasons of the study.

These estimates of reproductive success do not incorporate males which were not assigned paternity of any calves. Although the number of candidate males varied across years of the study, 57-69% of candidate males were not assigned paternity of any calves over the twelve years of the study. Inclusion of these males would reduce estimates of average reproductive success to 0.47-0.71 calves per male.

As expected, none of the 13 males of known age (*i.e.*, first identified as calves, ranging from 5 to 11 years old during the season of fertilization) were identified as

putative fathers during the study (*Table 3-5*). These males, as well as some proportion of the males of unknown age, were not sexually mature for all or part of the study. Of those males which were identified as putative fathers, all except one (only identified using the relaxed criterion) were identified prior to the 2000 season, and the majority (n=14, 77.8%) had been first identified by the end of the second season of the study (*Table 3-6*. All except two of the males were sighted at least once for six or more years of the study, with 14 males sighted for at least 8 of the 12 years of the study (*Table 3-6*). For the majority of assigned paternities (n=26 between 1999 and 2007), the putative father was identified on the feeding ground in the season prior to conception (77% of paternities) and/or the season following conception (73% of paternities).

Only one male was assigned paternity of 2 calves in any one season. Excluding this case, the average interval between successful reproductions was 2.8 years (relaxed criterion) to 3.75 years (stringent criterion). Although the maximum interval between assignments was six years, there were three males which were assigned as putative fathers early in the study and which were not assigned any additional calves for the following 8 to 11 seasons. Although some calves may have been lost before reaching the feeding ground, this finding suggested that intervals between successful mating may be even longer than illustrated with our dataset. The longest time span over which a male in the study was considered reproductively active was nine years, during which the male was assigned as the putative father of three calves.

In the seven to nine cases (stringent and relaxed criteria, respectively) in which a reproductive female had multiple calves which were assigned putative fathers, there was only one case in which the same male was assigned as the putative father of more than

one calf of the same female. Female Q had three calves during the study, and all three calves were assigned to the same male (I) under the relaxed criterion. One of these calves mismatched the assigned father at two of the 13 loci and was only assigned to the male in the relaxed analysis. One of the other two assignments for calves of this female was the case where the genotype of the calf matched that of two different putative fathers with no errors. Although male I was assigned as the most likely father, relatedness analysis (data not shown) suggests that the two putative fathers may represent a parent-offspring pair. Given that this was the only case in which more than one putative father had a genotype which matched that of a calf at all loci, the paternity analysis seemed to generally perform well at discriminating between relatives. However, it is possible that in at least this case the candidate male with the highest likelihood of being the true father shared a different relationship to the calf.

DADSHARE estimated that 15 males were likely to account for the 27 calves not assigned fathers in the CERVUS analysis. Average reproductive success among these 15 males was 1.8 calves per male. Relative to the paternity analyses, a larger proportion of these unsampled males (53%) were assigned paternity for two calves each during the study (*Graph 2-1*), suggesting these males may have greater reproductive success on average than those males which were sampled. When the DADSHARE analysis was run using only those calves which were assigned to putative fathers, 18 putative fathers were needed to account for the 30 calves, which corresponds exactly with the number of putative fathers identified in the "relaxed" CERVUS analysis. Similar to the results for the unassigned calves, however, the distribution of reproductive success among these 18 males was somewhat different than the observed pattern, with more males assigned as the

putative father of two calves during the study. Differences in reproductive success between the sampled and unsampled males may be an artifact of differences in the resolution of the two methods.

At least some of these unsampled males may be accounted for among the 28 animals which have been photographically identified on the Sakhalin feeding ground but which have yet to be genetically sampled. One of these is presumed to be a female based on its close and prolonged affiliation with a calf during the one season it was sighted, and nine are animals first identified as calves (≤ 9 years of age at the end of the study) and may not have been reproductively mature for much, if any, of the study period. This leaves at least 18 animals of unknown sex or age which have been identified on the feeding ground but are not represented in the sample set. Although some proportion of these animals may be males contributing to reproduction in the population, based on the overall sex ratio of the population (58% male, Weller *et al.* 2008a), it is unlikely that all of the missing males are included in this group of animals. However, obtaining samples from these animals could potentially increase the success of the paternity assessment.

When the observed results were compared with those generated via the simulation of random mating (*Graph 3-2, Graph 3-3*), the average number of calves per father was significantly higher in both the relaxed ($p \leq 0.014$) and the stringent ($p \leq 0.037$) analysis. These results were due to significantly fewer than expected candidate males which were assigned only one offspring in the analysis ($p \leq 0.036$, stringent criterion; $p \leq 0.039$, relaxed criterion). The average numbers of males assigned paternity of two calves were similar between the simulated and observed results, while the average number of males assigned three calves over the study period was higher in the observed than the simulated

results, although the differences were not significant. In addition, the number of males which were not assigned the paternity of any calves during the study was significantly higher than would be expected under random mating for both the stringent- and relaxed-criterion analyses ($p \leq 0.037$ and $p \leq 0.007$, respectively).

The standardized variance calculated from the results of the paternity analysis (SV_{obs}=0.42) was higher than that calculated from the data simulated under expectations of random mating (SV_{exp}=0.27). When compared to other mysticete studies, the SV_{obs} was most similar to the value calculated in the study of paternity in North Atlantic right whales (SV_{RW}=0.35; Frasier *et al.* 2007) and was higher than that calculated for the humpback whale population (SV_{HW}= 0.23; Cerchio *et al.* 2005).

DISCUSSION

Paternity assessment

Approximately half (46-53%) of the calves sampled on the Sakhalin feeding ground were assigned putative fathers which had been identified and sampled in the same area. Using the stringent criterion, all assignments were supported at the 95% confidence level, and the panel of loci utilized in this study provided sufficient resolution to discriminate between all possible candidates using a simple exclusion approach in all except for one case. Even when the more relaxed criterion was applied, all except one of the assignments was supported with high confidence (95%), and only four additional paternities were assigned. Assignment success was in relatively close agreement for both criteria, and it is likely that the true patterns of paternity are encompassed within this range of estimates.

Similar paternity assignment success rates have been generated in other studies of mysticete mating systems, including those conducted for humpback whales in the Mexican Pacific (32.5 to 49.6 %, Cerchio *et al.* 2005) and for North Atlantic right whales (41.4 to 62.1%, Frasier *et al.* 2007). Although sampling in the humpback whale population was not as complete, it is notable that in both our study and the North Atlantic right whale study, a very high proportion of photographically identified individuals had been sampled. As such, the success rates of the paternity assignments were somewhat less than might be expected given the overall pattern of sampling. As discussed below, this pattern may have implications for our understanding of the population's status.

Distribution of male reproductive success

A mild skew in male reproductive success was detected over the 12 seasons covered by the study. Although most (56-59%) of the putative fathers identified were assigned paternity of only one calf each, this proportion was lower than that predicted in the simulations based on random mating. While not statistically significant, more males than expected were assigned paternity of three to four calves during the study, suggesting that some males achieved higher reproductive success than others. These results are consistent with those observed in both humpback whales and right whales, both of which demonstrated mild skews compared to random mating expectations (Frasier *et al.* 2007, Cerchio *et al.* 2005). However, in all cases the skew was slight, with most males siring only one calf during each of these studies. While the differences in reproductive success among males were relatively small over the course of the study, continuation of this pattern over the lifespan of these individual males would result in a substantially higher

reproductive advantage for some males. However, if male reproductive success varied with age, the advantage gained by individuals during the study period would level out over time.

Based on testes to body size ratios, both gray and right whales are thought to utilize sperm competition (Brownell and Ralls 1986). The standardized variance of reproductive success, a measure often used for comparisons across species, was found to be high in North Atlantic right whales relative to values found in other aquatically mating species (Frasier *et al.* 2007), including a population of humpback whales (Cerchio *et al.* 2005). These results suggested that sperm competition may result in higher variance in reproductive success when compared to tactics employed by some other marine mammals (Frasier *et al.* 2007). The standardized variance estimated for western gray whales was comparable to that found in North Atlantic right whales, providing further support for the role of sperm competition in generating variance in reproductive success among males.

A high proportion of sampled males were not assigned any offspring during the 12 seasons of the study. These findings may suggest that many of the animals of unknown age were too young to successfully compete for mating opportunities. Rice and Wolman (1971) found that 24% of the animals from their sample were sexually immature and estimated that the total proportion of immature animals in the eastern gray whale population was approximately 44-61%. If the results of the paternity analysis are combined with the results of the DADSHARE analysis, the proportion of males (53-54%) that are potentially too young to reproduce falls within the range estimated by Rice and Wolman (1971). It is important to note, however, that successful fertilization not only

necessitates that males are sexually mature but also that they are able to successfully compete for fertilization opportunities. Therefore, estimates derived from the paternity analysis are not necessarily representative of the proportion of animals which have not reached sexual maturity. In addition, this estimate assumes that the unsampled males are only those which are contributing to reproduction; if some proportion of non-breeding males has also not been sampled off Sakhalin, this percentage would be lower.

The results suggest a lack of mate fidelity among breeding pairs, with only one female with more than one calf assigned to the same male. These findings agree with expectations based on morphology and behavior. Similar results have been found in paternity analyses in humpback whales (Clapham and Palsboll 1997) and right whales (Frasier *et al.* 2007).

Identification of reproductive males

The paternity assignment identified 17 to 18 males as putative fathers, and analysis of relatedness patterns among the calves with unassigned paternities suggested that approximately 15 additional reproductive males have yet to be sampled. Twenty-four females were determined to be the mother of at least one calf in the western population between 1995 and 2007 (Weller *et al.* 2008a). Combining this information suggests that approximately 57 animals are capable of reproduction. These numbers are slightly higher than previous estimates (Weller *et al.* 2002), which indicated that the number of mature individuals was approximately 39-49 animals if the population was growing and 55 animals if the population was stable. These estimates were based on parameters (*e.g.*, percent of immature animals) derived from the eastern gray whale population and on the

western population's size in 1999. Integrating information on the number of putative fathers with the number of females known to reproduce provides a more direct assessment of the number of animals contributing to reproduction in the population, including those which may not be regularly sighted on the primary feeding ground. Although slightly higher than previous estimates of the number of mature animals, the estimate incorporating the results of the paternity analysis supports the need for continued concern over the small size of the population. In particular, the low number of reproductive females may contribute to the low population growth and recovery (Weller *et al.* 2008a).

Although one of the putative fathers was not identified until the last year of the study, all other males identified as putative fathers were identified early in the study. These animals demonstrated a high degree of seasonal site fidelity to the primary feeding area, indicating that at least this subset of reproductive males are regular visitors to the Sakhalin area. Although some of the unsampled males may be represented among those animals which have been sighted on the feeding ground but not yet sampled, it seems likely that at least some of the "missing fathers" are animals which do not utilize the Sakhalin feeding ground on a regular basis.

The majority of the putative fathers had four of the five most common mtDNA haplotypes found in the western population. Only two (one of which was identified only in the relaxed analysis) of the nine males which have haplotypes considered to be rare in the western population were identified as putative fathers. These "rare haplotype males" have been hypothesized to represent possible dispersers from the eastern population (Chapter Two), although additional analyses evaluating this hypothesis have yet to be

conducted. However, these results suggest that the majority of these "rare haplotype males" may not be currently contributing to reproduction in the population.

No males of known age were identified as putative fathers during the study; therefore, no conclusions about the minimum age at which males attain reproductive success can be derived from these results. However, the lack of assigned fathers among the known-age males suggests that the age of first reproduction in males may be later than in females. Despite similar limitations in sample size, two females of known age (seven and eleven), out of 17 possible through the 2009 season, have been identified with calves (Bradford *et al.,* submitted). In right whales, paternity analysis suggested that most males do not attain their first successful mating until they were almost twice as old as the average age of fertilization for females (~15 years in males as compared to ~8 years for females; Frasier *et al.* 2007). Although no direct evidence was provided in this study, the lack of paternities assigned to males of known age (≤ 11 yrs) suggests that a similar pattern may be true in western gray whales.

Conservation implications

Despite the high proportion of sampled individuals, the paternity analysis was only able to identify putative fathers for about half of the animals first sighted as calves on the Sakhalin feeding ground. Some of the "missing fathers" may be accounted for by the animals which have been sighted off Sakhalin but not genetically sampled. However, these results suggest that many of the males which are contributing to reproduction in the population may not be regular visitors to the Sakhalin feeding ground, raising questions about the identity and habitat use patterns of these individuals.

A potential explanation for the high proportion of unassigned paternities in the western gray whale population is that some gene flow with the eastern gray whale population may be occurring. Previous work has demonstrated that the eastern and western populations are genetically distinct (LeDuc *et al.* 2002, Chapter Two); however, the low level of nuclear differentiation identified between the two populations raised the possibility that some limited degree of interchange may occur (Chapter Two). Such interchange might be characterized by mixing of animals from the two populations on the feeding ground, or might involve some degree of interbreeding. If gene flow between eastern and western populations occurs on a regular basis, then the percentage of candidate fathers that have been genetically sampled would be greatly reduced and a lower assignment success would be expected. Running the paternity analysis with the eastern males included did not identify any additional paternities (see Supplementary Information), but given the very small percentage (<1%) of the eastern population that has been sampled, this result is not very meaningful. However, although genetic drift acts strongly to maintain distinctiveness in small populations, the degree of interbreeding needed to account for the unassigned paternities (~50% of the reproduction in the population) would be likely to dissolve differentiation between the two populations.

If we assume that mating occurs primarily while on migratory routes as has been described in eastern gray whales, two other considerations are important. First of all, if any of the males identified off Sakhalin are animals which originated from the eastern Pacific, then they have a high probability of already being sampled. Therefore, interpopulation breeding between animals of eastern origin and females sampled off Sakhalin can only be used as an explanation for the "missing fathers" if the eastern males

demonstrate lower levels of fidelity to the Sakhalin feeding ground and/or utilize other feeding areas but migrate along routes commonly used by Sakhalin animals. Secondly, interbreeding with the eastern population could occur if reproductive females which utilize the Sakhalin feeding area then return to the eastern Pacific to overwinter. Given the increased energetic demands of pregnancy and lactation, females are generally considered to be less likely candidates for dispersal than are males. In addition, of the 18 females which had multiple calves during the study period, the majority (83%, n=15) had at least one calf which was assigned a putative father among the animals sampled off Sakhalin, linking these breeding pairs to the use of common migratory routes during at least some seasons of the study.

An alternate explanation for the unassigned paternities, however, is that many of the males which are contributing to reproduction in the western population utilize other areas in the western Pacific to feed and are rarely found in the waters off Sakhalin. Similar reasoning was invoked to explain the relatively low paternity assignment success observed in North Atlantic right whales, in which only 51% of fathers were identified despite presumed high rates of sampling (69% of identified males; Fraser *et al.* 2007). The discrepancy between the number of assigned paternities and the proportion of whales which were thought to be sampled led the authors to conclude that the size of the North Atlantic right whale population is slightly larger than previously estimated. In addition, information from paternity analysis, in combination with photo-identification records suggesting that as many as one-third of the identified animals were "missing" during a given season (*i.e.*, could not be accounted for within areas known to be utilized by this

species), supported the existence of additional habitat(s) utilized by North Atlantic right whales but not yet located by researchers.

The results of the paternity analysis in the western gray whale population may suggest a similar pattern. Although it is possible to account for the "missing fathers" among animals identified but not sampled while on the Sakhalin feeding ground, it is unlikely that such a high proportion of the unsampled animals are reproductive males. However, sightings of animals identified as western gray whales have been made in other areas of the Okhotsk Sea (Weller *et al.* 2002), as well as the southwestern Bering Sea (Weller *et al.* 2003) and southeastern Kamchatka (Tyurneva *et al.* 2009). In addition, a relatively high proportion (n=39 of 78; 50%) of the whales sighted off southeastern Kamchatka have not been sighted on the Sakhalin feeding ground (Tyurneva *et al.* 2009). Although these individuals may be of eastern origin, they may also represent western gray whales which use the Sakhalin area infrequently or not at all. These observations suggest that at least some animals in the western population may range more widely during summer and may not have been identified on the Sakhalin feeding ground.

Patterns of relatedness among the unassigned calves suggest that the "missing fathers" may number approximately 15 different animals. Current population assessment models, which indicate that the population contains approximately 130 animals, assume that all western gray whales are sighted off Sakhalin, although not necessarily in all seasons (Cooke *et al.* 2008). The results of the paternity analysis suggest that this assumption may be violated, although the relatively small number of "missing fathers", some of which may be accounted for by photographically identified but not sampled individuals, likely wouldn't change estimates of the population's size or trajectory

dramatically. However, these results raise questions about the proportion of animals of other classes which may also not be accounted for in current estimates. Although little is known about the sex of most animals sighted in other parts of the Okhotsk Sea and eastern Kamchatka, sightings of mother-calf pairs thus far have been largely confined to the waters of the primary feeding ground off Sakhalin, with only one sighting of a female with a calf in other parts of the range (Tyurneva *et al.* 2009). This female had previously been identified with a calf while utilizing the Sakhalin feeding ground. Thus, although females may range more widely during some seasons, they appear to exhibit particularly strong fidelity to the primary feeding ground in years when they have produced a calf. As such, the proportion of sampled to unsampled reproductive females is likely to be higher than the ratio suggested for males. Interestingly, a male bias has already been documented to exist among those western gray whales which have been sampled, such that approximately 60% of animals first identified (and sampled) as adults or subadults on the Sakhalin feeding ground are males. Results of the paternity analysis suggest that this male bias could be more pronounced than previously estimated.

Conclusions

Much of our understanding of the role that males play in the mating system of baleen whales is based on general patterns derived from behavioral and physiological data as well as predictions based on known differences in the reproductive cycles of males and females. While genetic analyses can provide valuable information on the distribution of reproductive success among males, in many species such studies are limited by the difficulty of collecting a sample set that is representative of population

patterns. Due in large part to its small size and the high degree of site fidelity demonstrated by individuals, the western gray whale population is one of the most thoroughly sampled of all mysticete populations, providing a rare opportunity to learn more about the mating system of baleen whales. The findings presented here indicate that the distribution of reproductive success in this small population is similar to that described in North Atlantic right whales. Such comparisons suggest that sperm competition may create differential reproductive success among males, but that the degree of skew is mild in comparison to terrestrially mating mammals. Longer-term studies are needed, however, to determine how differential reproductive success over the relatively short time span of this study compares with patterns produced over the lifespan of individuals.

The lower-than-expected success rate in the paternity assignment for western gray whales raises many questions and suggests that the structure of this population may be more complicated than previously thought. In particular, the results presented here suggest that some animals which are part of the western population may not routinely visit the Sakhalin feeding area. Although this group of "missing fathers" may be small in number, they play a significant role in the reproduction of the population. As such, increasing our understanding of the habitat use and behavior of these animals is important. Genetic sampling of animals identified in other areas of the western Pacific, particularly those which have been sighted off Kamchatka but have not been identified as animals utilizing the Sakhalin feeding area, is one avenue that may elucidate habitat use of animals outside of the primary feeding area. Genetic analysis could be used to determine if these animals are any of the "missing fathers", and genetic assignment tests

could be used to better understand if these animals originated from the eastern or western populations.

Although the relatively high proportion of calves which could not be assigned fathers is puzzling, assignment of putative fathers for approximately 50% of sampled calves provides strong evidence for intrapopulation breeding among animals demonstrating fidelity to the western feeding ground. Most females had at least one calf which was assigned a putative father from among the animals sampled off Sakhalin, suggesting the use of common migratory routes among these animals and the putative fathers which were identified. In the future, combining the results of the paternity analysis with genetic assignment tests may provide additional information on the extent and nature of any dispersal which may be occurring between the eastern and western populations.

The material found in Chapter Three will be submitted for publication. I was the primary researcher. The co-authors D. Weller and A. Burdin supervised the field effort through which the genetic samples were collected. The co-authors D. Weller, R. LeDuc, and R. L. Brownell, Jr. supervised the research.

Table 3-1. Diversity of the microsatellite loci utilized in the parentage analysis as calculated in CERVUS. The number of alleles (k), observed (H_{obs}) and expected (H_{exp}) heterozygosities, and polymorphic information content for each locus are shown. No loci were found to be out of Hardy-Weinberg equilibrium. The probability for non-exclusion of a parent pair, the probability of identity (assuming Hardy-Weinberg equilibrium), and the probability of identity assuming full siblings are represented in the data area are also shown.

Locus	**k**	**H_{Obs}**	**H_{Exp}**	**PIC**
D17t	14	0.846	0.896	0.881
EV14t	8	0.701	0.752	0.71
EV37	16	0.923	0.856	0.835
EV94t	9	0.782	0.754	0.708
Gata028	5	0.795	0.751	0.702
Gata098	6	0.615	0.604	0.562
Gata417	7	0.688	0.641	0.569
Gt023	7	0.654	0.685	0.632
RW31	9	0.859	0.832	0.805
RW48	5	0.39	0.414	0.386
SW10t	9	0.808	0.783	0.748
SW13t	8	0.649	0.648	0.58
SW19t	7	0.744	0.648	0.595
Overall	8.5	0.73	0.71	0.67

Non-exclusion probability (parent pair):	7.00×10^{-8}
Probability of identity:	2.83×10^{-13}
Probability of identity (sibling):	1.38×10^{-5}

Table 3-2. Paternities assigned for western gray whale calves in each season of the study, including the year in which the calves were born, the number of sampled males included as candidates for each year, the number of sampled mother-calf (M-C) pairs, and the number and percentages of paternities assigned under the stringent and relaxed criteria. Unless otherwise noted, all paternities were assigned at 95% confidence.

			Paternities Assigned			
			Stringent		Relaxed	
Year	No. of sampled males	No. of sampled M-C pairs	No. Assigned	%	No. Assigned	%
1995	42	3	1	33	1	33
1997	42	1	1	100	1	100
1998	42	5	1	20	2	40
1999	42	1	1	100	1	100
2000	42	2	0	0	0	0
2001	44	6	3	50	3†	50
2002	44	6	3	50	4	67
2003	46	10	5	50	5	50
2004	49	6	4	67	4	67
2005	50	5	1	20	2	40
2006	53	3	1	33	1	33
2007	55	9	5	56	6	67
Total	55	57	26	46	30	53

†One paternity resolved at 80% confidence

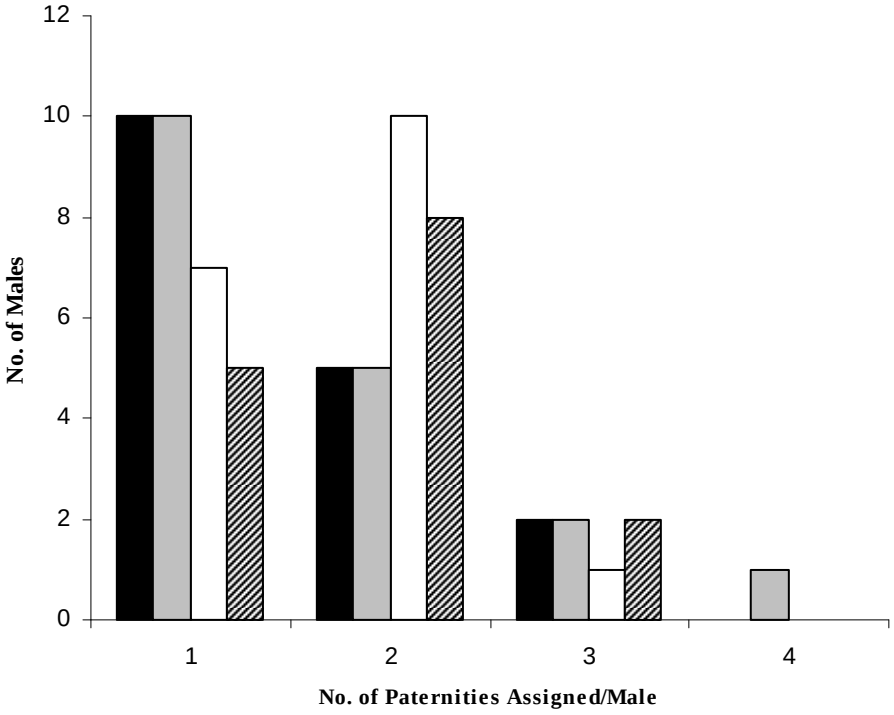
Table 3-3. Paternities assigned for calves of each reproductive female, including the number of sampled offspring for each reproductive female, and the number and percentage of offspring which were assigned a putative father in the analysis under both the stringent and relaxed criteria. Unless otherwise noted, all paternities were assigned at 95% confidence.

		Stringent		Relaxed	
Mother's ID	No. of sampled offspring	No. Assigned	%	No. Assigned	%
A	1	0	0	0	0
B	4	1	25	2	50
C	3	1	33	1	33
D	4	3	75	3	75
E	2	1	50	2	100
F	3	0	0	0	0
G	5	1	20	1	20
H	5	3	60	3	60
I	2	2	100	2	100
J	2	2	100	2	100
K	1	0	0	0	0
L	2	0	0	0	0
M	2	1	50	1	50
N	4	2	50	2	50
O	1	1	100	1	100
P	2	1	50	1	50
Q	3	2	67	3	100
R	3	1	33	1	33
S	3	3	100	3	100
T	2	0	0	0	0
U	2	1	50	1	50
V	1	0	0	1	100
Total	57	26	0	30	0.53

†One paternity resolved at 80% confidence

Table 3-4. Distribution of reproductive success among the putative fathers identified in the paternity analysis. Included are the candidate father's ID, his mtDNA haplotype, the year in which he was first photographically identified, and the number and birth year of the offspring he was assigned under the stringent and relaxed criteria analyses. Mean reproductive success for all fathers, along with the standard deviation, is shown at the bottom of the table.

			Stringent	Relaxed	
Father ID	**Year Identified**	**Father's Haplotype**	**No. of Offspring**	**No. of Offspring**	**Year(s)**
A	1994	A	2	2	2002, 2004
B	1995	B	1	1	2004
C	1997	A	1	1	2007
D	1995	D	1	1	1999
E	1997	A	3	3	1997, 2002, 2006
F	1995	B	1	1	2007
G	1997	B	1	1	2003
H	1997	D	1	1	2003
I	1995	A	2	4	1998, 2001, 2002, 2003
J	1995	C	1	1	2003
K	1997	A	3	3	2002 & 2007 (2)
L	1998	J	1	1	1998
M	1995	B	1	1	1995
N	1994	D	2	2	2004 & 2005
O	1999	B	2	2	2001 & 2003
P	1999	B	2	2	2001 & 2007
Q	1995	A	1	2	2004, 2005
R	2007	Q		1	2007
Average:			1.5	1.7	
SD:			0.72	0.9	



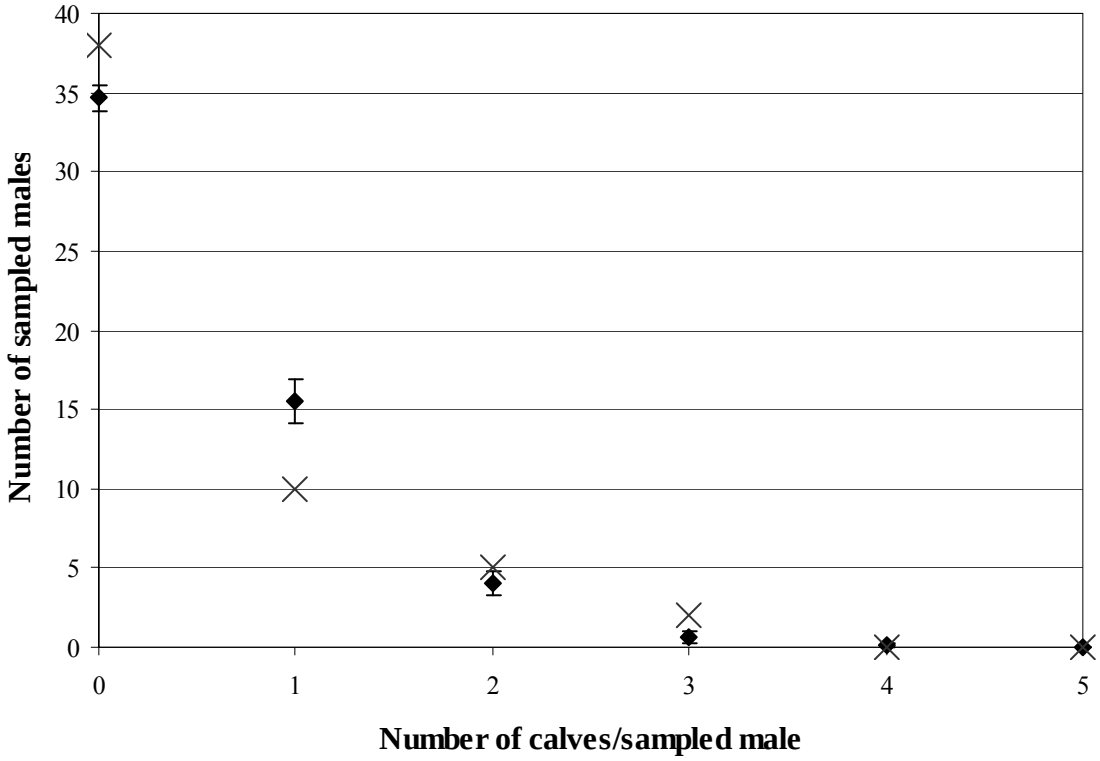
Graph 3-1. Comparison of the number of males which were assigned one, two, three, and four offspring in the stringent CERVUS analysis (shown in black), the relaxed CERVUS analysis (shown in gray), and the DADSHARE analysis using only those calves which were assigned putative fathers in the relaxed analysis (shown in white), and the DADSHARE analysis using only those calves which were not assigned putative fathers in the relaxed analysis (black and white pattern).

Table 3-5. Number of known age males for each year of the study. Included are the year of each study, the number of mother calf (M-C) pairs sampled in each year, the number of paternities assigned, the number of males in each age category (5 to 11) for each year, and the total number of known age males included in the paternity analysis for each year. Age categories refer to the approximate age of the male in the season during which fertilization would have occurred.

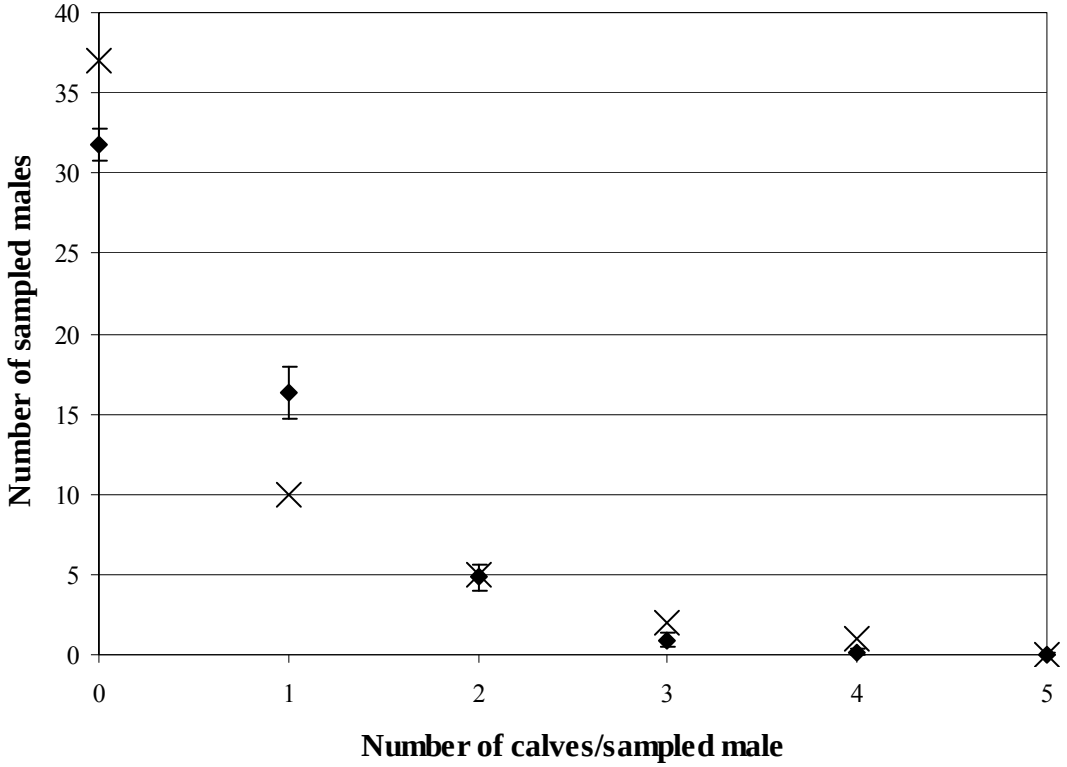
Year	**No. of M-C pairs**	**No. of assigned paternities**	**Approximate age of males during reproduction (Year -1)**							**No. of known age males**
			5	**6**	**7**	**8**	**9**	**10**	**11**	
2001	6	3	2							2
2002	6	3		2						2
2003	10	5	2		2					4
2004	6	4	3	2		2				7
2005	5	1	1	3	2		2			8
2006	3	1	3	1	3	2		2		11
2007	9	5	2	3	1	3	2		2	13

Table 3-6. Sighting patterns of males identified as putative fathers in the paternity analysis. Included are the father's ID number and the date on which he was first photographically identified. Years in which the male was sighted at least one are shaded in gray; numbers in each cell refer to the number of calves identified in each season which were assigned to that father. The * symbol is used to denote offspring only assigned under the relaxed criteria. The percentage of years that each candidate male was sighted on the Sakhalin feeding ground of all years of the study following his initial identification is also shown.

ID	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	% of years sighted
A							1		1				100%
B									1				92%
C												1	82%
D				1									67%
E		1					1				1		100%
F												1	83%
G								1					73%
H								1					91%
I			1			1*	1*	1					100%
J								1					83%
K							1					2	73%
L			1										80%
M	1												75%
N									1	1			69%
O						1		1					44%
P						1						1	67%
Q									1	1*			58%
R												1*	100%
Total	1	1	2	1		3	4	5	4	2	1	6	30



Graph 3-2. Comparison of the expected distribution of paternities based on simulations of random mating with the observed results for the stringent criterion analysis. Expected values, with error bars representing standard deviations, are shown with black diamonds, while the observed values are displayed with an X.



Graph 3-3. Comparison of the expected distribution of paternities based on simulations of random mating with the observed results for the relaxed criterion analysis. Expected values, with error bars representing standard deviations, are shown with black diamonds, while the observed values are displayed with an X.

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SUPPLEMENTAL INFORMATION

A. Additional CERVUS simulations

A series of simulations were run in the program CERVUS to evaluate the effect of incorporating different values for some of the parameters which are required as input into the analysis. For all of the following analyses, only males of known age (n=42) were included in the paternity assessment; animals first identified as calves which may have matured over the study period were not incorporated. Unless otherwise noted, the parameters incorporated in the simulation were consistent with those used in the above analyses and incorporated an error rate of 0.01.

1) Proportion of candidate males sampled: Since the proportion of candidate males sampled was unknown for this study, the simulations employed by CERVUS were used to explore the effect of varying this parameter on the paternity results. The proportion of sampled males was varied between 0.20 (considered to be much lower than expected given the photo-identification results), 0.50 (as used in the analysis above), and 0.80 (consistent with the results of photo-identification studies). The total number of candidates was adjusted accordingly, such that when the simulation was based on 50% of candidate males being sampled, the number of candidate males was assumed to be 84.

Results: Results are shown in *Table S3-1*. Varying the proportion of candidate males sampled in the study did not change the number of assigned paternities or the identity of assigned fathers. As compared to the assumption used in the analysis (e.g. the proportion

of candidate parents sampled is 0.50), reducing the proportion sampled (e.g. p=0.20) acted to increase the critical delta value, making the paternity assessment more stringent. As such, one of the assignments previously made at the 95% confidence level was only supported at the 80% confidence level. Assuming the proportion of candidate males was high (0.80) had the reverse effect, reducing the critical delta value and thus the stringency of the test. As such, the assignment previously made at 80% confidence in the original (e.g., p=0.50) assessment was supported at 95% confidence using these parameters. Of note, the expected and observed results were very similar when the simulations assumed that the proportion of candidate males sampled was 50%, but were quite disparate for the other simulations.

2) Possible effects of increased error rates: Simulations were conducted in CERVUS to examine the effect that potential errors in the genotype data might have on the paternity assignment success rate. Error rates were allowed to vary between 0.00, 0.01, and 0.10.

Results: Results are shown in *Table S3-2*. As expected, when the error rate was high (10%) the number of assigned paternities at the 80% confidence level increased to 61% (n=35). However, allowing for an increased error rate also raised the critical value of delta, resulting in fewer assigned paternities at the 95% confidence level. Allowing the error rate to increase to 10% also allowed for up to 4 mismatches between the mother-calf dyad and the putative father. Thus even if a significant source of genotyping error is present in the data, the number of calves for which paternity could not be assigned is still

larger than would be expected given that ~80% of photographically identified animals have been sampled.

3) Possible effects of relatedness: Given the small size of the western gray whale population, it is likely that some proportion of the animals included in the study may be related to other included individuals. The presence of such relatives might provide a high rate of false positive assignments in the study, such that a male might be assigned as the true father which shares a different relationship with the calf. However, pending relatedness analysis, the proportion of related animals in the population is currently unknown. To further explore potential biases caused by incorporating related individuals, simulations were run in CERVUS which allowed some proportion of the animals to be related. Based on the results presented below, and the fact that baleen whales are not expected to be monogamous, the presence of full siblings, which are the most likely to be confused with parent-offspring relationships, is unlikely. As such, the two scenarios explored were: 1.) some proportion (ranging from 0.20 to 0.50) of candidate males are related at the level of half siblings (r=0.25) with other candidate males; 2.) some proportion (ranging from 0.20 to 0.50) of candidate males are related to the mother of the calf; 3.) some proportion (ranging from 0.20 to 0.50) of candidate males are half siblings (r=0.25) with the calves being analyzed in the study.

Results: Assuming that some proportion of the candidate males are related either to each other or to the calves being analyzed acts to increase the critical delta values considerably (see *Table S3-3*) over those in the standard analysis. As would be expected, the minimum

number of paternities (n=24 calves with assigned fathers) were assigned when assuming the highest proportion of animals were related; however, this minimum value is very similar to that generated by the analysis with stringent criteria (n=26), suggesting that even if relatives are included the analyses presented above are within the range of expected results. The type of relationship presumed (i.e. whether the candidate males were related to each other or were related to the offspring) did not make a large difference in the number of assigned paternities and only made a slight difference in the number of paternities expected to be assigned. In all cases the identity of the assigned father remained the same.

Assuming a high proportion of related individuals, irregardless of the type of relationship, reduced confidence in the assignments, such that in two cases father-offspring assignments were no longer supported. Of the four father-offspring assignments that included mismatches between the genotypes of the calf and the assigned male, one was no longer significant and two others were supported at the 80% confidence level. Assuming only 20% of individuals were related also reduced confidence in all except one of the father-offspring assignments that included mismatches.

The stringency of the analysis did not change appreciably when simulations were run assuming that some proportion of the candidate males were related to the mothers of the calves. Further evidence that the assigned fathers were not related to the mother of the calf being assigned can be derived from comparing the mtDNA haplotypes of the mother-calf dyad to that of the assigned father. Only 8 of the assigned paternities shared mtDNA haplotypes with the mother-calf dyad to which they were assigned, supporting that

approximately two-thirds of the assigned fathers could be definitively ruled out as sharing a maternal half-sibling relationship with the calf or with the mother.

B. Paternity analysis incorporating males sampled in the eastern North Pacific:

To further evaluate the ability of our data to resolve father-offspring relationships, the paternity analysis was rerun after incorporation of samples collected from gray whales on feeding grounds or migratory routes in the eastern North Pacific (for details see Chapter Two). Those eastern animals determined via molecular methods to be males (n=87) were included with the candidates from the western population in the pool of candidate males. Because differences in the sampling strategies between the two populations made estimation of input parameters (e.g. proportion of candidate males sampled) complicated, a simple exclusionary approach was utilized for this analysis, such that no mismatches were allowed between the genotype of the calf and the putative father.

Results: The inclusion of males sampled as part of the eastern population into the paternity analysis did not result in any additional paternity assignments being identified.

C. Paternity analysis for calves with unknown mothers:

An additional four animals were first identified as calves on the study area but had already separated from their mother when they were first identified and could not be genetically linked to any sampled females. As well, one calf was behaviorally linked to

an identified female from which no genetic sample was obtained, and two calves were linked behaviorally to adult females but the affiliation was not supported by genetic analysis. Confidence in parentage assignments is greatly reduced when one known parent is not included, so these seven animals were not included in the primary parentage analysis but were run separately to evaluate the possibility of identifying additional reproductive males contributing to the population.

Results: No fathers were assigned to the calves without identified mothers.

Table S3-1. Comparison of the observed and expected number of paternities assigned when the proportion of candidate males assumed to have been sampled is allowed to vary from 0.20 to 0.80.

Proportion of candidate males sampled	**Critical Delta***	**Number of paternities assigned Observed (Expected)**	
		95%	**80%**
0.2	3.77 (0.50)	28 (12)	30 (14)
0.5	1.00 (0.00)	29 (29)	30 (30)
0.8	0.00 (0.00)	30 (47)	30 (47)

* Denotes critical delta value at the 80% confidence level

Table S3-2. Comparison of the observed and expected number of paternities assigned when the error rate is allowed to vary from 0 – 0.10.

Proportion of candidate males sampled	Critical Delta*	Number of paternities assigned Observed (Expected) 95%	80%
0.00	0.00 (0.00)	26 (29)	26 (29)
0.01	1.00 (0.00)	29 (29)	30 (30)
0.10	3.91 (1.66)	27 (22)	35 (31)

* Denotes critical delta value at the 80% confidence level

Table S3-3. Comparison of the observed and expected number of paternities assigned when related individuals are included in the analysis. The proportion related refers to the average proportion of all candidate parents which are related. In all cases except that were no relatives are incorporated into the analysis, all relationships refer to that of half-siblings (e.g., r=0.25).

Candidate male related to:	Proportion related:	Critical Delta*	Number of paternities assigned Observed (Expected) 95%	80%
Calf:	0.20	6.48 (1.79)	26 (25)	28 (34)
	0.50	8.17 (3.70)	24 (18)	28 (32)
True father:	0.20	5.54 (1.06)	26 (27)	29 (35)
	0.50	7.77 (2.85)	24 (20)	28 (34)
True mother:	0.20	1.06 (0.00)	29 (30)	30 (31)
	0.50	1.13 (0.00)	29 (30)	30 (31)
No relatives:	0.00	1.00 (0.00)	29 (29)	30 (30)

* Denotes critical delta value at the 80% confidence level

IV. CHAPTER FOUR

Exploring patterns of genetic heterogeneity among gray whales (*Eschrichtius robustus*) sampled on a feeding ground in the western North Pacific

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ABSTRACT

Much of what is known about western gray whales is derived from studies based on the population's feeding ground off Sakhalin Island, Russia. Although genetic studies have supported the differentiation of this critically endangered population from the much larger eastern North Pacific population, previous analyses have suggested that some degree of male-biased dispersal may occur, raising the possibility that some of the animals identified on the feeding ground may be of eastern origin. In this chapter, a suite of different genetic analyses were used to assess whether genetic heterogeneity exists among animals sampled on the Sakhalin feeding ground and to explore potential processes creating such heterogeneity. Patterns of substructure were identified, with two genetic clusters detected within the feeding ground samples. The similarity of one of the clusters to the eastern population suggests that dispersal influenced the clustering pattern. Both the results of a genetic assignment test, designed to identify putative first-generation migrants between populations, and the significant differentiation detected between males and females (as well as between males and animals first identified as calves), suggest that such dispersal is largely driven by, although not exclusive to, males. However, when relatedness analysis was used to identify putative mother/offspring relationships between animals first identified as non-calves, the results indicated that, as has been illustrated by field observations, the fidelity demonstrated by some females and their offspring has been important in shaping the structure of the population. Although further studies are needed to elucidate the extent and nature of possible dispersal of eastern animals onto the western feeding ground, these results suggest that not all animals

identified on the western feeding ground may be western gray whales, which has potential consequences for assessment of this small population's status.

INTRODUCTION

The population of gray whales found in the western North Pacific was greatly depleted by commercial whaling, which continued through at least 1966 (Brownell and Chun 1977, Kato and Kasuya 2002). Today the population survives as a small remnant and is considered one of the most critically endangered baleen whale populations (Clapham *et al.* 1999, Baillie *et al*. 2004). The continued survival of western gray whales is threatened by a wide range of potential anthropogenic threats, including but not limited to disturbance due to oil and gas development on its feeding ground (Weller *et al.* 2002, Reeves *et al.* 2005, IISG 2006) and mortality due to incidental entrapment in nets while migrating past Japan (Brownell *et al.* 2007, Kato *et al*. 2007).

Concern for this small population led to the initiation of a joint Russia-U.S. research program in 1995, which has focused on studying these animals on their primary feeding ground located in the coastal waters of northeastern Sakhalin Island, Russia (Weller *et al.* 1999, 2008). Monitoring of the population has incorporated both boat-based photo-identification surveys and genetic sampling. Information from photo-identification surveys has revealed that most of the identified animals demonstrate high levels of seasonal site fidelity and annual return to this feeding ground (Weller *et al.* 1999, 2008). The population is estimated to contain approximately 130 individuals of age one or older, of which only 23 are known to be reproductive females (Cooke *et al.* 2008, Weller *et al.* 2008).

Genetic differentiation of the small western population from the much larger population of gray whales found in the eastern North Pacific was initially described on the basis of mitochondrial DNA (mtDNA) haplotype frequencies (LeDuc *et al.* 2002). Subsequent studies utilizing microsatellites provided additional support for recognition of the two populations as distinct units, with small but statistically significant differences in microsatellite allele frequencies identified between the two populations (Chapter Two). These studies also revealed that, although the mtDNA haplotype diversity found in the western population is markedly smaller than that found in the eastern population (h=0.77 versus h=0.95; LeDuc *et al.* 2002, Chapter Two), the western population has maintained a relatively high number of mtDNA haplotypes (n=22) given its small size. The amount of nuclear genetic diversity found in the western population is comparable to that found in the eastern population, indicating that significant amounts of genetic diversity have yet to be lost (Chapter Two).

Although the level of genetic differentiation between the two populations using microsatellites was highly significant statistically, the degree of differentiation was relatively low (F_{st} = 0.009, Chapter Two). Bayesian clustering analysis using the microsatellite data provided support for the presence of two populations within the dataset, but many of the individuals in both populations showed low or equivocal assignment indices to their source population. While the low level of observed divergence might be representative of relatively recent separation between the two populations, sex-specific comparisons indicated substantially higher levels of differentiation between females of the two populations than between males, for which, in the case of the microsatellite comparisons, comparisons were not statistically significant

(Chapter Two). Since relatively recent separation between the two populations should affect males and females in a similar fashion, these comparisons suggested that the low level of observed differentiation was more likely due to the occurrence of some degree of male-biased dispersal between the two populations.

Given that current records of western gray whales outside of their feeding range are limited, much of our understanding of the status of this population has been derived from monitoring on the Sakhalin feeding ground. Many of the analyses that have been conducted, including estimates of abundance and measures of genetic diversity, have assumed that all of the animals sampled on the western feeding ground represent western gray whales. If, as suggested by the sex-specific analyses reported in Chapter Two, some of the animals identified on the western feeding ground are dispersers from the eastern population, these assessments may need to be re-evaluated.

If such dispersal is occurring, a signal of genetic heterogeneity could be created within the western sample set. However, studies of other baleen whale populations have shown that intra-population processes can also generate sub-structuring within populations, particularly those that are out of genetic equilibrium due to recovery from whaling. For example, genetic heterogeneity has been found in the Bering-Chukchi-Beaufort Seas (BCB) stock of bowhead whales (*Balaena mysticetus*, Givens *et al.* 2007, Jorde *et al.* 2007; LeDuc *et al.* 2007). Although much debate has centered around the source(s) of this heterogeneity, mtDNA differentiation between age cohorts has been identified (LeDuc *et al.* 2007), and simulation-based studies have verified that detectable differences could be generated between age cohorts given the stock's history and the long

life span characteristic of the species (Ripley *et al.* 2006, Archer *et al.* 2007, Martien *et al.* 2007).

Genetic heterogeneity within a population can also arise through unequal reproductive success among individuals. Differential reproductive success among matrilines has been demonstrated in humpback whales (*Megaptera novaeagliae*) feeding in the Gulf of Maine and was shown to have the potential to substantially affect the frequency and distribution of maternal lineages in this population over time (Rosenbaum *et al.* 2002). In addition, high reproductive success of a relatively small number of females over time would create cohorts of maternal half-siblings in the population, introducing relatedness structure into the population.

Examination of the mtDNA haplotype distribution found in the western gray whale population provides some indication that either or both of these two mechanisms may be influencing the structure of the population. Unlike in the eastern gray whale population, in which haplotypes are relatively evenly distributed among individuals, the distribution of haplotypes in the western population is highly skewed, with two haplotypes found in very high frequencies (36% and 31% of all sampled animals), six in moderate frequencies (2 - 5% of sampled animals), and 14 in only one to two individuals (LeDuc *et al.* 2002, Chapter Two). The high frequencies of the two dominant haplotypes suggest that females in these matrilines may have enjoyed relatively high reproductive success over the past several decades. Among those haplotypes found in only one or two individuals, eleven are found in only a single male. Although two of these males were first identified as calves (either without an identified mother or with a mother who was not sampled) during the field study, the remaining nine were identified as non-calves.

These nine males (referred to as the "rare haplotype" males) have been hypothesized to represent possible dispersers from the eastern population (LeDuc *et al.* 2002, Chapter Two). Since whaling on this population continued through at least 1966 (Brownell and Chun 1977), an alternative explanation is that some of these males might represent animals which survived extirpation. Given that males cannot pass down their mtDNA, the haplotypes found in these animals could represent remnant haplotypes which were present (although likely not common) in the population prior to the end of exploitation and which will be lost when these males die.

Although these findings suggest the potential for both intra- and inter-population processes to be creating genetic heterogeneity within the western gray whale population, additional analysis may be able to better assess the influence of these factors on the genetic structure of the population. To evaluate whether a signature of genetic heterogeneity can be identified within the samples collected on the western feeding ground, Bayesian clustering analysis, incorporating a model designed to detect subtle patterns of structure, is used here to identify the number of genetic clusters found among the gray whale data. The sample set is also stratified according to various criteria and analyzed to determine whether differences between these strata can be detected. Finally, relatedness analysis and a genetic assignment test are used to better assess whether differential reproductive success of females and/or putative dispersal between populations, respectively, may be factors influencing the genetic structure of the population.

METHODS

Details on sample collection are included in Chapter Two. Most of the analyses described below utilized only samples collected in the western North Pacific (n=142), although samples (n=136) collected in the eastern North Pacific were included for comparative purposes for some analyses. When appropriate, samples collected from animals which were first identified as calves (n=64) on the western feeding ground were excluded from analysis. The analyses described below were conducted using information on the sex, mtDNA sequence, and microsatellite genotype (n=13 loci) generated from each sample as described in Chapter Two.

Clustering analysis

A Bayesian model-based clustering approach (STRUCTURE v2.3.2, Pritchard *et al.* 2000, Falush *et al.* 2003) was used with the microsatellite data to evaluate how many genetic clusters were present in the eastern and western gray whale sample sets. Unlike the approach taken in Chapter Two, information on the location in which individuals were sampled (eastern Pacific versus western Pacific) was incorporated into the model using the LOCPRIOR option and assuming admixture with correlated allele frequencies. Like the USE POPINFO option in STRUCTURE, the LOCPRIOR option makes use of information on the location in which individuals were sampled. However, unlike the former option, which assumes that the information on sampling location is usually correct and that population structure is relatively strong, the LOCPRIOR option was designed to be most useful in scenarios where only weak structure has been observed (Hubisz *et al.* 2009). Although information on sampling locations is assumed to be informative, this

option allows such *a priori* information to be ignored for individuals whose ancestry appears uncorrelated. As in previous analyses, five independent runs of K=1-5 were performed with a burn-in period of 50,000 iterations followed by 100,000 Markov-chain Monte Carlo repetitions. After averaging across runs, the number of clusters (K) most compatible with the data was identified as the value of K with the highest log probability (Ln P(X|K).

To further investigate sub-structuring within the western population, the STRUCTURE analysis was rerun using only those samples collected from animals in the western Pacific. A model of admixture with correlated allele frequencies was used; additional input parameters for the analysis were identical to those outlined in Chapter Two.

Genetic differentiation

The sample sets were stratified using two approaches to evaluate factors potentially contributing to genetic heterogeneity among animals sampled on the primary western feeding ground. First, samples collected on the western feeding ground were stratified by their status as having been first identified as a calf or non-calf. Animals initially identified as non-calves were then further stratified by sex. The eastern sample set was also stratified by sex. For both the mtDNA and microsatellite data, frequency-based (F_{ST}) estimates of differentiation (Weir and Cockerham 1984) among these five strata were generated using ARLEQUIN v3.0.1 (Excoffier *et al.* 2005). Significance was assessed using 20,000 permutations, and the false discovery rate procedure of Benjamani & Hochberg (1995) was used to correct for multiple comparisons.

In addition, the results of the STRUCTURE analysis, when run utilizing only those animals sampled on the western feeding ground and assuming K=2, were used to assign individuals into strata based on Q values. Using the same methods as stated above, these clusters were compared both to each other and to the eastern sample set. In addition, a Markov-chain approximation of an exact test, as implemented in GENEPOP v3.4 (Raymond and Rousset 1995) was used to test for departures from Hardy-Weinberg expectations and for linkage disequilibrium between all pairs of loci within each cluster.

Identification of putative mother/offspring pairs

Relatedness analysis was conducted to identify individuals that shared a potential mother/offspring relationship with another animal sampled in the population. Given that parent-offspring relationships for those animals first identified as calves were presented in Chapter Three, only sampled animals which were first identified as non-calves were assessed here. For these animals (n=78), putative mother/offspring pairs were identified as those pairs of individuals which shared at least one allele at each microsatellite locus and had the same mtDNA haplotype. Because determining the directionality (*i.e.*, which animal was the putative mother and which the possible offspring) was complicated due to the lack of information or proxy for age, animals were not identified as either the mother or the offspring but were simply labeled as pairs.

Note that this analysis differs in several ways from the paternity analysis presented in Chapter Three. First, in the paternity analysis, the maternal contribution to the calf's genotype is removed prior to attempting to identify a putative father, requiring in most cases (unless the genotype of the calf and the mother match at both alleles for a

given locus) that the putative father's genotype have one specific allele at each locus in order to match the genotype of the calf. In identifying putative mother/offspring relationships among animals first identified as non-calves, however, no parental contribution can be removed from the animal's genotype; thus for loci that are heterozygous, putative matches can be made at either of the two alleles, making the matching criteria less stringent than used in the paternity analysis. Secondly, the criterion used for assessing confidence in assignments in the paternity analysis was based on the difference between the most likely candidate parent and the second- most- likely candidate parent (Δ). Use of this criterion was possible because the directionality of the relationship was known and only one animal could represent the true father. However, in the identification of mother/offspring pairs among non-calves, directionality of the relationship could not be reliably determined; if successive offspring of the same female were included in the sample set, that female would share a mother/offspring relationship with more than one of the other sampled animals. Therefore, comparing likelihood scores between possible candidates was not a viable approach, and the criterion used to assess confidence in the paternity analysis could not be implemented here. Given these differences, the identification of putative mother/offspring pairs among animals first identified as non-calves should be considered less stringent than the method used to identify putative fathers for calves with known mothers. This lower level of stringency may have been counter-balanced to a small extent by the requirement that mother/offspring pairs share the same mtDNA haplotype and that the genotypes of putative mother/offspring pairs had at least one matching allele at all loci. The latter

criterion may have resulted in the elimination of some true mother/offspring pairs due to genotyping errors or null alleles.

Assignment test

The "detection of first-generation migrants" function, as implemented in GENECLASS 2.0 (Piry *et al.* 2004, Paetkau *et al.* 2004), was used with the microsatellite data to identify putative dispersers between the eastern and western populations. Putative dispersers are defined as animals born in a population other than that in which they were sampled; therefore, animals first identified as calves on the western feeding ground were excluded from this analysis. The test statistic L_{home}/L_{max}, which represents the ratio of the likelihood of an individual's genotype in its source population (L_{home}) to the highest likelihood of that individual's genotype in either of the two possible source populations (L_{max}), was computed using the Bayesian criterion of Rannala and Mountain (1997). This test statistic is the most powerful of the options provided in GENECLASS and is considered appropriate in scenarios where all source populations are thought to be sampled (Piry *et al.* 2004, Paetkeau *et al.* 2004). The probability that each individual was not a first- generation migrant was then computed using the re-sampling algorithm of Paetkau *et al.* (2004) to create 10,000 simulated individuals. For the "conservative" analysis, the type- I error rate (denoting the false classification of a resident as a disperser) was set to 0.01, which is thought to represent the appropriate balance between stringency and power (Paetkau *et al.* 2004). The results were also evaluated using a more relaxed error rate of 0.05.

RESULTS

Clustering analysis

Using a model based on admixture with correlated allele frequencies and which incorporated information on the sampling location of individuals (via the LOCPRIOR option described in Hubisz *et al.* 2009), the highest likelihood was observed for K=3 clusters being represented in the combined eastern and western gray whale sample sets (*Table 4-1*). However, when choosing K, the authors of the STRUCTURE manual recommend that users choose the smallest value of K which captures the major structure in the data, and they mention that the value of K often "more or less plateaus" when the true K is reached (Evanno *et al.* 2005, Pritchard *et al.* 2010). Inspection of the graphical representation of the likelihood values (*Graph 4-1*) suggests the majority of structure was captured using K=2 clusters, with a plateau in likelihood values after K=2 is reached. To further evaluate the true number of clusters contained in the data, ΔK was calculated according to Evanno *et al.* (2005). Although this measure, which represents the second-order rate of change in the likelihood, cannot be used to evaluate the probability that the data contain only one cluster, it has been shown to be more accurate at detecting the uppermost hierarchical level of structure when the true K is greater than one (Evanno *et al.* 2005). A clear peak in ΔK was observed at K=2, confirming that the most likely number of clusters in the dataset was considered to be two.

These results closely mirrored those presented in Chapter Two, which did not include information on sampling locations but also supported the presence of two clusters within the dataset. However, when sampling location information was not utilized, average Q_{source} values, denoting the proportion of an individual's genotype which could

be attributed to its source cluster, were relatively low for individuals in both populations (mean $Q_{east} = 0.69$; mean $Q_{west} = 0.60$), and only 80% and 65% of the individuals sampled in the east and west, respectively, were assigned to their source population. Within the eastern sample set, the incorporation of information on sampling location increased the average Q_{source} value (mean $Q_{east} = 0.98 \pm 0.047SD$). All of the animals sampled as part of the eastern population were assigned to that region, with 97% of individuals having $Q \geq 0.90$ and only one animal with $Q \leq 0.75$ (*Figure 4-2*). In contrast, the average Q_{source} value decreased for animals sampled in the western Pacific, and Q values varied greatly among individuals (mean $Q_{west} = 0.53 \pm 0.367SD$). Only 51% (n=73) of animals sampled in the west were assigned to their source cluster, with only 42 individuals (30%) with $Q \geq 0.90$ (*Figure 4-2*). There were 31 animals (28% of sampled individuals) which were sampled in the western Pacific but had $Q \geq 0.90$ to the eastern cluster.

Although examination of the results indicated that the majority of structure in the combined eastern and western dataset was captured by two clusters, the assignment of individuals when K=3 clusters were defined was examined to evaluate the potential for additional sub-structuring within the western sample set. Under this scenario, the third cluster that was created consisted of a small number (n=20) of animals sampled in the western Pacific, most of which (n=12, 60%) demonstrated low assignment probabilities ($Q \leq 0.75$) to this cluster. A high proportion (n=62, 44%) of western animals continued to be assigned to the eastern group, suggesting that inter- versus intra-population processes were largely responsible for driving the clustering pattern.

When only those samples collected from animals identified on the western feeding ground were utilized in the STRUCTURE analysis, the highest probability was

observed for K=3 clusters (*Table 4-2*). However, similar to the results above, calculation of ΔK indicated that the majority of structure in the data was captured at K=2. Average Q values were relatively high for both clusters ($Q_{cluster1}$ = 0.85 ± 0.125SD, $Q_{cluster2}$ = 0.84 ± 0.117SD; *Figure 4-2*). Based on their Q scores, 59 individuals were assigned to western cluster 1, while 83 were assigned to western cluster 2. All except one of the individuals which were assigned to the eastern population in the above analysis were assigned to western cluster 2. However, this cluster also contained an additional 15 animals which had been assigned to the western cluster in the previous analysis.

Animals first identified as calves were assigned into both clusters (n=31 into western cluster 1, n = 33 into western cluster 2). The majority (n=42 of 57; 74%) of calves grouped in the same cluster as their mother. For the nine cases in which a calf with an assigned father was grouped in a cluster other than that shared with its mother, the calf's cluster was shared with the assigned father. Animals identified as reproductive females and putative fathers (Chapter Three) were apportioned relatively evenly among the two clusters.

All loci in both clusters were found to be in Hardy-Weinberg equilibrium. However, three pairs of loci were in linkage disequilibrium in western cluster 1, while one loci pair was in linkage disequilibrium in the second cluster.

Genetic differentiation

Estimates of genetic differentiation after stratification by sex and by status of being first identified as a calf or non-calf (western samples only) are shown in *Table 4-3*. As mentioned in Chapter Two, all between-population comparisons were significant

except for comparisons between eastern males and western males, where there was no significant differentiation in either microsatellite allele or mtDNA haplotype frequencies after correction for multiple comparisons. Although no within-population comparisons were statistically significant for animals sampled in the eastern Pacific, within the western sample set significant differences in microsatellite allele frequencies, but not mtDNA haplotype frequencies, were identified between males and females and between males and animals first identified as calves between 1995 and 2007.

In addition, animals sampled in the western North Pacific were assigned to clusters using the results of the STRUCTURE analysis, and these strata were compared to each other and to the samples from the eastern North Pacific. Significant differences in both mtDNA haplotype and microsatellite allele frequencies were found in all comparisons (*Table 4-4*). However, the level of differentiation identified between western cluster 2 and the eastern sample set was markedly lower than that identified between western cluster 1 and the eastern samples.

Assignment test

Using the most stringent criteria in GENECLASS ($\alpha \leq 0.01$), six individuals were identified as being probable first-generation migrants (*Table 4-5*). Of those individuals, two were sampled as part of the eastern population and four were sampled as part of the western population. Under the more relaxed criterion ($\alpha \leq 0.05$), an additional 8 putative migrants were identified, including three more animals originally sampled in the eastern Pacific and five additional animals sampled as part of the western population. When the self-assignment probabilities of putative dispersers were examined in more detail, the

animals sampled in the west but assigned to the east had markedly higher assignment probabilities for the eastern population. However, the animals sampled in the east but assigned to the west had more similar probabilities of originating from either of the two source populations, suggesting the genotypes of these animals contained alleles common to both populations.

Four of the five animals which were sampled in the eastern Pacific but were assigned as putative dispersers from the western population were females. With one exception, samples from these animals were collected from animals which stranded along the migratory route. Sample #4159, however, was taken from an animal killed as part of the aboriginal harvest off Chukotka, Russia.

A male bias was present among the putative dispersers sampled in the west, with eight of the nine animals being males. Five of the nine putative dispersers had one of the 12 haplotypes which have been identified in males but not females sampled in the west. Three of those putative dispersers belong to the subset of animals (n=11) labeled as "rare haplotype males" because they are the only animals which carry their haplotype in the western population (*Table 4-5*).

All of the putative dispersers sampled in the western population have demonstrated site fidelity to the western feeding ground, with the majority (n=6) being sighted for at least two-thirds of all seasons subsequent to their initial identification and all being sighted in at least 50% of such seasons (*Table 4-6*). All putative dispersers were identified on the Sakhalin feeding ground for at least three seasons of the field study, with two animals sighted over nine seasons.

To evaluate the role of the putative dispersers in generating genetic heterogeneity within the western population, these animals (n=14) were removed from the dataset and the analysis of genetic differentiation was repeated. In contrast to the previous results, no statistically significant differences were found when males and females of the western population were compared (*Table 4-7*). In addition, after putative dispersers were removed, significant differences in microsatellite allele frequencies were found between eastern and western males (*Table 4-7*).

Identification of maternal-offspring relationships

Among those animals (n=78) which were not first identified as calves, there were 42 animals which shared a putative mother/offspring relationship with at least one other animal. The 36 individuals for which no putative mother/offspring relationships were identified among the "non-calf" sample set included 12 females (33% of all sampled female non-calves) and 24 males (57% of all sampled male non-calves). The majority of animals identified as either mothers (78%, 18 of 23 sampled) or as fathers (67%, 12 of 18 sampled) in the analysis of paternity in animals first identified as calves (Chapter Three) also shared a putative mother/offspring relationship with at least one other non-calf animal. When combined with information about known mother-calf pairs and with the results of the paternity analysis, 75% (n=107) of animals sampled on the western feeding ground share a putative parent-offspring relationship with at least one other sampled animal.

Forty-two percent (n = 33) of animals sampled as non-calves and 56% (n = 80) of all sampled animals could be traced back through matrilines to a minimum of five reproductive females. Four of these females shared possible mother/offspring relationships with between four and seven non-calf offspring within the sample set, while one of the reproductive females could potentially account for up to 14 non-calf individuals over two generations. Two additional females were designated as putative mothers of only one other sampled non-calf. All of the five matrilines demonstrating high reproductive success had one of the two most common haplotypes (A and B) found in the western North Pacific. The majority (n=16, 70%) of the 23 sampled females identified as reproductive during 1995 through 2007 (Weller *et al.* 2008) also shared one of these two common haplotypes; with one exception, these females were included in the matrilines described above.

Cluster composition

Integrating the results from the assignment test and the relatedness analysis with those of the Bayesian clustering approach revealed some patterns worthy of mention. First, all of the animals (n=9) identified as putative dispersers were grouped with western cluster 2, as were all of the rare haplotype males. All but one of the animals which were grouped in cluster 1 were identified as members of a putative mother/offspring pair, while only half (n=42, 50%) of the animals which were grouped in cluster 2 shared this distinction.

In addition, the majority (88%, n=23 of 26 total) of animals which were first identified (as non-calves) during the later years of the study (1999 – 2007) were grouped

with cluster 2. Only six of these animals shared a putative mother/offspring relationship with another sampled animal. This subset of animals, which was comprised of 15 males and 11 females, included five of the putative dispersers as well as six of the rare haplotype males.

DISCUSSION

Both the clustering analysis and comparisons of various strata indicate that some degree of genetic heterogeneity exists among the animals sampled on the Sakhalin feeding ground. The patterns identified suggest that the structure of this group of animals is complex and is likely mediated by both intra- and inter-population processes. Although many questions remain about the extent to which these processes are influencing measures of genetic diversity and differentiation within and between gray whale populations, some insight into the factors most likely to be shaping the structure of this group of animals can be derived from the above analyses.

Within-population processes

Genetic differentiation between age cohorts was demonstrated in the BCB stock of bowhead whales (LeDuc *et al.* 2007); simulation-based analysis showed that these differences were generated as a result of comparisons of older males, which had retained mtDNA diversity characteristic of pre-exploitation levels, with younger animals carrying levels of diversity representative of current, post-exploitation and recovery levels (Ripley *et al.* 2006, Archer *et al.* 2007, Martien *et al.* 2007). This work illustrated that non-equilibrium dynamics, particularly in such a long-lived species, could produce patterns

often interpreted as stock structure. Although the expected life span of gray whales is much shorter than that found in bowhead whales, given the relatively recent end of commercial whaling in the western population it is possible that similar mechanisms may be influencing the population's genetic diversity. The high number of mtDNA haplotypes found only in a single male in the western population provides some support for this hypothesis. However, although the lack of known age of many of the animals in the western population limits the conclusions that can be drawn, the results of the sex- and age-specific comparisons are somewhat inconsistent with this explanation. Given the matrilineal inheritance pattern of mtDNA, differences between age cohorts should be most apparent in the mtDNA comparisons of males and younger animals. However, age- and sex-related differences among animals sampled on the western feeding ground were only observed in the microsatellite comparisons.

The lack of mtDNA differentiation detected when non-calf males and younger animals were compared may be related to the history of exploitation in the western gray whale population. Relative to the BCB bowhead whale population, in which exploitation was intense but occurred over only a few decades, the decline of the western gray whale population was more extended, with a peak in catches occurring between 1911 and 1919 that was followed by several decades of continued takes. The more prolonged period of exploitation in the western gray whale population would likely have resulted in a steady decrease in the population's diversity over time but may not have created sharp differences between age cohorts.

Differences in reproductive success among females have been shown to influence population structure in humpback whales (Rosenbaum *et al.* 2002). The relatedness

analysis provided some support for differential reproductive success among matrilines found in the western population, indicating that when animals first identified as calves were included, 56% (n=80) of animals sampled in the population could be traced back to as few as five females, all of which shared one of the two most common haplotypes found in the western population. Relative to other females sampled in the population, females of these five matrilines appear to have enjoyed high reproductive success over the past several decades.

Although the majority (70%) of reproductive females identified during the field study also carried one of the two most common haplotypes, six of the other seven females which produced calves during that time had haplotypes which were either not found in any other animals first identified as non-calves, or which were found in only one other sampled non-calf. If these females, or their mothers, have been exhibiting site fidelity to the Sakhalin feeding ground prior to 1995, then these results indicate that females in these matrilines have experienced low reproductive success and/or high offspring mortality over the last couple of decades, and suggest that, in some cases, even those haplotypes which are found among females could be in danger of disappearing from the western population. Of note, however, these measures of reproductive success assume that all females demonstrate similar levels of fidelity to the western feeding ground over this time period.

Of the two groups identified in the clustering analysis, one was comprised almost exclusively of animals which were part of the five identified matrilines, suggesting that the high reproductive success of these females may have played a role in generating the pattern of clustering. The other cluster contained all except one of the animals for which

no putative mother/offspring relationships could be identified among the sampled animals. The genetic similarity of this cluster to animals sampled in the east is difficult to explain; although significant differences between the two western clusters might be derived from relatedness structure within the population, both clusters should still be more closely related to each other than they are to the eastern population in the absence of intermixing between the two populations.

Inter-population processes

Previous work has indicated that some degree of male-biased dispersal may exist between eastern and western gray whale populations and could provide an explanation for the relatively low levels of nuclear divergence observed between populations (Chapter Two). The results of the genetic assignment test support this hypothesis, suggesting that some level of dispersal between the two populations is likely occurring and that it is primarily, although not exclusively, driven by males.

It is important to note that simulation-based studies have shown that the accuracy of assignment-based approaches is correlated with the degree of divergence between source populations (Berry *et al.* 2004, Paetkau *et al.* 2004, Latch *et al.* 2006, Waples and Gaggioti 2006). Although limited, some evidence exists that such tests may provide valid results even when differentiation is moderate, particularly when populations are in genetic disequilibrium (Hall *et al.* 2009). In light of these findings, the assignment test results presented here should be considered preliminary until simulation-based testing can be used to evaluate how well this approach works under the level of divergence observed and the sampling protocol used in this specific study. However, the results of the

assignment test were generally concordant with those generated using the other approaches. At the individual level, none of the possible male dispersers shared a putative mother/offspring relationship with any other non-calf animal, and five of them carried haplotypes which have not been identified in females in the western Pacific and which, with one exception (the animal carrying a haplotype that is unique in both populations), are more common among eastern animals. At the population level, the differentiation observed between males and females in the west, the differentiation between the two western clusters (one of which contained all of the potential dispersers), and the lack of significant differences found when males of the two populations were compared all indicate that dispersal, rather than recent divergence, is driving the low level of differentiation found between the two populations.

If dispersal of eastern gray whales onto the western feeding ground is occurring, it may be a response to relatively recent changes in prey availability on traditionally used eastern feeding areas coupled with the increasing size of the population. In the 1980s, the Chirikov Basin, in the northern Bering Sea, was considered one of the primary foraging areas for eastern gray whales, based on both high densities of gray whales (Braham 1984, Kim and Oliver 1989, Highsmith and Coyle 1990) and their ampeliscid amphipod prey (Grebmeier *et al.* 1989, Highsmith and Coyle 1990). By 2002, however, sighting rates of gray whales in this area had decreased considerably (Moore *et al.* 2003). During this same time period, amphipod biomass in the Chirikov Basin declined by nearly 50% (Coyle *et al.* 2007), likely as a response to foraging whales (Highsmith *et al.* 2006) and/or ecosystem changes (Grebmeier *et al.* 2006). The downturn in amphipod biomass during a time when the gray whale population would have been increasing suggests that gray

whales simply expanded their foraging range (Moore *et al.* 2003). Although other causes couldn't be ruled out, these declines in amphipod biomass have also been implicated as a possible cause of the 1999-2000 gray whale mortality event, in which the number of stranded gray whales, many of which were emaciated, increased by an order of magnitude over previous levels (Gulland *et al.* 2005). Beginning in 1999, gray whales have also been sighted foraging year-round off Kodiak Island, Alaska (Moore *et al.* 2007), an area traditionally considered part of the migratory route. The primary prey of whales feeding in this area is cumaceans, which are not considered a typical prey species for gray whales (Nerini 1984, Darling 1998, Dunham and Duffus 2002).

This evidence suggests that gray whales are capable of expanding their foraging range in response to declines in prey abundance, and that conditions favoring such an expansion may have been present within at least the past decade. Given these observations, it seems plausible that some eastern gray whales, rather than feeding in more southern or more northern areas, may instead have traveled farther west. In recent years, sightings of gray whales off the eastern coast of Kamchatka have raised questions about potential mixing of eastern and western gray whales in this area, with some of the identified animals known to utilize the western feeding ground off Sakhalin but others being of unknown origin (Tyurneva *et al.* 2009). Increased monitoring, via both photo-identification and genetic studies, of whales utilizing this area might provide additional insight into the possibility of mixing of eastern and western gray whales off Sakhalin.

Such dispersal, if occurring, seems to be resulting in long-term fidelity to the Sakhalin feeding area, rather than occasional use of the area by eastern whales. All of the putative dispersers, as well as the majority of whales within the cluster showing similarity

to eastern animals, have demonstrated site fidelity to the Sakhalin feeding area. In general, our understanding of long-term patterns of feeding ground fidelity in gray whales is limited. Within the eastern gray whale population, a subset of individuals, generally referred to as the Pacific Coast Feeding Aggregation, terminate their northward migration in lower latitudes and feed along the coasts of California, Oregon, Washington, British Columbia, and Alaska (Darling 1984, Calambokidis *et al.* 2002). Within this region, many whales return on an annual basis, although they may utilize different areas within the broader region within seasons or between years (Calambokidis *et al.* 2002, 2004). Recruitment into this aggregation is not well understood. Initial genetic studies have not found support for these animals being a maternal isolate (Steeves *et al.* 2001, Ramakrishnan *et al.*2001), although studies utilizing more samples are currently underway and may provide additional insight. Sighting patterns of individual whales have also suggested that fidelity to the area may be mediated by foraging success or failure (Calambokidis *et al.* 2004). Additional sampling of gray whales utilizing other feeding areas would be valuable in increasing our understanding of how the fidelity observed on the Sakhalin feeding ground and within the PCFA compares with that on other feeding areas.

Although the results presented here suggest that some dispersal of eastern animals onto the western feeding ground may be occurring, determining whether such dispersal can be characterized as feeding ground mixing only, or whether it entails gene flow between populations, is not clear. While approximately half (n = 18 of 42) of the males first identified as non-calves were assigned as putative fathers (Chapter Three), only one of the eight males designated as possible dispersers was identified as a putative father,

and the only female has never been sighted with a calf. Although these individuals could potentially be animals that are too young to reproduce, these results suggest that most, although potentially not all, of the putative dispersal events have yet to result in genetic exchange between the two populations. The maintenance of genetic differentiation between the two populations (Chapter Two) also indicates that significant gene flow is unlikely. Future work using simulation-based approaches will be valuable in assessing how much confidence can be placed on the assignment test results and may also allow exploration of the extent of gene flow which could occur between the populations while still allowing genetic differentiation to persist.

Summary

Complex patterns of structuring, driven by both intra- and inter-population processes, exist among animals sampled on the Sakhalin feeding ground. The sex-specific analyses presented in the second chapter, which demonstrated markedly lower levels of differentiation between males of the two populations when compared to females, suggested that the low level of nuclear differentiation between the two populations was likely derived from some degree of male-biased dispersal between the eastern and western populations. The results presented here are largely congruent with that hypothesis, suggesting that heterogeneity exists between males and females utilizing the Sakhalin feeding ground. Furthermore, the results of the genetic assignment test indicate that any dispersal between populations is largely mediated by, although not necessarily exclusive to, males.

As discussed in Chapter Two, increasing our understanding of the extent and nature of any dispersal that may be occurring between the two gray whale populations has important consequences for evaluating the status of the western gray whale population. If dispersal is characterized not only by mixing on the feeding ground but also by interbreeding of migrants with western animals, it has likely been important in providing "genetic rescue" to the western population by contributing valuable genetic diversity and reducing the incidence of breeding among close relatives. On the other hand, if putative eastern dispersers demonstrate fidelity to the western feeding ground during summer months but return to the eastern Pacific to overwinter, current estimates of the population's abundance and of the genetic diversity it has maintained may be artificially inflated by the assumption that all animals identified off Sakhalin are western gray whales. Furthermore, these eastern interlopers might be increasing competition for food resources on the western feeding ground.

The eastern North Pacific gray whale has been heralded as a "sentinel of ecosystem change" based on several indications that the population is responding to alterations in its habitat over the past several decades (reviewed in Moore 2008). Although its value in this regard is based on the population's seasonal dependence on Arctic waters for feeding, the link between eastern gray whales and their environment is likely to have intensified with the population's recovery and the subsequent increase in competition for prey resources. If dispersal of eastern whales onto the western feeding ground is occurring, as suggested here, it may indicate that changes in the structure of gray whale populations could occur or be occurring both as a result of the eastern population's recovery and the changing Arctic environment. Additional efforts to

understand the extent and nature of connectivity between gray whale populations may provide insight into the potential for population recovery and habitat alteration to affect the structure of other, less well-studied populations of baleen whales.

Although the results presented here suggest that some dispersal of eastern animals onto the western feeding ground may be occurring, a strong signature of internal recruitment into the population was identified, such that 63% of sampled animals shared a putative mother/offspring relationship with at least one other sampled animal. In fact, over half (58%) of sampled animals could be traced back to as few as five females, indicating that the reproductive success of these females and their offspring has played an important role in shaping the genetic structure of the western population. This pattern is an extension of our understanding based on monitoring of the population between 1995 and 2007, during which time strong fidelity of reproductive females to the Sakhalin feeding area has been documented, with some females observed returning with four to five calves during this time (Weller *et al.* 2009). Evaluation of the numerous threats potentially facing this population, including but not limited to disturbance related to oil and gas development on their feeding ground as well as mortality resulting from incidental net entrapment on their migratory route should take into account the possible consequences of disruption of the fidelity of these matrilines to the Sakhalin feeding ground.

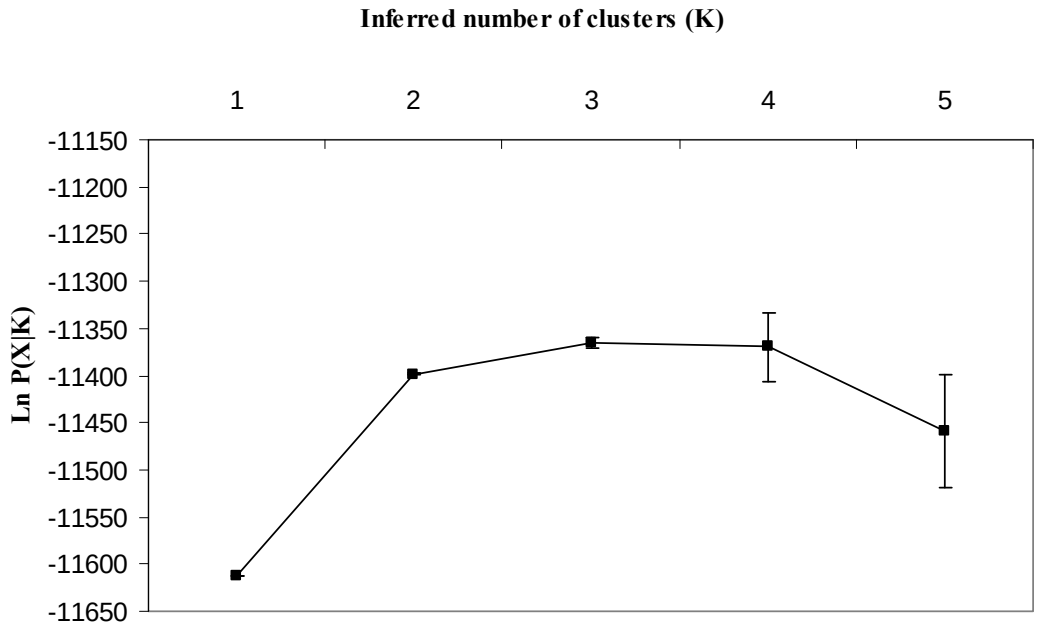
Some or all of the material found in Chapter Four will be submitted for publication. I was the primary researcher. The co-authors D. Weller and A. Burdin supervised the field

effort through which the genetic samples were collected. The co-authors D. Weller, R. LeDuc, and R. L. Brownell, Jr. supervised the research.

Table 4-1. Results of STRUCTURE analysis utilizing samples collected from both the eastern and western North Pacific. The inferred number of genetic clusters (K), the estimated log likelihood value (after averaging across runs) for the data given K (Ln P(X|K)), the posterior probability of K (Pr (K|X)), and the second order rate of change in the likelihood (ΔK) are shown. Note that ΔK cannot be calculated for the smallest or the largest K being tested. The parameters incorporated in the model are described in the text.

K	Ln P(X|K)	Pr (K|X)	ΔK
1	-11612.42	≤ 0.001	NA
2	-11398.74	≤ 0.001	14.3
3	-11365.8	0.983	1.1
4	-11369.88	0.016	1.7
5	-11458.62	≤ 0.001	NA

Graph 4-1. Graphical representation of STRUCTURE results utilizing samples collected from both the eastern and western North Pacific. The log-likelihood values (LnP(X|K)) shown are based on averages across 5 runs. Error bars denote standard deviations. The parameters incorporated in the model are described in the text.



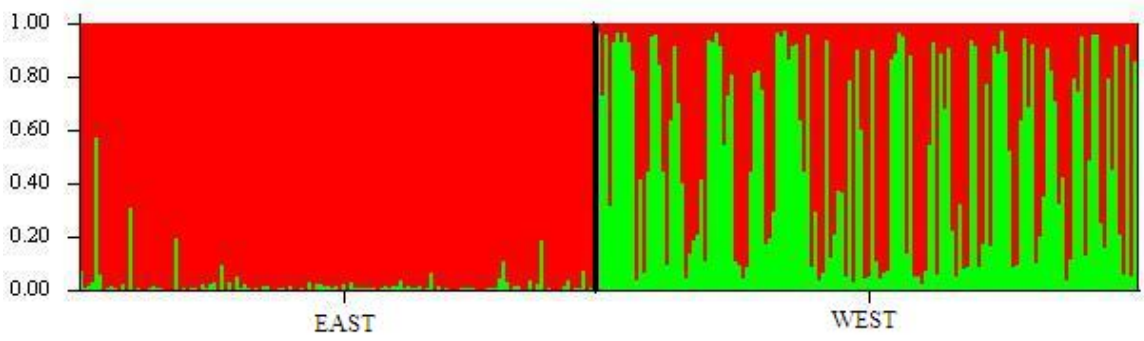


Figure 4-1. STRUCTURE barplot for samples collected in both the eastern and western North Pacific. The plot for K=2 using a model based on admixture with correlated allele frequencies and incorporating information on the sampling location of individuals (Hubisz *et al.* 2009) is shown. Individuals are represented by vertical bars, and the different colors of the bars represent the proportion of admixture, or ancestry, from a certain inferred genetic cluster. The Y-axis represents Q, the proportion of admixture. Individuals are grouped according to the population in which they were sampled, and the black line denotes the boundary between animals sampled in the eastern and western Pacific.

Table 4-2. Results of STRUCTURE analysis using only the samples collected in the western North Pacific. The inferred number of genetic clusters (K), the estimated log likelihood values (after averaging across runs) for the data given K (Ln P(X|K)), the posterior probabilities of K (Pr (K|X)), and the second order rate of change in the likelihood (ΔK) are shown. Note that ΔK cannot be calculated for the smallest or the largest K being tested.

K	Ln P(X|K)	Pr (K|X)	ΔK
1	-5700.86	≤ 0.001	NA
2	-5565.66	≤ 0.001	7.1
3	-5532.32	1	1.4
4	-5728.7	≤ 0.001	0.8
5	-5681.9	≤ 0.001	NA

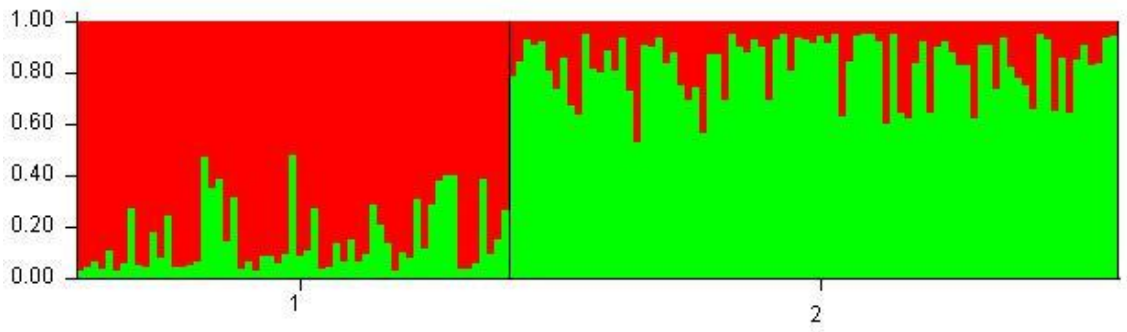


Figure 4-2. STRUCTURE barplot for samples collected in the western North Pacific. The results for K=2 clusters are shown. Individuals are represented by vertical bars, and the different colors of the bars represent the proportion of admixture, or ancestry, from a certain inferred genetic cluster. The Y-axis represents Q, the proportion of admixture. Individuals are grouped by the cluster to which they were assigned, and the black line denotes the boundary between animals in the two clusters.

Table 4-3. Estimates of genetic differentiation after stratification by sex and by status as calf or non-calf when first identified (western samples only). F_{st} values for mtDNA haplotype frequency comparisons are shown above the diagonal and for microsatellite allele frequencies below the diagonal. Significant values are displayed in bold.

		East		West		
		Females	**Males**	**Females**	**Males**	**Calves**
East	Females	*	≤ 0.001	**0.078**	**0.043**	**0.099**
	Males	≤ 0.001	*	**0.058**	**0.033**	**0.075**
West	Females	**0.013**	**0.013**	*	≤ 0.001	≤ 0.001
	Males	**0.005**	0.002	**0.007**	*	0.003
	Calves	**0.012**	**0.014**	≤ 0.001	**0.005**	*

Table 4-4. Estimates of genetic differentiation between strata identified by the STRUCTURE analysis. F_{st} values for mtDNA haplotype frequencies are shown above the diagonal while those for microsatellite allele frequencies are shown below the diagonal. Values in bold were statistically significant after correction for multiple comparisons.

			West Cluster 1	West Cluster 2
	n	**East**	**1**	**2**
East	136	*	**0.161**	**0.036**
Western Cluster 1	59	**0.034**	*	**0.285**
Western Cluster 2	83	**0.006**	**0.036**	*

Table 4-5. Putative dispersers identified by the GENECLASS assignment test. The information presented includes each animal's identification number (ID), the population in which the individual was sampled (Source Population), the probability of being a first generation migrant ($Prob_{FGM}$), the assignment probabilities to both the eastern ($Prob_{ENP}$) and western ($Prob_{WNP}$) populations, the sex and mtDNA haplotype of each individual, and the number of other animals in each population carrying that haplotype.

ID	Source Population	$Prob_{FGM}$	Assignment $Prob_{ENP}$	Assignment $Prob_{WNP}$	Sex	MtDNA Haplotype	No. of other animals with haplotype (E/W)
32759	West	0.002	0.084	0.000	F	A	15/27
16564	East	0.002	0.131	0.244	F	N	5/0
15161	West	0.003	0.748	0.078	M	D	7/3
19056	West	0.005	0.537	0.019	M	D	7/3
1997	East	0.006	0.528	0.589	F	C	12/6
19053	West	0.009	0.687	0.132	M	A	15/27
12136	East	0.013	0.821	0.864	F	V	2/1
68989	West	0.015	0.204	0.015	M	V	3/0
32754	West	0.027	0.446	0.067	M	B	10/21
15159	West	0.033	0.913	0.407	M	F	0/0
4159	East	0.035	0.887	0.821	F	A	14/27
9840	East	0.037	0.868	0.831	M	V	2/1
19052	West	0.04	0.821	0.309	M	Z	2/0
32790	West	0.04	0.334	0.057	M	A	15/27

Table 4-6. Sighting patterns for animals sampled on the western feeding ground and identified as putative dispersers in the assignment test. "X" denotes years in which an animal was photographically identified on the Sakhalin feeding ground. The total number of seasons sighted, along with the percentage of seasons in which each animal was sighted following its initial identification, is shown in the last column.

ID	1994	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	No. (%) of seasons sighted
15161		X	X		X	X	X	X	X	X	X			9 (75%)
19056			X	X	X	X	X	X	X	X	X			9 (82%)
19052				X		X	X	X	X	X				6 (60%)
32754					X		X	X	X	X	X	X		7 (78%)
15159	X	X	X	X	X	X	X							7 (54%)
19053					X	X		X		X	X		X	6 (67%)
32790					X			X	X	X			X	5 (56%)
32759							X	X		X	X			4 (57%)
68989											X	X	X	3 (100%)

Table 4-7. Estimates of genetic differentiation after stratification by sex and removal of animals identified as putative dispersers. F_{st} values for mtDNA haplotype frequency comparisons are shown above the diagonal and for microsatellite allele frequencies below the diagonal. Significant values are displayed in bold.

		East		West	
		Females	**Males**	**Females**	**Males**
East	Females	*	≤ 0.001	**0.075**	**0.05**
	Males	≤ 0.001	*	**0.056**	**0.038**
West	Females	**0.015**	**0.015**	*	≤ 0.001
	Males	**0.005**	**0.006**	0.005	*

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V. CHAPTER FIVE

Possible movements of two gray whales (*Eschrichtius robustus*) between the eastern and western North Pacific inferred using genetic tags

ABSTRACT

Genetic tagging approaches that utilize microsatellite genotypes to provide a genetic profile useful in identifying individuals have proven valuable in detecting movement patterns of individuals. In the course of a study designed to evaluate the population structure of gray whales (*Eschrichtius robustus*) in the North Pacific, two individuals were identified in the western North Pacific which had identical microsatellite genotypes (n=13 loci), mtDNA haplotypes, and sexes as those obtained from two biopsy samples collected off central California. While previous studies have supported genetic differentiation between the eastern and western populations of gray whales, the relatively low level of genetic differences observed at nuclear markers suggests that some dispersal between the two populations could be occurring. The finding of two whales apparently sampled on both sides of the North Pacific, although subject to numerous caveats, provides support for that possibility. In addition, if the genetic matches represent true dispersal events between the eastern and western Pacific, our understanding of the reproductive history of the animals sampled in the west indicates that such dispersal may result in a limited amount of gene flow between populations. Given sampling limitations, these findings cannot be used to evaluate the magnitude of such dispersal, but they highlight the need for additional genetic, photo-identification, and satellite tagging studies to assess this question. The results also demonstrate how the combination of genetic information with long-term field studies can be valuable in elucidating factors affecting population structure in cetaceans.

INTRODUCTION

Like most baleen whales, gray whales (*Eschrichtius robustus*) exhibit seasonal movements between high- latitude summer feeding grounds and low- latitude wintering areas. The current distribution of this species is limited to the eastern and western margins of the North Pacific (Rice and Wolman 1971), where two populations have been identified. Animals from the eastern North Pacific population spend their summers feeding in the waters of the Bering, Beaufort, and Chukchi Seas, with some animals demonstrating fidelity to more southern feeding areas ranging from Southeast Alaska to northern California (Darling 1984, Calambokidis *et al.* 2002). Although some gray whales may overwinter at high latitudes (Stafford *et al.* 2007), most animals from this population migrate south to the lagoons and coastal waters off Baja Mexico to spend their winter months. Although this stock of whales was greatly depleted by commercial whaling, the population was removed from the Endangered Species list in 1994 and currently numbers ~20,000 – 22,000 animals (Rugh *et al.* 2008, Punt and Wade 2010).

In contrast, the population of whales in the western North Pacific has been estimated to contain only about 130 animals of age one or older (Cooke *et al.* 2008) and is currently listed as Critically Endangered by the IUCN (Weller *et al.* 2002, Baillie *et al.* 2004). The primary feeding ground for this population is located in the coastal waters of northeastern Sakhalin Island, Russia (Weller *et al.* 1999, 2002), although use of areas farther offshore off Sakhalin as well as off the southern and eastern coasts of Kamchatka have also been documented (Yakovlev *et al*. 2007, Tyurneva *et al.* 2009). The location of the wintering ground(s) for this population is unknown, but information from sightings,

strandings, and catches suggests that at least some animals may winter in the coastal waters of southern China (Zhu 1998, Kato and Kasuya 2002, Weller *et al*. 2002).

Genetic studies utilizing both mtDNA and microsatellites have established that the two populations are genetically differentiated (LeDuc *et al.* 2002, Chapter Two). However, the level of nuclear differentiation found between the two populations is relatively low, suggesting that some amount of dispersal between them may exist. The results of sex-specific analysis, as well as of genetic assignment tests, have suggested that any such dispersal is likely to be male-biased (Chapter Two and Chapter Four).

As part of the above studies, the mtDNA haplotype, sex, and the genotypes for 13 microsatellite loci were generated from 142 samples collected on the western feeding ground located off Sakhalin Island, Russia. With one exception, these samples are linked to individuals photographically identified on the study area, and they represent 83% of all animals (n=169) photographed in the area. Photographic records documenting the use patterns of these animals within the study area also exist (Weller *et al.* 1999, 2002, 2008). For comparative purposes, 136 samples collected from animals in the eastern Pacific were also analyzed. Given the size of the eastern population, however, these samples represent less than 1% of the population, and with only a few exceptions these samples are not linked to any photographic records.

Traditionally, cetacean studies have relied on the use of natural markings to identify individuals and document movements between areas (e.g. Hammond *et al.* 1990a). In the past decade or so, however, numerous microsatellite loci have been developed for use with cetaceans (*e.g.*, Valsecchi and Amos 1996, Berube *et al.* 2000, 2005), supplying an alternative method for discriminating between individuals. When a

sufficient number of loci are utilized, microsatellite genotypes can provide a "genetic tag" which allows animals to be tracked through space and time (Palsboll 1999). In cetaceans, this approach was first used in a study of humpback whales (*Megaptera novaeangliae*) in the North Atlantic (Palsboll *et al.* 1997), where genetic tags were used to document movements of whales between feeding areas and mixing of animals on winter breeding grounds, as well as to estimate abundance. Genetic tagging studies are now widely used to estimate population size, often utilizing noninvasive sampling strategies (e.g., Eggert *et al.* 2003). This approach has also provided information on the movements of individual animals, including the seasonal migration of a humpback whale between the Norwegian Sea and the eastern Caribbean (Berube *et al.* 2004) as well as the surprising movement of a male humpback whale between two wintering regions in different ocean basins (Pomilla and Rosenbaum 2005).

Given that questions have been raised about the potential for movements of gray whales between the eastern and western North Pacific, genetic tagging could provide a method to evaluate contemporary dispersal between areas. Based on the size of the eastern population, much more extensive sampling of this population would be needed to make such an approach viable for making inferences about the extent and nature of any such dispersal. Despite the limitations of the currently available dataset, however, two pairs of individuals with matching genotypes, haplotypes, and sexes were identified in our study. In both cases, one animal of each pair was sampled in the eastern Pacific and, the other in the western Pacific. Each pair may represent a single whale. Although additional studies are needed before any conclusions can be drawn, the possible significance of these finding is discussed below.

METHODS

One hundred forty-two western gray whale samples were collected between 1995 and 2007 via biopsy darting of free-ranging whales on the population's feeding ground off Sakhalin Island, Russia. All except for one of the western gray whale samples are linked to a photographically identified animal, and this sample set represents 83% of all animals (n=169) identified on the western feeding ground through 2007. One hundred thirty-seven eastern gray whale samples obtained from the archive at the Southwest Fisheries Science Center were used for comparison to the western population. These samples were taken primarily from stranded animals, with some samples obtained from directed subsistence takes, fisheries bycatch, and biopsies of free ranging whales. Collection locations ranged from southern California north to the Chukotka Peninsula in Russia (*Table 5-1*).

The sex, mtDNA haplotypes, and microsatellite genotypes were determined for these samples as part of an earlier study examining genetic differentiation between eastern and western populations (Chapter Two). The microsatellite loci utilized in the study are shown in *Table 1-1* (Chapter Two); the diversity of the loci in each population is shown in *Table 5-2.* The EXCEL add-in MS_TOOLKIT (Park 2001) was used to identify samples with genotypes that matched at all 13 loci. The mtDNA haplotype and sex of animals with identical genotypes were used to confirm all identified matches.

The program GENECAP (Wilberg and Dreher 2004) was used to calculate the probability of identity using the microsatellite genotypes. The probability of identity (PID) is defined as the probability that two individuals drawn randomly from the dataset will have the same genotype at multiple loci. This statistic was initially calculated under

the assumption of Hardy-Weinberg equilibrium (PID_{HW}, Paetkau and Strobeck 1994). However, such estimates may be biased in the presence of population structure. Calculations assuming the presence of full siblings within the dataset (PID_{SIB}) are considered more conservative (Waits *et al.* 2001) and were calculated using the formula of Evett and Weir (1998). PID values were calculated using the combined dataset and also utilizing the data for each population separately.

The match probability (*e.g.*, individual probability of identity) is defined as the probability that given the genotype of one individual, a second individual will have the same genotype. The match probability was calculated for all identified pairs of duplicate genotypes both under the assumption of Hardy-Weinberg equilibrium and assuming that the two individuals were full siblings (Woods *et al.* 2009).

RESULTS

Two pairs of animals with identical genotypes, mtDNA haplotypes, and sexes were identified. In both cases, one animal of the pair was sampled as part of the eastern population and the other as part of the western population. The average probability of identity utilizing the combined dataset and assuming Hardy Weinberg equilibrium was calculated as 8.65×10^{-14}, while PID_{sib} was calculated as 1.04×10^{-5}. When the average probability of identity was calculated for each population separately, the PID_{sib} was 6.72×10^{-6} for the eastern population and 1.48×10^{-5} for the western population. PID_{HW} was 1.25×10^{-14} and 4.13×10^{-13} for the eastern and western populations, respectively. Match probabilities (P_{HW} and P_{SIB}) for both pairs, as well as the mtDNA haplotype and sex of the matching animals, are shown in *Table 5-3*. The two pairs of matching genotypes were

heterozygous for 10 of the 13 loci utilized. All other samples utilized in the study had genotypes which mismatched at 5 (n=1 pair), 6 or more loci.

Interestingly, both of the biopsies from the eastern population were collected during the same expedition. Sample #3947 was collected on 20 March 1995, and sample #3950 on 23 March 1995. Both samples were taken from whales in the Santa Barbara Channel off central California. Although some video was taken during this sampling trip, it proved to be of too poor resolution to be useful in photographic comparisons.

Sample #12186 was collected from an animal on the Sakhalin feeding ground on 14 August 1998. Photo-identification records link this whale to an animal which was first identified in that area on 19 August 1995. This male was sighted off Sakhalin during ten of the 12 seasons covered by the study. Sample #50728 was collected from a whale on the Sakhalin feeding ground on 27 August 2004. Photo-identification was used to link this animal to a whale first identified in that area in 1999. This female was then sighted off Sakhalin in all subsequent years of the study. Extensive photo and video documentation exists for both of these animals.

DNA was extracted from the two samples collected in the eastern Pacific in June 1995, prior to the arrival of any tissue samples collected from the western Pacific. Sample #12186 was cleared in 1999 and was first extracted in April. The initial microsatellite amplification of #3947, 3950, and 12186 were conducted as part of the same batch. However, when the genetic match between #12186 and #3950 was first identified, both of these samples were re-extracted and re-amplified; no genotyping errors were identified. Sample #50728 was cleared in October 2005 and was extracted in November 2005; no samples collected in the eastern Pacific were included in this batch of

extractions. All four samples were re-extracted in October of 2008. The mtDNA haplotypes from the new extractions were sequenced, and microsatellite genotypes were generated from all four of the new extractions as part of the same run to control for possible errors in calibration across runs. No errors were identified.

DISCUSSION

Before considering the implications of these results for our understanding of gray whale population structure, possible explanations should be addressed. Precautions were taken to ensure that the matching genotypes were not an artifact of lab error. Given that the initial archiving and extraction of tissue samples were conducted as part of three separate batches in three different years, the probability that a mixup at the level of the tissue is extremely low. For all samples, genotypes were replicated after re-extraction of DNA from the tissue; no errors were identified, suggesting that genotyping errors were also unlikely.

The power of the microsatellite panel used to discriminate between individuals was high ($PID_{HW} = 8.65 \times 10^{-14}$; $PID_{SIB} = 1.04 \times 10^{-5}$) and comparable to that used in other studies utilizing genetic tagging to infer movements of individuals between areas (*e.g.*, $PID_{ave} = 1.51 \times 10^{-7}$, Palsboll *et al.* 1997; $PID_{sib} = 2.8\text{-}3.11 \times 10^{-5}$, Pomilla and Rosenbaum 2005). The more conservative estimates of the match probabilities (P_{sib}) calculated from the gray whale microsatellite data suggest that the probability of finding two animals with these identical genotypes is 1/50,000 (for the match between females) and 1/100,000 (for the match between males); and the less conservative measures (P_{HW}) suggest that the probability is almost infinitesimally small. It is likely that the true

probability lies somewhere between these two estimates, given that there is evidence for population structure in our data but it is unlikely that many full siblings were represented, based on studies of paternity in western gray whales (Chapter Three).

Based on these considerations, the probability that the two sets of matching genotypes identified here are an artifact of laboratory errors or a lack of resolution in the markers used is vanishingly small. However, even if all 130 of the animals in the western Pacific were to have visited the eastern Pacific during the study period, it is highly unlikely that one of the western animals would have been sampled given the size of the eastern population and the relatively low proportion of animals in the eastern Pacific which have been sampled. The probability of sampling one of ~130 western animals among an estimated 20,000 eastern gray whales is approximately 1/150 ($p = 0.006$); assuming the two events are independent, the probability of capturing two western animals is approximately 1/22500 ($p = 4.17 \times 10^{-5}$). These probabilities would be even lower if only a small number of the animals identified in the western Pacific travel to the eastern Pacific. Only 115 eastern samples were collected during the period of time (*i.e.*, in 1995 or later) in which an animal identified on the western feeding ground could have feasibly been sampled (*Table 5-1*). Only 19 of these samples were collected from live animals, meaning that almost all of the animals sampled in the east were not present during the entire study period.

Given the low probability of sampling a western animal in the eastern Pacific, these calculations indicate that if the matching genotypes do represent animals which have travelled between the two areas, some source of capture heterogeneity may exist which acts to increase the probability of sampling an animal sighted in the western

Pacific relative to those which remain in the eastern Pacific. Mark-recapture studies based on photo-identification have identified several sources of capture heterogeneity among cetaceans (Hammond *et al.* 1990b). While some of these are specific to photo-identification methods (*e.g.*, variation in the distinctiveness of marking patterns), others, including differences in behavior between individuals, could potentially increase the probability of sampling a western animal relative to that of sampling an eastern animal. It is plausible that, given the long-term field study conducted on the western feeding ground, western whales may have become more accustomed to being monitored by small boats and thus may be more easily approached for sampling than eastern whales are. However, both of the animals sampled in the eastern Pacific were sampled prior to the start of field efforts in the western Pacific, suggesting that the source of any capture heterogeneity between eastern and western animals may be more subtle.

However, if the genotype matches do represent true dispersal events, the tightly linked timing of the two sampling events in the eastern Pacific raises questions about the independence of the two events. If these putative movements represent some colonization of the western feeding ground by eastern animals, perhaps such events occur as one animal follows another into a new area. Another possibility is that some segregation takes place on the migratory route relative to the feeding location. Southbound migration timing has been correlated with feeding ground origin in North Atlantic humpback whales (Stevick *et al.* 2004), which utilize two different feeding areas but a common breeding area in the West Indies. Animals which fed in the Gulf of Maine and eastern Canada had earlier mean sighting dates in the West Indies than did animals known to feed in Greenland, Iceland, and Norway, suggesting that the migration from feeding area

to breeding area might be segregated. Although stratification of the gray whale migration relative to age, sex, and reproductive status is known to occur (Rice and Wolman 1971), no additional mechanisms for segregation have been identified.

Although previous studies have confirmed that the eastern and western gray whale populations are genetically distinct, the relatively low level of differentiation observed at nuclear markers has suggested that some degree of dispersal of eastern animals onto the western feeding ground may occur (Chapter Two and Chapter Four). Although rare, "extralimital" movements have been observed in other baleen whale species. In a study similar to that reported here, Pomilla and Rosenbaum (2005) used genetic tagging to document the transoceanic movement of a male humpback whale from wintering grounds off the northeastern coast of Madagascar in the southwestern Indian Ocean to wintering grounds off the coast of Gabon in the eastern South Atlantic Ocean. Although the movement of this whale was initially detected using genetic evidence, the match was later confirmed via photo-identification, further validating the utility of genetic studies to track individuals. Photo-identification studies have also documented movements of humpback whales in the North Pacific between different breeding regions and between western Pacific breeding regions and eastern North Pacific wintering regions (Darling *et al.* 1997, Salden *et al.* 1999, Calambokidis *et al.* 2001, 2008). In addition, movement of a North Atlantic right whale (*Eubalaena glacialis*) from the western North Atlantic to northern Norway and back has been documented using photoidentification (Jacobsen *et al.* 2004).

Previous studies of gray whale population structure (LeDuc *et al.* 2002, Chapter Two) have noted that the western gray whale population contains a relatively high

number of mtDNA haplotypes (n=22) and that many of those haplotypes (n=11) have thus far been found in only a single male. These males were hypothesized to represent good candidates for dispersal from the eastern Pacific to the western feeding ground (LeDuc *et al.* 2002, Chapter Two). However, the male which was apparently sampled in both the east and the west carried a haplotype (B) which is common in both populations, providing no additional information on the likelihood of this animal being a migrant. The haplotype (35) carried by the female samples has been identified in only one other sample collected in the eastern Pacific and six samples obtained from whales in the western Pacific. However, these six samples include three of the western female's offspring, as well as one other female and her two offspring. Given the low sampling coverage in the eastern Pacific, it is likely that this haplotype would be found in additional animals on that side of the ocean basin with more complete sampling.

In addition to the temporal proximity of the two sampling events in the eastern Pacific, a couple of other aspects of the timing in which the samples were collected should be addressed. First of all, the sample from the male animal off Santa Barbara was obtained approximately five months prior to the first sighting of the whale associated with sample 12186 on the Sakhalin feeding ground, suggesting a maximum travel time of 150 days. Assuming that a whale moving between these two areas would likely have traveled along the Aleutian Islands and then down the eastern coast of Kamchatka, the distance between the two sampling locations is approximately 10000 km, which would entail a travel speed of ~70km/day. Speeds of approximately 150km/day are considered representative of travel rates for southbound migrating gray whales (Rugh *et al.* 2001),

suggesting that a gray whale would be capable of traveling between these two areas in the given time.

Secondly, the eastern gray whale samples were collected off central California in March, indicating that the samples were collected from whales which were likely migrating north after having spent the winter off Baja Mexico. The samples collected in the western Pacific were obtained from whales which were utilizing the Sakhalin feeding area and which have demonstrated high levels of fidelity to that region. Therefore, the putative movements of these whales could provide evidence of feeding ground exchange, such that these individuals feed in the western Pacific but continue to return to the eastern Pacific during winter months. Alternatively, they could represent more permanent dispersal into the western Pacific, such that subsequent to "discovering" the Sakhalin feeding area the animals then utilized wintering areas in the western Pacific.

Integrating additional genetic evidence with that obtained from photo-identification of the western animals may provide some insight into the nature of these putative movements. Paternity analysis of sampled calves born into the population between 1995 and 2007 indicated that the male associated with sample #12186 was the putative father of a calf born in 2007 (Chapter Three). The female associated with sample #50728 is identified (both behaviorally and genetically) as the mother of three calves born during the same time period; although two of her calves were not assigned a putative father among the sampled western animals, her 2007 calf was assigned a putative father which has been sighted regularly on the Sakhalin feeding ground. This evidence suggests that both of the whales sampled as part of the western population interbred at least one time with other animals considered to be western gray whales. Given that

mating in gray whales is thought to primarily occur while on migratory routes (Rice and Wolman 1971), these results suggest that the whales would have used migratory routes in the western Pacific at least on some occasions.

SUMMARY AND FUTURE STUDIES

If these genetic matches do indeed represent movements of animals between the eastern and the western Pacific, such dispersal raises questions about the degree and nature of the connectivity of these two populations. Previous work has shown that the eastern and western populations are genetically distinct, although the relatively low level of nuclear differentiation suggested that some dispersal may occur between the two areas (Chapter Two). The putative dispersal events described here provide further support for that possibility. However, the conclusions that can be drawn from these events are limited by the lack of photographic documentation of the animals sampled in the east, as well of the paucity of genetic samples analyzed from that area.

Some resolution to the questions raised here may come with future studies integrating photo-identification comparisons and satellite tagging with the genetic data. Extensive photo-identification records exist for the western gray whale population, documenting individual use patterns of the Sakhalin feeding area over 12 summer feeding seasons (Weller *et al.* 1999, 2008). However, the Sakhalin photo-identification catalogues have not been compared with those existing for the animals in the eastern Pacific. Photo-identification studies have been conducted over many years in the calving lagoons of Baja Mexico, and additional studies have been conducted in various regions of the eastern population's feeding range. Comparison of photo-identification records between

the eastern and western Pacific would provide some insight into the frequency and nature of any movements between the two areas.

In addition, satellite tagging studies for western Pacific gray whales are scheduled to begin in the summer of 2010. The objective of these studies is to learn more about the location of the primary wintering area for the western population, which has yet to be confirmed. However, such studies may also provide more direct evidence of movements between populations or perhaps indicate that few, if any, whales move between areas.

Some or all of the material found in Chapter Five will be submitted for publication. I was the primary researcher. The co-authors D. Weller and A. Burdin supervised the field effort through which the genetic samples were collected. The co-authors D. Weller, R. LeDuc, and R. L. Brownell, Jr. supervised the research.

Table 5-1. List of genetic samples used in this study which were collected from gray whales in the eastern North Pacific. The year of sample collection and source of tissue are shown.

Year	Biopsy	Fishery	Harvest	Strand	Total
1979				1	1
1990				1	1
1992				5	5
1993				2	2
1994			12	2	14
1995	6				6
1996				1	1
1997				5	5
1998		1		13	14
1999		1		15	16
2000				41	41
2001	2			1	3
2002				3	3
2003	2			4	6
2004				8	8
2005	3	1		1	5
2006	6			1	7
Total	19	3	12	104	138

Table 5-2. Microsatellite data for gray whales. Includes number of alleles per loci (k), expected heterozygosities (H_e), observed heterozygosities (H_o), and number of private alleles (k_p). The overall results include averaged values over all loci for k, H_e, and H_o, and the sum of all private alleles for k_p.

	East				West			
Locus	**K**	**H_e**	**H_o**	**Kp**	**K**	**H_e**	**H_o**	**Kp**
D17t	15	0.89	0.9	1	15	0.88	0.85	1
EV14t	9	0.81	0.78	1	9	0.76	0.74	1
EV37	17	0.88	0.89	1	17	0.85	0.91	1
EV94t	11	0.79	0.74	2	9	0.75	0.75	0
Gata028	8	0.78	0.82	3	5	0.75	0.78	0
Gata098	10	0.65	0.65	3	7	0.63	0.61	0
Gata417	7	0.71	0.71	0	7	0.63	0.65	0
Gt023	9	0.72	0.76	1	8	0.68	0.68	0
RW31	10	0.82	0.83	1	9	0.82	0.85	0
RW48	5	0.4	0.42	0	5	0.36	0.34	0
SW10t	9	0.77	0.76	1	9	0.75	0.77	1
SW13t	8	0.63	0.67	1	8	0.67	0.68	1
SW19t	10	0.71	0.67	3	7	0.64	0.67	0
Overall	9.8	0.74	0.74	18†	8.8	0.7	0.71	5†

Table 5-3. Match probabilities, as calculated in GENECAP, for the two pairs of identical genotypes identified in the gray whale microsatellite data. P_{HW} refers to probabilities calculated assuming Hardy-Weinberg equilibrium, while P_{SIB} refers to probabilities calculated assuming that the two individuals are full siblings. Information on the number of microsatellite loci typed, the mtDNA haplotype, and the sex of the animals sampled is also provided.

Sample ID	**Source Population**	**Loci Typed**	**MtDNA Haplotype**	**Sex**	**P_{HW}**	**P_{SIB}**
12186	West	13	B	M	1.87 x 10-13	2.10 x 10-5
3950	East	13	B	M		
50728	West	13	35	F	5.43 x 10-15	1.06 x 10-5
3947	East	13	35	F		

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VI. CONCLUSIONS

The work presented here used a suite of different genetic approaches to characterize the population structure of gray whales in the North Pacific. The results highlight the complexity of elucidating patterns of movements in animals which are capable of traveling long distances, are sensitive to environmental changes, and whose life history dictates that they utilize different areas for feeding and breeding. While the information presented here contributes to our understanding of gray whale population structure, many additional questions were raised about the extent and nature of connectivity between the two populations.

Summary

Although some dispersal of eastern animals onto the western feeding ground may be occurring, the maintenance of genetic differentiation between the eastern and western populations supports their continued recognition as separate populations. Both field-based and genetic studies indicate that recruitment into this small population is driven in large part by the fidelity of females and their offspring to the primary feeding ground. In addition, the results of the paternity analysis indicate that interbreeding among individuals known to utilize the Sakhalin feeding ground occurs, presumably while these animals are travelling along common migratory routes.

Whether any dispersal which occurs between populations is representative of feeding ground mixing only, or if it entails gene flow between populations, is not clear. At the population level, the maintenance of genetic differences between eastern and western populations suggests that any gene flow that is occurring is likely to be minimal. However, genetic drift could be acting to counterbalance some restricted degree of

genetic interchange between populations, and the balance between these two forces in this small population is not well understood. Based on the individual-level analyses, only one of the nine animals designated as a putative disperser was identified as potentially contributing to reproduction in the population, indicating that most, although potentially not all, of the putative dispersal events did not result in genetic exchange during the study period. However, the results of the paternity analysis indicated that both of the two western animals which shared identical genetic profiles to animals sampled in the eastern North Pacific had interbred with other animals on the western feeding ground, suggesting that, if these genetic matches represent real movements of individuals, some gene flow may be occurring. While these results are intriguing, the caveats associated with both findings suggest additional studies are needed before any conclusions can be drawn.

Discriminating between gene flow and feeding ground mixing has important consequences for our understanding of the status of the western gray whale population. As aforementioned, if dispersal of eastern animals onto the western feeding ground is resulting in gene flow, then these dispersers may be acting to "genetically rescue" the remnant western population by providing an additional source of genetic diversity. Mixing on the feeding grounds without gene flow, however, could be artificially inflating our estimates of both genetic diversity and population size, which would suggest that the western population is more vulnerable than currently thought.

Finally, a number of different observations suggest that the habitat use patterns of gray whales in the eastern Pacific have recently shifted as a result of some combination of the population's growth and recent environmental changes. If dispersal of eastern whales onto the western feeding ground is occurring, as suggested here, it may indicate

that changes in the structure of gray whale populations could also result from these conditions. Additional efforts to understand the extent and nature of connectivity between gray whale populations may provide insight into the potential for population recovery and habitat alteration to affect the structure of other, less well-studied populations of baleen whales.

Future Studies

Although continuing to collect biopsies from unsampled animals, particularly calves, on the western feeding ground would be valuable in further evaluating the patterns described here, expanding sampling efforts to include other areas in the western Pacific would contribute to our understanding of the size of the population in the western Pacific and the potential for intermixing with eastern animals. In particular, the collection of genetic samples from animals of unknown origin which utilize the waters of southeastern Kamchatka during summer months could provide information on the relationship of these animals to those sampled off Sakhalin. In addition, genetic analysis of any animals sighted, stranded, or entrapped in areas used as migratory corridors or wintering areas would be helpful in elucidating movements of individuals outside of the primary feeding ground. Analysis of historic gray whale samples, such as bones or baleen, collected in the western Pacific would be useful in evaluating how much genetic diversity has been lost in this population and has the potential to provide insight into which animals are more likely to represent “true” western gray whales.

Future work using simulation-based modeling would provide valuable context for interpreting the patterns identified using the genetic data. This approach could be used to

assess how much confidence can be placed into the assignment test results as well as to explore the extent of gene flow and/or intermixing which could occur between populations while still allowing genetic differentiation be detected.

Integrating the genetic data with information gained via other approaches might also provide resolution to the questions raised here. Although not a trivial undertaking, comparison of photo-identification records between the eastern and western Pacific would provide some insight into the frequency and nature of any movements between the two areas. In addition, satellite tagging of western gray whales, which is scheduled to begin in the summer of 2010, may provide valuable information about the location of migratory routes and wintering ground(s) in the western Pacific and the identity of whales which utilize these areas.

VII. APPENDIX

Why **not** Y? Lack of variability in the Y chromosome of gray whales (*Eschrichtius robustus*)

INTRODUCTION

Comparison of variation and population structure at Y chromosome loci with that found in maternally-inherited mitochondrial DNA (mtDNA) and biparentally-inherited microsatellite markers can provide valuable information on sex-specific population parameters and insight into reproductive strategies and dispersal (*e.g.*, Vila et al. 2003, Eriksson *et al.* 2006, Douadi *et al.* 2007). While mtDNA and microsatellites are often used to study cetaceans, knowledge of intraspecific Y chromosome variability has been limited to fin whales, which demonstrated relatively high levels of polymorphism at Y loci when compared with that observed in many other mammal species (Hatch 2004, Hatch *et al.* 2006). The intent of this work was to expand our understanding of Y chromosome diversity in cetaceans by assessing variability in the gray whale. Although previous work utilizing mtDNA and nuclear microsatellites has indicated that eastern and western gray whale populations are genetically distinct (LeDuc *et al.* 2002, Chapter II), several questions remain about the role that male dispersal may have played in both historic and current differentiation between populations. The use of Y markers could potentially address these questions.

METHODS

Seventeen Y-chromosome markers designed for use in other studies (Hatch 2004, Hellborg and Ellegren 2003, Hatch *et al.* 2006) were selected based on their successful amplification in other cetacean species (*Table A-1*). These markers included three anonymous regions designed from the Y chromosome of fin whales (Hatch 2004) and shown to amplify in a range of other mysticete species, including gray whales (Hatch *et*

al. 2006). The remaining 14 primer sets were designed from regions known to be conserved across mammals (Y Chromosome Conserved Anchored Tagged Sequences, YCATS) and amplified introns (Hellborg and Ellegren 2003). Although a total of 48 YCATS have been screened on mammals, the fourteen markers chosen here had been shown to successfully amplify in Risso's dolphins (Hellborg and Ellegren 2003).

To determine if these markers produced successful and male-specific amplification in gray whales, a PCR was conducted for each primer set using two samples collected from male gray whales and one sample collected from a female gray whale, which acted as a positive control. PCR conditions followed those described in the original studies (Hatch 2004, Hellborg and Ellegren 2003). Following PCR, products were visualized on a gel to determine if amplification was successful and male-specific. Those products which produced a single male-specific band on the gel were then sequenced using the marker-specific primers and following the sequencing protocol described in Chapter II.

The second step of the screening process was to determine if these markers amplified regions on the Y chromosome which were variable in gray whales. Samples collected from twenty male gray whales (n=10 from the eastern population and n=10 from the western population) were used to evaluate variability. These samples were chosen to maximize the chance of finding polymorphism by selecting samples which were known to have different mtDNA haplotypes and divergent genotypes. Amplification and sequencing for these markers followed the procedure described above; a female control was included in all amplifications.

RESULTS

Although eleven of the 17 Y-chromosome markers produced a product, only five of these markers produced a single, male-specific band when visualized on the gel (*Table A-1*). Sequencing of these five products, which totaled ~2.0 kb in length, revealed no variability among the twenty male gray whale samples selected for the screening. In addition, close inspection of the sequences for SMCY7 and UTY11 revealed that each sequence contained one site for which the base call was ambiguous. Given the lack of amplification in the female control, this finding suggested that amplification of Y-specific repetitive regions, known to be common on the Y chromosome (Skaletsky *et al.* 2003) may have been an issue. Although this problem might have been addressed by redesigning the primers used in the study, the lack of variation found in these regions indicated that such efforts would not be worthwhile.

DISCUSSION

In contrast to the relatively high levels of diversity observed in gray whales using mtDNA and microsatellite markers, analysis of ~2.0 kb of anonymous and intron sequences revealed no variation in the Y chromosome of gray whales. Although low polymorphism has been found on the Y chromosome of many mammal species (*e.g.*, Hellborg and Ellegren 2004), this lack of variation is inconsistent with that observed in fin whales. This raises questions about how other factors, such as life history traits and demography, may influence levels of Y chromosome diversity in cetaceans. These results also suggest that technical challenges, such as amplification of replicated regions, may continue to plague the amplification of Y chromosome regions in some species, although

new molecular techniques (reviewed in Greminger *et al.* 2009) may provide strategies to circumvent these issues in the future.

Table A-1. Y-chromosome loci screened in gray whales. The locus name and expected size were taken from the original studies. The results of the marker screening on gray whales are characterized by successful amplification, the presence of a single band, the presence of a male-specific band, and the length of the sequence (in basepairs) when amplified using DNA derived from gray whales.

Locus	Expected Size	Successful Amplification	Single band	Male-specificity	Sequence Length (bp)	Polymorphic Sites
DBY12[1]	200	Y	N	N	---	---
DBY4[1]	600	Y	N	N	---	---
DBY7[1]	400	Y	N	N	---	---
DBY8[1]	200	Y	N	N	---	---
DBY9[1]	300	Y	N	N	---	---
SMCY11[1]	350	N	---	---	---	---
SMCY12[1]	150	N	---	---	---	---
SMCY16[1]	500	N	---	---	---	---
SMCY5[1]	200	N	---	---	---	---
SMCY7[1]	500	Y	Y	Y	487	0
SMCY8[1]	100	N	---	---	---	---
UBE1Y6[1]	300	Y	Y	Y	246	0
UBE1Y7[1]	500	N	---	---		---
UTY11[1]	550	Y	Y	Y	340	0
LH_Y10[2]	404	Y	N	---	---	---
LH_Y13[2]	648	Y	Y	Y	606	0
LH_Y02[2]	428	Y	Y	Y	292	0

[1] Hellborg and Ellegren 2004

[2] Hatch 2004

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Update on the use of a simulation-based approach to evaluate plausible levels of recruitment into the Pacific Coast Feeding Group of gray whales

Lang, A.R., and Martien, K. K.
Protected Resources Division, Southwest Fisheries Science Center, La Jolla, CA 92037

ABSTRACT

Previous genetic comparisons of the Pacific Coast Feeding Group (PCFG) of gray whales with whales feeding north of the Aleutians have shown significant levels of mitochondrial differentiation. The magnitude of the differentiation, along with the relatively high levels of genetic diversity identified within the PCFG, have raised questions about how much immigration into the group could occur before the signal of mtDNA differentiation is erased. Here we use a simulation-based approach to evaluate the range of plausible levels of immigration into the PCFG that could be occurring. The simulations incorporate annual immigration ranging from between 0 and 16 animals per year (once the larger ENP population reaches K), and simulations both with and without a pulse of +20 immigrants over two years are included. Results suggest that under the scenarios tested, current immigration into the PCFG of one migrant per year or less would produce levels of genetic diversity and differentiation that are inconsistent with the empirical data. The simulations were less informative with regard to placing an upper limit on the number of animals per year which could be immigrating into the PCFG, although comparison of F_{ST} and χ^2 (per degree of freedom) values between the simulated and empirical data suggests that immigration higher than 8 animals per year is unlikely. Comparisons between the observed and simulated values for the number of haplotypes, F_{ST}, and χ^2 (per df), which were the most informative measures, suggest that immigration of approximately 4 animals per year is most plausible.

INTRODUCTION

Genetic comparisons of samples collected from gray whales considered to be part of the Pacific Coast Feeding Group (PCFG) with those from animals that feed north of the Aleutians have revealed small but significant levels of mtDNA differentiation but no nuclear differentiation (Lang *et al.* 2011). In addition, a relatively large number of mtDNA haplotypes were identified within the PCFG (n=23 haplotypes, Lang *et al.* 2011), which is estimated to contain ~200 animals (IWC 2011). Analysis of photo-identification data indicates that on average, 10 animals per year were recruited[1] into the PCFG between 2004 and 2008, with larger numbers of recruits identified between 2000 and 2002 (IWC 2011). These recruits could be internal (i.e., calves born to PCFG mothers) or external (animals that previously fed north of the Aleutians and subsequently immigrated into the PCFG). An average of three calves per year were identified in the PCFG between 1998 and 2008 (Calambokidis *et al.* 2010), and it is presumed that at least half of the calves born each year may not have been identified as such (IWC 2011). Based on those assumptions, an estimated four animals per year may have recruited into the PCFG from northern feeding area(s) between 2004 and 2008, and a pulse of higher immigration may have occurred between 1999 and 2002, potentially in response to the increase in gray whale mortality that occurred in 1999 and 2000.

The results of these genetic and photo-id studies of the PCFG have raised questions about how much external recruitment into the PCFG could occur while still maintaining the observed level of mtDNA differentiation between the PCFG and animals feeding north of the Aleutians. The use of a simulation-based approach has the potential to provide information relevant to this question. As part of a previous IWC exercise (the Testing of Spatial Structure Methods, or TOSSM, project), simulated genetic datasets representing different population structure archetypes were created for performance testing of different analytical methods (Martien *et al.* 2009). The demographic parameters underlying the dataset generation model were based on the vital rates of

[1] Here a 'recruit' is defined as an individual first photographed in the PCFG seasonal range (within the area spanning 41-52°N and between June 1 and November 30) in a given year and resighted within the seasonal PCFG range in at least one subsequent year.

eastern gray whales (Martien *et al*. 2004, Martien 2006). In discussions with the IWC Stock Definition subcommittee, it was agreed that the TOSSM dataset generation model could be useful in creating simulated datasets that would allow the plausibility of different hypotheses (e.g., different immigration rates into the PCFG) to be evaluated.

METHODS

Rmetasim

Simulated datasets were produced using the *rmetasim* package (version 1.1.05, Strand 2002) as run in the R statistical environment (R 2.14.1). *Rmetasim* performs individual-based population genetic simulations utilizing stage-based matrix population models. The transition probabilities in the matrices are used to randomly assign births, stage transitions, and deaths of individuals over time. Density dependent growth is implemented by the linear interpolation between matrices representing survival and reproduction rates at carrying capacity (K) and at zero population density (ZPD). A pre-birth pulse model is used, such that at the end of each simulation year, the youngest animals in the population are one year old.

Stage-based matrices

As previously mentioned, vital rate estimates for eastern Pacific gray whales (as described in Martien *et al.* 2004, Martien 2006) were used to parameterize stage-based matrices for the TOSSM exercise. Since the construction of these matrices, additional information has become available on the life history of gray whales. This new information was utilized to update the stage-based matrices from TOSSM, and when possible the vital rates used in constructing the new matrices were chosen to be the same as those utilized in the IWC's Implementation Review of gray whales. The following changes were made:

1) Adult survival rate was increased to the median estimate from Punt & Wade 2010 (S_A=0.982)
2) A separate term for calf survival rate (set to S_c=0.732, the median estimate in Punt & Wade 2010) was utilized. In the previous matrices, calf survival was the same as juvenile survival.
3) The median estimate from Punt & Wade 2010 was utilized for the rate of increase at ZPD (λ =1.063)
4) The age of first reproduction (AFR) was increased to 7 years at ZPD based on the Bradford *et al.* 2010 review.
5) A third juvenile stage was added to provide better control of AFR.

In addition, three identical adult stages for each sex were included in the new matrices. In contrast, the matrices used in the TOSSM project included a single adult male stage and separate fertile and lactating stages for adult females. This change was implemented for two reasons. First, it allowed for better control of generation time and greatly reduced the proportion of individuals in the simulations that lived to unrealistic ages under the increased adult survival rate. Secondly, it reduced the number of multiple births by the same female in a given year. In *rmetasim*, the fertility term represents the mean number of calves produced per female based on a Poisson distribution (Strand 2002). This results in some females producing more than one calf per year. Eliminating the separate fertile and lactating stages allowed us to reduce the fertility term (since it was applied to all adult females, not just a subset in the lactating stage), thereby reducing the number of multiple births (Table 1). However, this change also eliminated the minimum two-year calving interval that had been enforced in the TOSSM matrices. As such, under the new matrices some females in the simulation will give birth in consecutive years (Table 2).

Given the number of changes implemented in the new matrices, we ran the simulations using both the updated nine-stage matrices as well as the original five-stage matrices (as described in Martien 2006) utilized in the TOSSM exercise. The vital rates used to construct the original matrices and those utilized in the updated 9-stage matrices are detailed in Table 3. The parameter for juvenile survival rate was not derived from the literature but was calculated from the matrices to produce the desired value of lambda. The

Maximum Sustainable Yield Rate (MSYR) calculated from the 9-stage matrices is ~3.3%, while MSYR for the 5-stage TOSSM matrices is ~3.6%.

These vital rates were used to construct stage-based matrices representing the demography of the population near carrying capacity (K) and near zero population density (ZPD). Transition probabilities were calculated according to Caswell (2001) and the resulting matrices are shown in Table 4.

Population Trajectories

Dataset generation followed the steps outlined in Martien 2006, with the exception that coalescent datasets were generated using FastSimcoal (Excoffier and Foll, 2011) rather than SimCoal 2.1.2 (Laval and Excoffier 2004) to establish the effective size (Ne). In all scenarios, a single population was simulated in *rmetasim* for 4000 years to provide datasets representing the equilibrium population. This time period was shown to be sufficient for reaching equilibrium in a similar exercise for bowhead whales (Archer *et al.* 2010), that have a markedly longer generation time.

The mutation parameter incorporated in the simulations was adjusted to produce genetic diversity levels (as measured by the number of haplotypes and the haplotypic diversity) that are similar to the values observed for the "North" strata in the Lang *et al.* 2011 study. A range of mutation parameters were explored before setting the mutation parameter to 3.8×10^{-3} per generation, which produced measures of genetic diversity that were the most consistent with the observed data.

Carrying capacity (K) for the larger ENP population of gray whales was set to 20,000 animals, similar to the most recent abundance estimate (19,126 animals in 2006/2007; Laake *et al.* 2009). Carrying capacity for the PCFG was set to 200 in accordance with the estimated abundance of 194 animals in 2008 (Annex F, IWC 2011).

For all population trajectories, depletion due to commercial whaling was simulated as having occurred between 1846 and 1930. Attempts were made to utilize the catch history (Annex E, IWC 2011) with a multiplier to produce the desired level of depletion in 1930 (10% of K). However, when this modification was incorporated it resulted in a high number of simulation runs that failed due to the simulated population(s) going extinct. As such, the depletion per year was set to a constant proportion of K, such that the population was depleted by 7.1% of K in each year for the duration of the simulated whaling period. This level of depletion allowed the population to reach the desired level (0.10 of K, or ~2000 animals) by 1930. Examples of the population trajectories produced are shown in Figure 5.

Given that little is known about the origin of the PCFG, two different population histories were simulated. The first scenario ("post-whaling split") assumes that the PCFG split from the larger ENP population following depletion. After reaching equilibrium a single population was projected forward through the 1846-1930 whaling period with depletion occurring as described above. In 1930, 20 animals (10% of K_{PCFG}) were split from the larger population to represent the PCFG. The two populations were then allowed to increase until reaching K. *Rmetasim* employs a "hard ceiling" to restrict population growth to K, such that individuals are killed off randomly after reaching levels >10% higher than K.

The second scenario ("pre-whaling split") assumes that the PCFG split from the larger ENP gray whale population prior to the depletion of gray whales due to commercial whaling. In this scenario, the equilibrium population was split into two feeding groups to represent the northern feeding ground (K_{ENP}=20,000) and the PCFG (K_{PCFG} = 200). The split was presumed to occur at the start of the Little Ice Age (considered here to be at 1540), a period in which it seems plausible that ice conditions would have been favorable for gray whales to begin using more southern feeding grounds. Both populations were projected forward until 1846, when the depletion due to commercial whaling was simulated as described above. After reaching 1930, the simulated depletion ceased and the two populations were allowed to grow until reaching K.

Immigration rates ranging from 0 to 0.0008 were simulated. These migration rates correspond to the immigration of between 0 and 16 animals per year into the PCFG from the larger ENP population once it has reached K (Figure 6). In addition, each population history and migration rate combination was also simulated with a migration "pulse" of 20 individuals over two years. This pulse is reflected in the abundance of the PCFG in 2000 and in 2001. Examples of abundance trajectories for the PCFG under the different immigration scenarios are shown in Figure 7.

Additional simulations were performed in which the value of K_{PCFG} was increased from 200 to between 500 and 5000. These simulations incorporated a post-whaling split of the PCFG from the larger ENP, with the pulse migration of +20 animals over two years but no annual immigration into the PCFG. As in the "post-whaling split" scenarios described above, the split of the PCFG from the larger ENP was modeled such that the number of animals colonizing the PCFG in 1930 was 10% of K.

A final set of simulations were performed that incorporated a more recent split (between 1940 and 1990) of the PCFG from the larger ENP population. The number of animals splitting off to form the PCFG in a given year was derived by taking an average (over ten replicates) of the simulated abundance of the PCFG in each year when the abundance trajectories were modeled under the scenario of a post-whaling split of the PCFG in 1930 with no annual immigration.

A list of scenarios that have been simulated to date is included in Table 7. Of note, the simulations incorporating a pre-whaling split of the PCFG from the larger ENP are in progress and have not yet been completed.

Sampling and Genetic Analyses:

To generate the simulated dataset, the number of simulated animals sampled per year was set to match the number of animals sampled per year and per stratum in the Lang *et al.* (2011) study (Table 8). In the empirical study, some animals were sampled multiple times, and only one sample per individual was retained for the data analysis. For the simulated sampling, the year of sampling for such individuals was assigned as the first year that the animal was sampled. A total of 103 samples were collected from simulated ENP individuals and 71 samples were collected from simulated PCFG individuals.

These sampled individuals were used to generate summary statistics for each group. Genetic diversity was characterized by the number of mtDNA haplotypes, the mtDNA haplotype diversity, and the mtDNA nucleotide diversity. Differentiation between the two simulated groups was measured using F_{ST}, χ^2 (per degree of freedom), and ϕ_{ST}. The summary statistics generated from the simulated datasets were then compared to the observed summary statistics generated for the PCFG and the North strata in Lang *et al.* 2011.

To further evaluate how well the shape of the haplotype frequency distribution for the simulated ENP population matched the shape of the distribution for the North stratum in the empirical data, a χ^2 test was used to compare the two haplotype frequency distributions, and the number of significant tests ($p<0.05$) was calculated. In addition, the frequency of the most common haplotype in each replicate simulation was calculated and compared to the frequency of the most common haplotype in the empirical data for the North stratum. Given that the mtDNA summary statistics produced for the simulated ENP population under all scenarios was similar, these tests were only conducted using the data for the simulated ENP population produced under the model with a post-whaling split with pulse migration but no annual immigration.

In addition to showing the proportion of simulations that had higher and lower values for each statistic than the values generated from the empirical data, we used interpolation to calculate the "crossover point" at which the 50% probability (median) was reached (i.e. the point at which the proportion of simulated runs had values higher than the observed reached 50%). For the number of haplotypes, the crossover point was

calculated as the point at which the lines representing the proportion greater than and the proportion less than crossed (as for the other statistics), but because some simulation replicates had values equal to (rather than less than or greater than) the observed value, this point was slightly lower than the 50% probability.

RESULTS

Although the goal is to produce 500 replicates of each scenario, currently only 100 replicates of each scenario are complete and are utilized in the results shown here.

Comparison of simulated and observed data for ENP

Table 9 includes a summary of the number of haplotypes, haplotypic diversity and nucleotide diversity for the simulated ENP population for the model incorporating the 9-stage matrices with a post-whaling split and pulse immigration. Results were similar under all scenarios tested (data not shown). Overall, median values for both the haplotypic diversity and the number of haplotypes were similar among the simulated and empirical datasets. The haplotypic diversity values generated in the simulated data were slightly lower than that in the observed data, with median values for the simulated data ranging from 0.948 to 0.950 (as compared to the observed haplotypic diversity of 0.952) and with 52-64% of replicates under the different immigration scenarios having lower haplotypic diversity than found in the empirical data. In contrast, the median number of haplotypes generated in the simulated datasets (33 to 34 haplotypes) was slightly higher than that found in the observed data (32 haplotypes). Between 62 and 75% of replicates for the different immigration scenarios generated values higher than the number identified in the empirical dataset. Although the nucleotide diversity calculated from the empirical data fell within the 90% range of the simulated values, nucleotide diversity in the simulated data was higher than that found in the observed data.

To evaluate whether the shape of our simulated haplotype distributions matched the shape of the observed distribution, we used a χ^2 test to compare the observed (North stratum) versus the simulated haplotype frequency distributions for the ENP population. The χ^2 test evaluates whether the haplotype distributions representing the empirical and simulated data could have been generated by random sampling of a single population. The χ^2 test is particularly sensitive to the frequencies of the most common haplotypes, as those haplotypes are the most likely to be represented in the random draws that represent immigration events. In our comparison, 12% of tests showed significant ($p<0.05$) differences (Figure 10), suggesting that the shape of the observed and simulated distributions were similar in most cases. We also compared the frequency of the most common haplotype in the empirical data with the frequency of the most common haplotype in the simulations. We found that the frequency of the most common haplotype was higher than that found in the empirical data for 47% of the simulation replicates. This finding is consistent with the expectation that if two samples are drawn from the same distribution, the frequency of most common haplotype would be expected to be greater in one sample than the other 50% of the time.

Comparison of simulated and observed data for the PCFG

Figure 11 shows a graphical representation of the proportion of simulated values for each statistic that are lower (shown in black) or higher (shown in gray) than the observed value generated from the empirical data for one of the scenarios tested (post-whaling split with pulse immigration, nine-stage matrices). Summaries of the number of mtDNA haplotypes (Table 12), mtDNA haplotype diversity (Table 13), mtDNA nucleotide diversity (Table 14), F_{ST} (Table 15), Φ_{ST} (Table 16), and χ^2/df (Table 17) produced by the simulations under all completed scenarios are shown below.

With regard to comparisons between the observed and simulated data, the statistics based on haplotype frequencies (haplotypic diversity, $F_{ST,}$ and χ^2/df) and haplotype numbers were the most informative. For all four of these statistics, scenarios based on annual immigration of one animal or less per year (at K) produced values that were inconsistent with the empirical data. The comparisons were less informative with regard to the highest level of immigration that could be occurring, although comparison of F_{ST} and χ^2/df values suggested that levels of immigration including > 8 animals/year (along with the pulse immigration) would produce values inconsistent with those produced by the empirical data.

Similar to the pattern seen in comparison of the observed and simulated data for the larger ENP population, the nucleotide diversity identified among the simulated datasets was higher than that seen in the empirical data. In the ϕ_{ST} comparisons, the value generated in the empirical comparison was more consistent with the lower range of values for annual immigration and indicated that more than 8 immigrants per year into the PCFG would produce values of ϕ_{ST} lower than that observed. Caution should be applied when interpreting this pattern, however, given the lower nucleotide diversities identified in the observed data when compared to the simulated datasets.

Table 18 shows the results of simulations evaluating scenarios in which the PCFG splits from the larger ENP population between 1940 and 1990. The results shown suggest that for no annual immigration into the PCFG to be plausible, the PCFG would have had to split from the larger population after 1950.

Table 19 shows the results of simulations evaluating scenarios in which the carrying capacity for the PCFG was set to between 500 and 5000. The results indicate that the carrying capacity for the PCFG would need to be higher than 500 animals for the simulated results to be consistent with the empirical data under a scenario of no annual immigration. Examples of the abundance trajectory of the PCFG for the K values tested are shown in Table 20. For all K values simulated, the abundance of the PCFG was close to carrying capacity by 2010 (Table 21).

DISCUSSION:

Comparison of the simulated and empirical datasets for the larger ENP population suggests that the simulations represent the empirical data reasonably well with regard to the number of haplotypes and their distribution. Although the simulations predict that we would find slightly higher number of haplotypes and a slightly lower haplotypic diversity than is present in the empirical data, the differences are small and the χ^2 test suggests that the two samples would be interpreted as being drawn from the same population in the majority (88%) of cases. The results of these comparisons suggest that similar frequency-based comparisons of the simulated and empirical data representing the PCFG should be informative.

The level of nucleotide diversity in the simulated data representing the larger ENP population is higher than that found in the empirical data, indicating that there are some aspects of the population's history that are not being captured by the simulations. It is likely that the gray whales in the North Pacific have experienced numerous fluctuations in abundance due to changing ice conditions in the past, and historic K may have been substantially larger than we have simulated here (e.g., Alter *et al*. 2007). Our simulations incorporate only a simplified version of the recent history of gray whales, and our results suggest that the statistics relying on nucleotide differences (e.g., nucleotide diversity and ϕ_{ST}) may be more sensitive to violations of our assumptions about past (pre-commercial whaling) population size and equilibrium. As such, the results derived from the comparisons of nucleotide diversity and ϕ_{ST} warrant further investigation and should be interpreted with caution.

The comparison of frequency-based statistics between the simulated and empirical datasets representing the PCFG suggests that annual immigration into the PCFG is likely to be higher than 1 immigrant per year under the scenarios tested. The simulations were less informative with regard to the upper bound on annual immigration that could be occurring. Although the F_{ST} and χ^2/df comparisons indicated that immigration of >8 animals/year would be inconsistent with the empirical data, the proportion of simulations with higher than the observed values for the number of haplotypes and the haplotypic diversity never exceeded 84% and 63%, respectively. For all four statistics, the proportion of simulations with higher (for the number of haplotypes and haplotypic diversity) or lower (for F_{ST} and χ^2/df) values than the observed appears to level off at the higher (8 -10 or more per year) levels of immigration. This pattern is particularly evident in the comparisons utilizing haplotypic diversity, where the proportion of simulations with higher or lower values than the observed levels off at ~50% for immigration of 8 or more animals per year. Haplotypic diversity is calculated based on the sum of squared allele frequencies. Given that relationship, as the number of haplotypes in a population increases, the addition of another haplotype, particularly one found in low frequencies as would be expected to be brought in by an immigrant, has little impact on diversity. As such, this statistic, and to a lesser extent the others, appear to have limited power to differentiate between the higher levels of immigration.

Although these statistics were limited in their ability to distinguish an absolute upper bound on how much immigration could be occurring, the calculation of the number of immigrants per year which corresponds to the "crossing point" provides some information on what the most plausible values of immigration could be (Table 22). The estimated number of migrants ranged from ~2 to 8 for the scenarios with pulse immigration under the updated matrices. For the reasons discussed above, the calculations based on ϕ_{ST} and haplotypic diversity may not provide the best estimates. Comparisons between the observed and simulated values for the number of haplotypes, F_{ST}, and χ^2/df, suggest that immigration of approximately 4 animals per year is most plausible. If the current abundance of the PCFG is approximately 200 animals, this represents immigration of ~ 2% per year. Of note, this estimate does not include the +20 animals which were simulated to immigrate into the PCFG in 2000 and 2001.

Although the simulation results could be sensitive to other parameters incorporated in the models, a limited evaluation of the effects of increased carrying capacity for the PCFG or a more recent founding time was conducted. These simulations suggested that to obtain the empirical results presented in Lang *et al.* 2011 under a scenario of no annual immigration, the abundance of the PCFG would have to be larger (>500 animals) than currently estimated. Gray whales have been observed feeding off of Kodiak Island, Alaska since at least 1999, with ~350-400 individuals counted during a single day in July 2000 (Moore *et al.* 2007). Approximately 20% of the animals photographically identified in this area between 2002 and 2005 are known to be animals that have also been photographed in the Pacific Northwest from northern California to southeast Alaska (Gosho *et al.* 2011). However, the median "crossing point" calculated from these comparisons suggest that values of K between 2000 (based on F_{ST}) and 3000 (based on the number of haplotypes) animals produce values that are most consistent with the empirical data, indicating that additional explanation may be needed.

The simulations exploring more recent founding times suggest that under a scenario with no annual immigration, the PCFG would have to have been founded after 1950, and more plausibly between the mid-1960s to mid-1970s, to produce simulated results that are consistent with the empirical data. Small numbers of gray whales have been sighted within the seasonal range of the PCFG since at least 1926 (Howell & Huey 1930, Gilmore 1960, Pike and MacAskie 1969, additional references in Rice & Wolman 1971), but photo-identification studies did not start until the 1970s, when the repeated return of individuals to the area was first documented (Hatler & Darling 1974, Darling 1984). Our simulations model an instantaneous colonization of the PCFG, such that for the scenarios modeling colonization in 1960 or later at least 60 whales become part of the PCFG in a given year. This aspect of our simulations is clearly an oversimplification. Given both the limited information available on use of the PCFG seasonal range prior to the 1970s and the limitations of our model, it is difficult to evaluate how the simulation results fit in with past records.

The simulations incorporating a pre-whaling split of the PCFG from the larger ENP population are in progress and are expected to be completed by the 2012 SC meeting. Future work will also include integrating the genetic data representing ENP gray whales in LeDuc *et al*. 2002 and Lang 2010 with the data represented in Lang *et al.* 2011 to ensure that the diversity values utilized here are as representative as possible of the larger ENP population. Simulations will also be performed to explore the effect of incorporating lower MSYR rates for the PCFG into the life history matrices underlying the models.

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Table 1. The proportion of birth events in the simulated data that resulted in multiple offspring for the same female in a given year.

	5-stage TOSSM matrices	9-stage matrices
Proportion of single offspring births:	64%	92%
Proportion of multiple offspring births:	36%	8%
Range of multiple offspring births:	2-7	2-3

Table 2. Calving intervals in the simulated datasets.

Measure	5-stage TOSSM matrices	9-stage matrices
Median	3	2
Mean	5.1	3.2
Variance	27.08	16.50
stdev	5.20	4.06
Min	2	1
Max	35	38

Table 3. Vital rates for gray whales. Generation time shown here is calculated based on a maximum age of 40 years (as in previous work).

	5-stage TOSSM matrices		9-stage matrices	
Vital Rate	At K	Near ZPD	At K	Near ZPD
Juvenile survival	0.925	0.94	0.905	0.935
Adult female survival	0.946	0.946	0.982	0.982
Adult male survival	0.954	0.954	0.982	0.982
Calf survival	0.925	0.94	0.732	0.732
Age of first reproduction	10	5	10	7
Rate of increase (λ)	1.003	1.072	1.000	1.064
Generation Time*	19.5	16.9	21.10	20.60

Table 4. The updated stage-based matrices for use at a) zero population density and b) carrying capacity are shown below.

a) Nine-stage matrices at ZPD:

	juv1	juv2	juv3	F1	F2	F3	M1	M2	M3
juv1	0.497	0.000	0.000	0.366	0.366	0.366	0.000	0.000	0.000
juv2	0.438	0.497	0.000	0.000	0.000	0.000	0.000	0.000	0.000
juv3	0.000	0.438	0.497	0.000	0.000	0.000	0.000	0.000	0.000
F1	0.000	0.000	0.219	0.942	0.000	0.000	0.000	0.000	0.000
F2	0.000	0.000	0.000	0.040	0.942	0.000	0.000	0.000	0.000
F3	0.000	0.000	0.000	0.000	0.040	0.942	0.000	0.000	0.000
M1	0.000	0.000	0.219	0.000	0.000	0.040	0.942	0.000	0.000
M2	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.942	0.000
M3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.942

b) Nine-stage matrices at K:

	juv1	juv2	juv3	F1	F2	F3	M1	M2	M3
juv1	0.633	0.000	0.000	0.176	0.176	0.176	0.000	0.000	0.000
juv2	0.272	0.633	0.000	0.000	0.000	0.000	0.000	0.000	0.000
juv3	0.000	0.272	0.633	0.000	0.000	0.000	0.000	0.000	0.000
F1	0.000	0.000	0.136	0.914	0.000	0.000	0.000	0.000	0.000
F2	0.000	0.000	0.000	0.068	0.914	0.000	0.000	0.000	0.000
F3	0.000	0.000	0.000	0.000	0.068	0.914	0.000	0.000	0.000
M1	0.000	0.000	0.136	0.000	0.000	0.068	0.914	0.000	0.000
M2	0.000	0.000	0.000	0.000	0.000	0.000	0.068	0.914	0.000
M3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.068	0.914

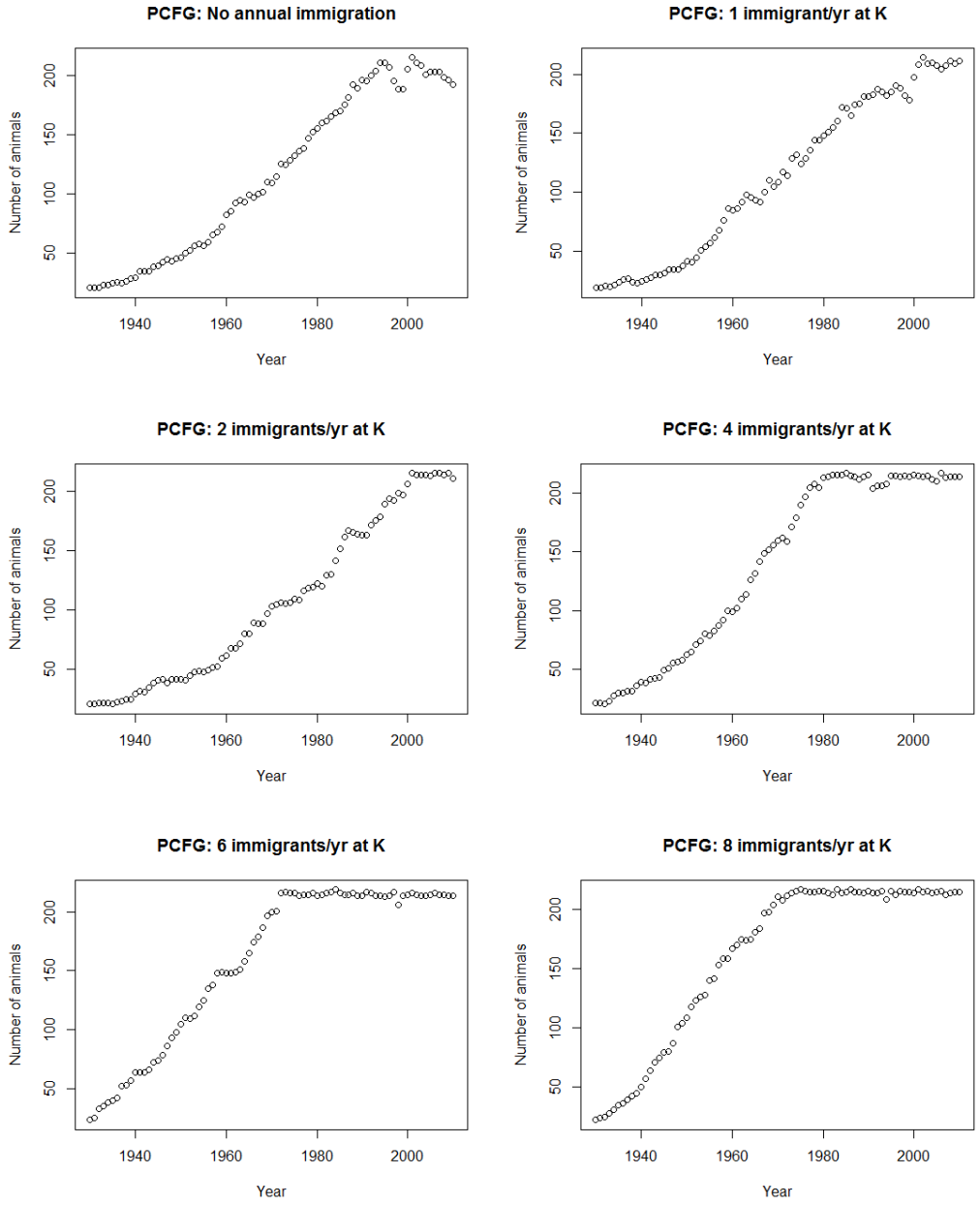
c) Five-stage(TOSSM) matrices at ZPD:

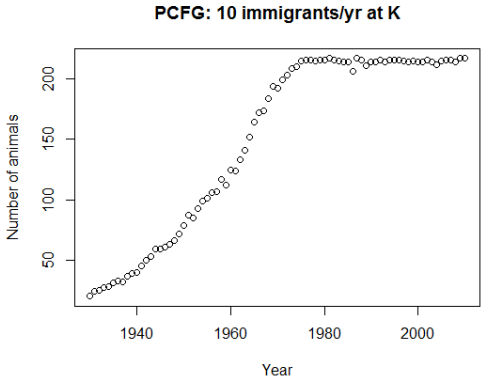
	juv1	juv2	fert	lact	male
juv1	0.730	0.000	0.000	0.940	0.000
juv2	0.210	0.000	0.000	0.000	0.000
fert	0.000	0.470	0.000	0.946	0.000
lact	0.000	0.000	0.946	0.000	0.000
male	0.000	0.470	0.000	0.000	0.954

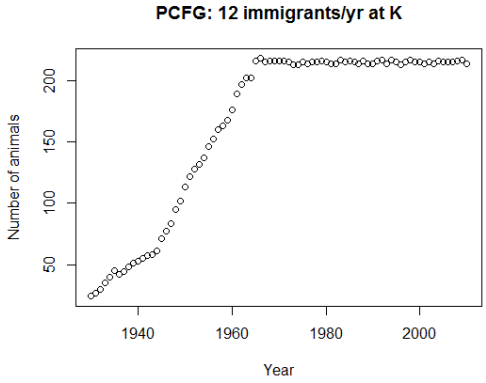
d) Five-stage (TOSSM) matrices at K:

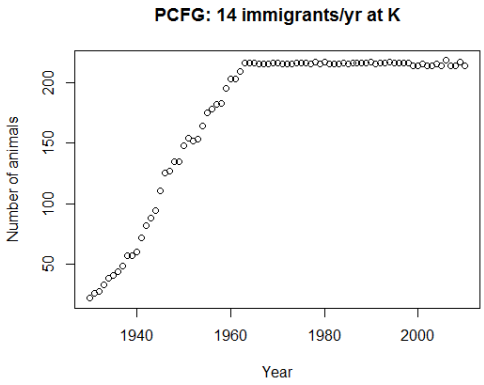
	juv1	juv2	fert	lact	male
juv1	0.768	0.000	0.000	0.925	0.000
juv2	0.157	0.720	0.000	0.000	0.000
fert	0.000	0.102	0.648	0.946	0.000
lact	0.000	0.000	0.298	0.000	0.000
male	0.000	0.102	0.000	0.000	0.954

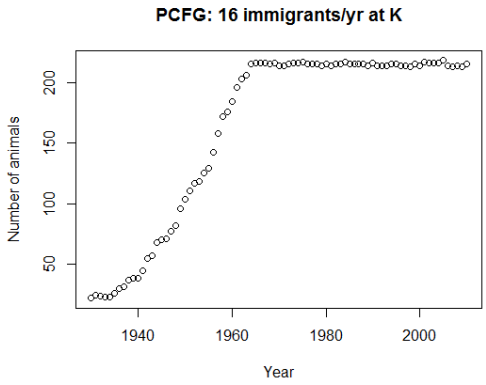
Figure 5. Examples of trajectories for PCFG, under a model incorporating a post-whaling split with pulse immigration. Plots for the abundance of the PCFG whales span 1930 to 2010, while the plot showing the abundance of the larger ENP population spans 1846 to 2010 to show the simulated depletion due to commercial whaling.




PCFG: 10 immigrants/yr at K
Number of animals
50
100
150
200
1940
1960
1980
2000
Year


PCFG: 12 immigrants/yr at K
Number of animals
50
100
150
200
1940
1960
1980
2000
Year


PCFG: 14 immigrants/yr at K
Number of animals
50
100
150
200
1940
1960
1980
2000
Year


PCFG: 16 immigrants/yr at K
Number of animals
50
100
150
200
1940
1960
1980
2000
Year

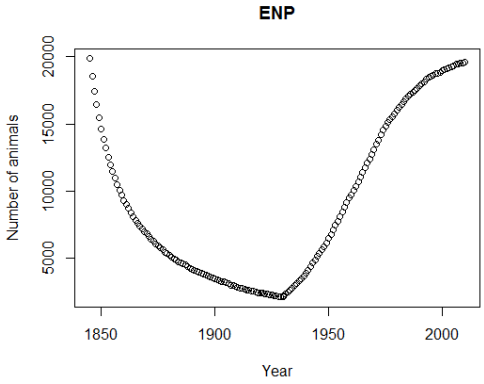
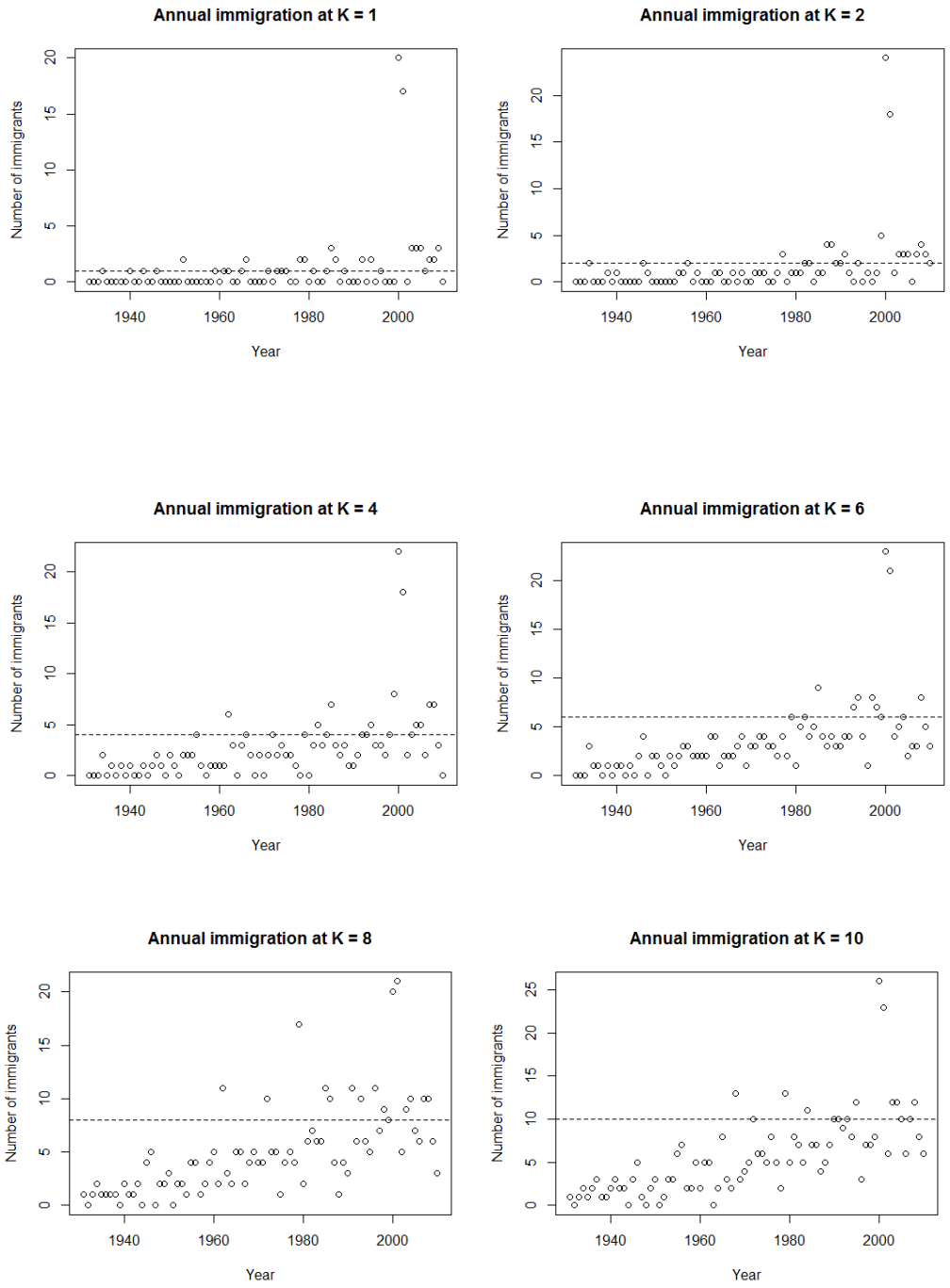
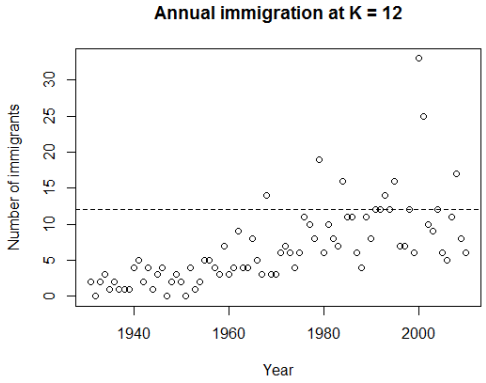
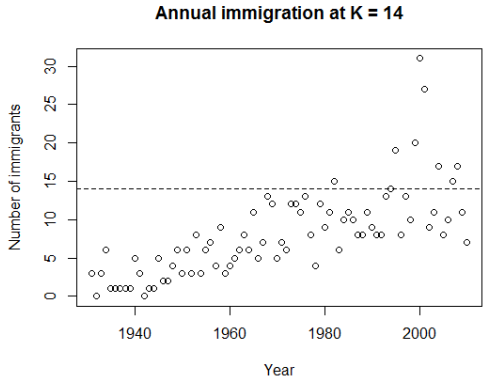

ENP
Number of animals
5000
10000
15000
20000
1850
1900
1950
2000
Year

Figure 6. Example of the number of immigrants per year generated for one replicate (9-stage matrices with pulse immigration). The dotted line represents the number of immigrants per year that would be expected when the ENP population reaches K.




Annual immigration at K = 12
Number of immigrants
0
5
10
15
20
25
30
1940
1960
1980
2000
Year


Annual immigration at K = 14
Number of immigrants
0
5
10
15
20
25
30
1940
1960
1980
2000
Year

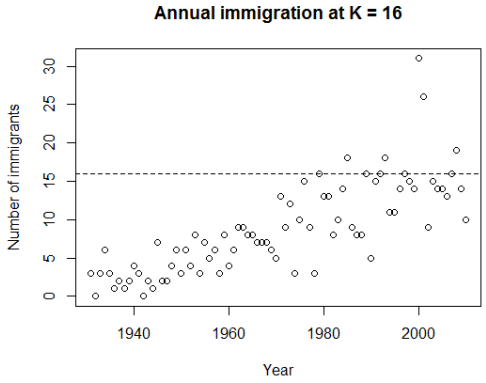

Annual immigration at K = 16
Number of immigrants
0
5
10
15
20
25
30
1940
1960
1980
2000
Year

Table 7. List of scenarios that have been completed for 100 replications.

Index	Matrices	Timing of split	Year of split	PCFG Carrying Capacity (K)	Immigrants/yr into the PCFG (at K)	Pulse immigration
1	9-stage	Post-whaling split	1930	200	0	Y
2	9-stage	Post-whaling split	1930	200	1	Y
3	9-stage	Post-whaling split	1930	200	2	Y
4	9-stage	Post-whaling split	1930	200	4	Y
5	9-stage	Post-whaling split	1930	200	6	Y
6	9-stage	Post-whaling split	1930	200	8	Y
7	9-stage	Post-whaling split	1930	200	10	Y
8	9-stage	Post-whaling split	1930	200	12	Y
9	9-stage	Post-whaling split	1930	200	14	Y
10	9-stage	Post-whaling split	1930	200	16	Y
11	9-stage	Post-whaling split	1930	200	0	N
12	9-stage	Post-whaling split	1930	200	1	N
13	9-stage	Post-whaling split	1930	200	2	N
14	9-stage	Post-whaling split	1930	200	4	N
15	9-stage	Post-whaling split	1930	200	6	N
16	9-stage	Post-whaling split	1930	200	8	N
17	9-stage	Post-whaling split	1930	200	10	N
18	9-stage	Post-whaling split	1930	200	12	N
19	9-stage	Post-whaling split	1930	200	14	N
20	9-stage	Post-whaling split	1930	200	16	N
21	5-stage	Post-whaling split	1930	200	0	Y
22	5-stage	Post-whaling split	1930	200	1	Y
23	5-stage	Post-whaling split	1930	200	2	Y
24	5-stage	Post-whaling split	1930	200	4	Y
25	5-stage	Post-whaling split	1930	200	6	Y
26	5-stage	Post-whaling split	1930	200	8	Y
27	5-stage	Post-whaling split	1930	200	10	Y
28	5-stage	Post-whaling split	1930	200	12	Y
29	5-stage	Post-whaling split	1930	200	14	Y
30	5-stage	Post-whaling split	1930	200	16	Y
31	9-stage	Post-whaling split	1940	200	0	Y
32	9-stage	Post-whaling split	1950	200	0	Y
33	9-stage	Post-whaling split	1960	200	0	Y
34	9-stage	Post-whaling split	1970	200	0	Y
35	9-stage	Post-whaling split	1980	200	0	Y
36	9-stage	Post-whaling split	1990	200	0	Y
37	9-stage	Post-whaling split	1930	500	0	Y
38	9-stage	Post-whaling split	1930	1000	0	Y
39	9-stage	Post-whaling split	1930	1500	0	Y
40	9-stage	Post-whaling split	1930	2000	0	Y
41	9-stage	Post-whaling split	1930	3000	0	Y
42	9-stage	Post-whaling split	1930	5000	0	Y

* Pulse immigration consists of +20 animals in per year as reflected in the abundance in 2000 and 2001

Table 8. The number of samples collected per year from each stratum in the Lang *et al*. 2011 study.

Year	North	PCFG
1994	11	0
1995	0	0
1996	0	3
1997	1	3
1998	0	7
1999	1	0
2000	1	2
2001	27	0
2002	0	1
2003	12	3
2004	12	3
2005	10	1
2006	0	0
2007	0	0
2008	0	0
2009	0	13
2010	28	35
Total	103	71

Table 9. Summary of the haplotypic diversity, number of mtDNA haplotypes, and nucleotide diversity generated in the simulated ENP population. Only the results from the post-whaling split with immigration pulse models are shown as results were similar under all other models.

Matrices	Scenario	Immigration (Inds/Yr at K)	With pulse?	Median_ENP	Min_ENP	Max_ENP	Prop < than ENP	Prop > than ENP
Haplotypic diversity:								
ENP: H_{obs} =0.952								
9-stage	Post-whaling split	0	Y	0.948	0.883	0.973	61	39
9-stage	Post-whaling split	1	Y	0.951	0.869	0.973	52	48
9-stage	Post-whaling split	2	Y	0.950	0.878	0.974	56	44
9-stage	Post-whaling split	4	Y	0.950	0.874	0.974	57	43
9-stage	Post-whaling split	6	Y	0.950	0.890	0.972	56	44
9-stage	Post-whaling split	8	Y	0.948	0.869	0.973	64	36
9-stage	Post-whaling split	10	Y	0.949	0.878	0.977	62	38
9-stage	Post-whaling split	12	Y	0.950	0.786	0.971	54	46
9-stage	Post-whaling split	14	Y	0.948	0.862	0.973	61	39
9-stage	Post-whaling split	16	Y	0.950	0.877	0.977	52	48
Number of haplotypes:								
ENP: Nb_haps_{obs}=32								
9-stage	Post-whaling split	0	Y	33	25	47	36	52
9-stage	Post-whaling split	1	Y	33	24	44	33	57
9-stage	Post-whaling split	2	Y	33	23	46	40	54
9-stage	Post-whaling split	4	Y	33	22	44	37	54
9-stage	Post-whaling split	6	Y	34	24	42	25	62
9-stage	Post-whaling split	8	Y	33	22	45	38	55
9-stage	Post-whaling split	10	Y	33	20	45	38	54
9-stage	Post-whaling split	12	Y	33	20	43	37	57
9-stage	Post-whaling split	14	Y	33	23	44	38	52
9-stage	Post-whaling split	16	Y	33	25	45	31	56
Nucleotide diversity:								
ENP: $\prod_{obs}$ = 0.0142								
9-stage	Post-whaling split	0	Y	0.026	0.012	0.065	7	93
9-stage	Post-whaling split	1	Y	0.025	0.011	0.060	10	90
9-stage	Post-whaling split	2	Y	0.024	0.012	0.056	9	91
9-stage	Post-whaling split	4	Y	0.025	0.011	0.059	9	91
9-stage	Post-whaling split	6	Y	0.025	0.011	0.060	10	90
9-stage	Post-whaling split	8	Y	0.025	0.011	0.067	8	92
9-stage	Post-whaling split	10	Y	0.024	0.011	0.059	8	92
9-stage	Post-whaling split	12	Y	0.025	0.010	0.057	9	91
9-stage	Post-whaling split	14	Y	0.025	0.011	0.071	7	93
9-stage	Post-whaling split	16	Y	0.025	0.011	0.066	9	91

Figure 10. Histogram showing the distribution of p-values for a χ^2 test comparing the observed to the simulated haplotype distributions for the larger ENP population.

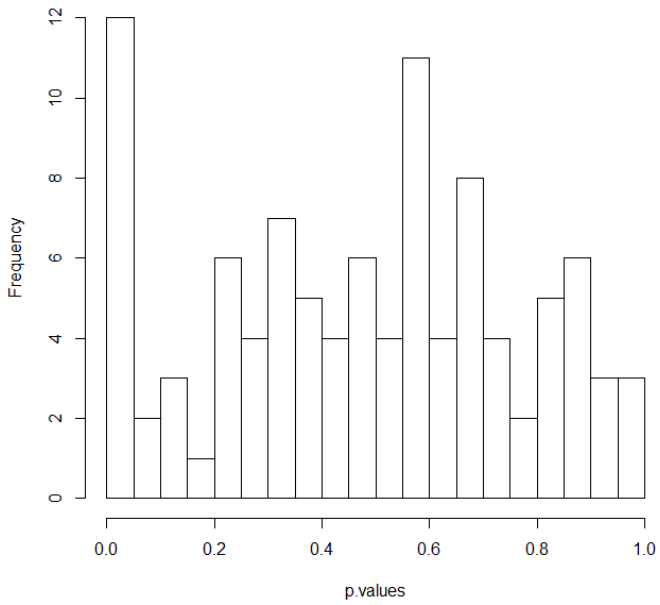
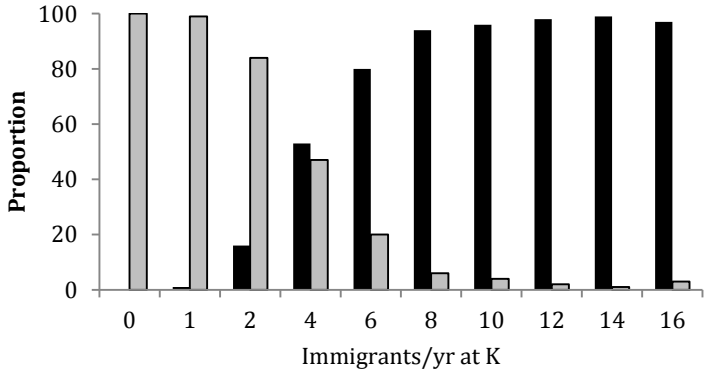
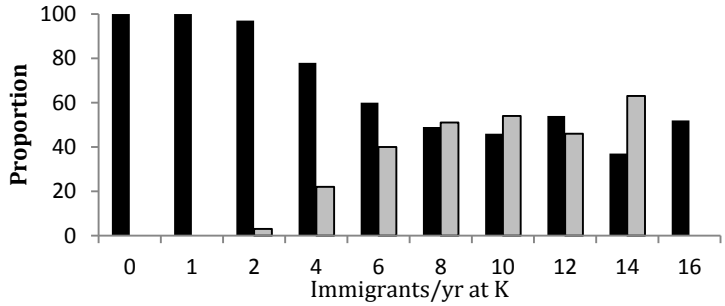


Figure 11. Graphical representation of the proportion of simulated values that are lower (shown in black) or higher (shown in gray) than the observed value generated from the empirical data. Simulated values are derived from the model incorporating a post-whaling split with pulse migration under the nine-stage matrices.

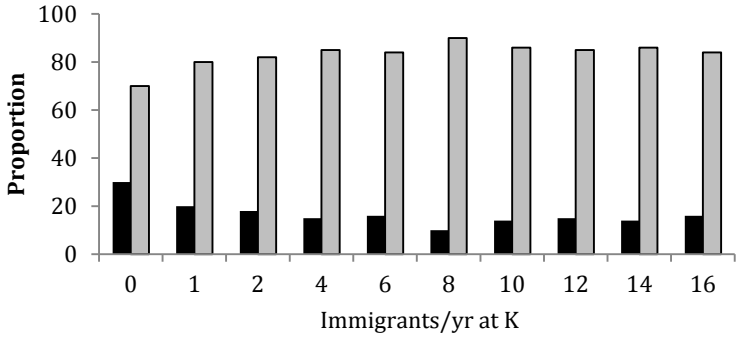
a.) Number of haplotypes:



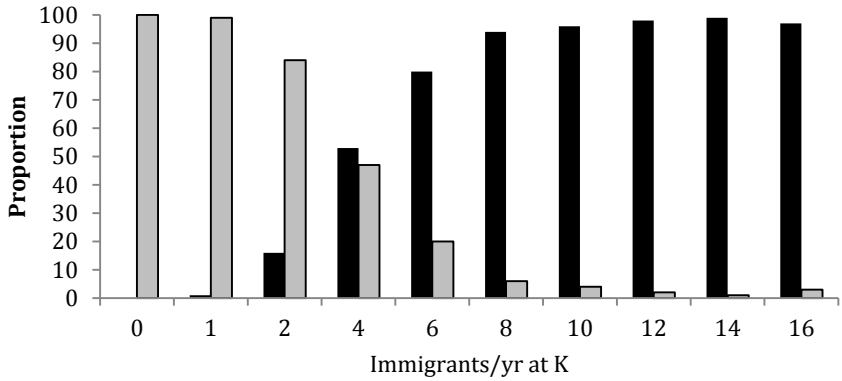
b.) Haplotypic diversity:



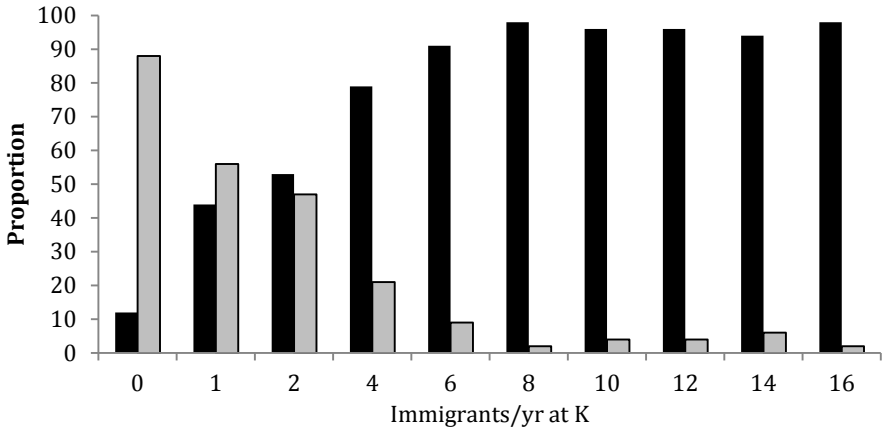
c.) Nucleotide diversity:



d.) F_{ST}:



e.) Φ_{ST}:



f.) χ^2/df:

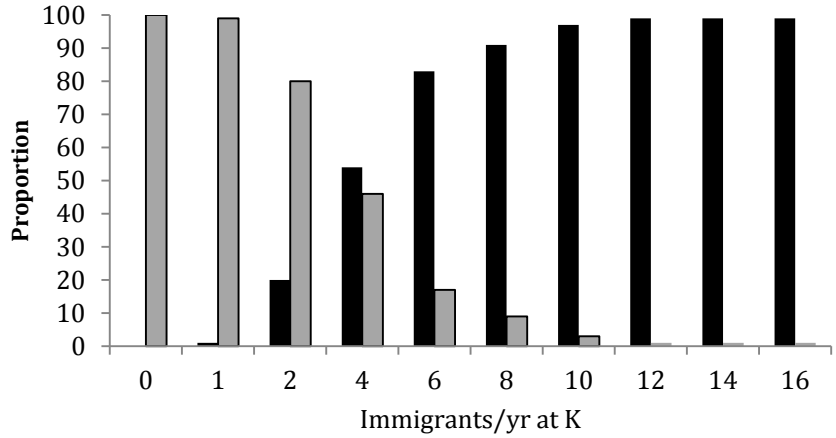


Table 12. Summary of number of mtDNA haplotypes in the simulated data for the PCFG. Scenarios highlighted in bold type produced results which were not consistent with those based on the empirical data.

PCFG: $Nb_haps_{obs}=23$

Matrices	Scenario	Immigrants/yr (at K)	With pulse?	Median_PCFG	Min_PCFG	Max_PCFG	Prop < PCFG	Prop > than obs
9-stage	**Post-whaling split**	**0**	**Y**	**12.0**	**6**	**19**	**100**	**0**
9-stage	**Post-whaling split**	**1**	**Y**	**16.6**	**11**	**26**	**96**	**2**
9-stage	Post-whaling split	2	Y	19.8	11	30	78	12
9-stage	Post-whaling split	4	Y	23.1	14	32	41	48
9-stage	Post-whaling split	6	Y	25.0	14	36	22	71
9-stage	Post-whaling split	8	Y	25.7	16	33	15	75
9-stage	Post-whaling split	10	Y	27.2	18	35	9	84
9-stage	Post-whaling split	12	Y	26.3	16	34	14	80
9-stage	Post-whaling split	14	Y	27.5	21	36	10	83
9-stage	Post-whaling split	16	Y	27.1	16	38	11	83
9-stage	**Post-whaling split**	**0**	**N**	**6.4**	**3**	**12**	**100**	**0**
9-stage	**Post-whaling split**	**1**	**N**	**12.5**	**6**	**20**	**100**	**0**
9-stage	**Post-whaling split**	**2**	**N**	**17.1**	**8**	**24**	**97**	**1**
9-stage	Post-whaling split	4	N	22.5	15	40	49	38
9-stage	Post-whaling split	6	N	23.9	12	32	36	52
9-stage	Post-whaling split	8	N	25.4	14	38	22	73
9-stage	Post-whaling split	10	N	25.8	17	37	27	66
9-stage	Post-whaling split	12	N	26.6	17	33	11	86
9-stage	Post-whaling split	14	N	27.0	17	36	11	84
9-stage	Post-whaling split	16	N	26.7	18	38	16	76
5-stage	**Post-whaling split**	**0**	**Y**	**10.4**	**6**	**16**	**100**	**0**
5-stage	**Post-whaling split**	**1**	**Y**	**15.0**	**7**	**23**	**99**	**0**
5-stage	Post-whaling split	2	Y	18.1	9	26	88	8
5-stage	Post-whaling split	4	Y	21.5	15	30	60	29
5-stage	Post-whaling split	6	Y	22.9	15	30	49	38
5-stage	Post-whaling split	8	Y	24.1	18	35	33	56
5-stage	Post-whaling split	10	Y	24.6	17	37	29	61
5-stage	Post-whaling split	12	Y	25.0	17	35	28	65
5-stage	Post-whaling split	14	Y	24.8	18	34	30	63
5-stage	Post-whaling split	16	Y	25.4	17	37	21	67

Table 13. Summary of haplotypic diversity in the simulated data for the PCFG. Scenarios highlighted in bold type produced results which were not consistent with those based on the empirical data.

PCFG: Hobs = 0.945

Matrices	Scenario	Immigration (Inds/Yr at K)	With pulse?	Median_ PCFG	Min_PCFG	Max_PCFG	Prop < than PCFG	Prop > than PCFG
9-stage	**Post-whaling split**	**0**	**Y**	**0.804**	**0.137**	**0.896**	**100**	**0**
9-stage	**Post-whaling split**	**1**	**Y**	**0.869**	**0.334**	**0.940**	**100**	**0**
9-stage	**Post-whaling split**	**2**	**Y**	**0.907**	**0.722**	**0.949**	**97**	**3**
9-stage	Post-whaling split	4	Y	0.933	0.699	0.970	78	22
9-stage	Post-whaling split	6	Y	0.939	0.810	0.971	60	40
9-stage	Post-whaling split	8	Y	0.945	0.848	0.972	49	51
9-stage	Post-whaling split	10	Y	0.948	0.857	0.974	46	54
9-stage	Post-whaling split	12	Y	0.943	0.825	0.969	54	46
9-stage	Post-whaling split	14	Y	0.951	0.842	0.972	37	63
9-stage	Post-whaling split	16	Y	0.944	0.866	0.979	52	48
9-stage	**Post-whaling split**	**0**	**N**	**0.754**	**0.344**	**0.867**	**100**	**0**
9-stage	**Post-whaling split**	**1**	**N**	**0.841**	**0.608**	**0.928**	**100**	**0**
9-stage	**Post-whaling split**	**2**	**N**	**0.888**	**0.748**	**0.946**	**99**	**1**
9-stage	Post-whaling split	4	N	0.932	0.788	0.974	84	16
9-stage	Post-whaling split	6	N	0.936	0.840	0.965	67	33
9-stage	Post-whaling split	8	N	0.941	0.835	0.974	59	41
9-stage	Post-whaling split	10	N	0.944	0.842	0.977	51	49
9-stage	Post-whaling split	12	N	0.946	0.870	0.971	45	55
9-stage	Post-whaling split	14	N	0.946	0.878	0.976	43	57
9-stage	Post-whaling split	16	N	0.947	0.841	0.976	48	52
5-stage	**Post-whaling split**	**0**	**Y**	**0.734**	**0.259**	**0.883**	**100**	**0**
5-stage	**Post-whaling split**	**1**	**Y**	**0.854**	**0.600**	**0.930**	**100**	**0**
5-stage	**Post-whaling split**	**2**	**Y**	**0.890**	**0.717**	**0.949**	**97**	**3**
5-stage	Post-whaling split	4	Y	0.915	0.752	0.958	92	8
5-stage	Post-whaling split	6	Y	0.929	0.768	0.963	79	21
5-stage	Post-whaling split	8	Y	0.931	0.796	0.965	74	26
5-stage	Post-whaling split	10	Y	0.934	0.720	0.973	78	22
5-stage	Post-whaling split	12	Y	0.935	0.747	0.968	64	36
5-stage	Post-whaling split	14	Y	0.937	0.823	0.965	67	33
5-stage	Post-whaling split	16	Y	0.934	0.834	0.971	68	32

Table 14. Summary of the mtDNA nucleotide diversity in the simulated data for the PCFG. Scenarios highlighted in bold type produced results which were not consistent with those based on the empirical data.

PCFG: ∏ obs = 0.0148

Matrices	Scenario	Immigration (Inds/Yr at K)	With pulse?	Median_PCFG	Min_PCFG	Max_PCFG	Prop < than PCFG	Prop > than PCFG
9-stage	Post-whaling split	0	Y	0.021	0.004	0.059	30	70
9-stage	Post-whaling split	1	Y	0.022	0.005	0.056	20	80
9-stage	Post-whaling split	2	Y	0.022	0.010	0.063	18	82
9-stage	Post-whaling split	4	Y	0.025	0.010	0.062	15	85
9-stage	Post-whaling split	6	Y	0.025	0.010	0.062	16	84
9-stage	Post-whaling split	8	Y	0.025	0.012	0.066	10	90
9-stage	Post-whaling split	10	Y	0.025	0.010	0.058	14	86
9-stage	Post-whaling split	12	Y	0.025	0.011	0.059	15	85
9-stage	Post-whaling split	14	Y	0.025	0.011	0.059	14	86
9-stage	Post-whaling split	16	Y	0.024	0.010	0.067	16	84
9-stage	Post-whaling split	0	N	0.020	0.002	0.080	32	68
9-stage	Post-whaling split	1	N	0.022	0.007	0.051	27	73
9-stage	Post-whaling split	2	N	0.023	0.007	0.064	18	82
9-stage	Post-whaling split	4	N	0.024	0.008	0.062	15	85
9-stage	Post-whaling split	6	N	0.025	0.010	0.064	13	87
9-stage	Post-whaling split	8	N	0.024	0.010	0.060	11	89
9-stage	Post-whaling split	10	N	0.026	0.010	0.074	14	86
9-stage	Post-whaling split	12	N	0.025	0.010	0.065	12	88
9-stage	Post-whaling split	14	N	0.025	0.011	0.059	12	88
9-stage	Post-whaling split	16	N	0.025	0.010	0.058	12	88
5-stage	Post-whaling split	0	Y	0.015	0.004	0.042	51	49
5-stage	Post-whaling split	1	Y	0.018	0.003	0.046	44	56
5-stage	Post-whaling split	2	Y	0.018	0.005	0.048	37	63
5-stage	Post-whaling split	4	Y	0.017	0.005	0.051	27	73
5-stage	Post-whaling split	6	Y	0.019	0.005	0.054	27	73
5-stage	Post-whaling split	8	Y	0.020	0.006	0.048	31	69
5-stage	Post-whaling split	10	Y	0.020	0.004	0.053	31	69
5-stage	Post-whaling split	12	Y	0.020	0.005	0.052	27	73
5-stage	Post-whaling split	14	Y	0.021	0.005	0.052	29	71
5-stage	Post-whaling split	16	Y	0.020	0.006	0.050	25	75

Table 15. Summary of F_{ST} values generated in the comparison of simulated data representing the PCFG and the larger ENP population. Scenarios highlighted in bold type produced results which were not consistent with those based on the empirical data.

$F_{ST\ obs}$ = 0.012

Matrices	Scenario	Immigration (Inds/Yr at K)	With pulse?	Median	Min	Max	Prop > than obseved	Prop > than observed
9-stage	**post-whaling split**	**0**	**Y**	**0.069**	**0.019**	**0.254**	**0**	**100**
9-stage	**post-whaling split**	**1**	**Y**	**0.040**	**0.005**	**0.189**	**1**	**99**
9-stage	post-whaling split	2	Y	0.023	0.002	0.096	16	84
9-stage	post-whaling split	4	Y	0.011	-0.004	0.033	53	47
9-stage	post-whaling split	6	Y	0.005	-0.005	0.030	80	20
9-stage	post-whaling split	8	Y	0.002	-0.004	0.017	94	6
9-stage	**post-whaling split**	**10**	**Y**	**0.002**	**-0.007**	**0.021**	**96**	**4**
9-stage	**post-whaling split**	**12**	**Y**	**0.001**	**-0.006**	**0.019**	**98**	**2**
9-stage	**post-whaling split**	**14**	**Y**	**0.001**	**-0.007**	**0.013**	**99**	**1**
9-stage	**post-whaling split**	**16**	**Y**	**0.001**	**-0.007**	**0.020**	**97**	**3**
9-stage	**post-whaling split**	**0**	**N**	**0.099**	**0.029**	**0.295**	**0**	**100**
9-stage	**post-whaling split**	**1**	**N**	**0.051**	**0.020**	**0.146**	**0**	**100**
9-stage	post-whaling split	2	N	0.032	0.006	0.098	9	91
9-stage	post-whaling split	4	N	0.012	-0.004	0.058	47	53
9-stage	post-whaling split	6	N	0.008	-0.003	0.035	71	29
9-stage	post-whaling split	8	N	0.003	-0.004	0.025	91	9
9-stage	post-whaling split	10	N	0.003	-0.006	0.022	93	7
9-stage	**post-whaling split**	**12**	**N**	**0.001**	**-0.007**	**0.015**	**98**	**2**
9-stage	**post-whaling split**	**14**	**N**	**0.002**	**-0.007**	**0.016**	**98**	**2**
9-stage	**post-whaling split**	**16**	**N**	**0.001**	**-0.006**	**0.048**	**92**	**8**
5-stage	**post-whaling split**	**0**	**Y**	**0.101**	**0.018**	**0.323**	**0**	**100**
5-stage	post-whaling split	1	Y	0.044	0.007	0.150	6	94
5-stage	post-whaling split	2	Y	0.025	-0.002	0.097	18	82
5-stage	post-whaling split	4	Y	0.009	-0.004	0.045	64	36
5-stage	post-whaling split	6	Y	0.004	-0.008	0.040	87	13
5-stage	post-whaling split	8	Y	0.002	-0.004	0.021	90	10
5-stage	post-whaling split	10	Y	0.003	-0.005	0.025	94	6
5-stage	**post-whaling split**	**12**	**Y**	**0.001**	**-0.007**	**0.014**	**96**	**4**
5-stage	**post-whaling split**	**14**	**Y**	**0.001**	**-0.006**	**0.016**	**98**	**2**
5-stage	**post-whaling split**	**16**	**Y**	**0.000**	**-0.006**	**0.019**	**97**	**3**

Table 16. Summary of ϕ_{ST} values generated in the comparison of simulated data representing the PCFG and the larger ENP population. Scenarios highlighted in bold type produced results which were not consistent with those based on the empirical data.

ϕ_{STobs}=0.023

Matrices	Scenario	Immigration (Inds/Yr at K)	With pulse?	Median	Min	Max	Prop > than observed	Prop < than observed
9-stage	Arch1_sc1	0	Y	0.065	0.000	0.332	12	88
9-stage	Arch1_sc2	1	Y	0.030	-0.002	0.240	44	56
9-stage	Arch1_sc3	2	Y	0.021	-0.004	0.080	53	47
9-stage	Arch1_sc4	4	Y	0.007	-0.009	0.074	79	21
9-stage	Arch1_sc5	6	Y	0.000	-0.011	0.062	91	9
9-stage	**Arch1_sc6**	**8**	**Y**	**-0.001**	**-0.011**	**0.036**	**98**	**2**
9-stage	**Arch1_sc7**	**10**	**Y**	**0.000**	**-0.011**	**0.028**	**96**	**4**
9-stage	**Arch1_sc8**	**12**	**Y**	**-0.003**	**-0.011**	**0.055**	**96**	**4**
9-stage	Arch1_sc9	14	Y	0.000	-0.011	0.044	94	6
9-stage	**Arch1_sc9**	**16**	**Y**	**-0.001**	**-0.010**	**0.032**	**98**	**2**
9-stage	Arch1_sc1	0	N	0.090	0.005	0.439	7	93
9-stage	Arch1_sc2	1	N	0.043	0.002	0.237	23	77
9-stage	Arch1_sc3	2	N	0.026	-0.008	0.187	48	52
9-stage	Arch1_sc4	4	N	0.009	-0.010	0.064	84	16
9-stage	Arch1_sc5	6	N	0.007	-0.009	0.087	86	14
9-stage	Arch1_sc6	8	N	0.001	-0.011	0.071	87	13
9-stage	Arch1_sc7	10	N	-0.002	-0.011	0.051	93	7
9-stage	Arch1_sc8	12	N	-0.002	-0.011	0.037	93	7
9-stage	Arch1_sc9	14	N	-0.001	-0.010	0.040	93	7
9-stage	Arch1_sc10	16	N	-0.002	-0.010	0.092	94	6
5-stage	Arch1_sc1	0	Y	0.099	0.007	0.501	7	93
5-stage	Arch1_sc2	1	Y	0.032	-0.004	0.321	40	60
5-stage	Arch1_sc3	2	Y	0.014	-0.008	0.181	67	33
5-stage	Arch1_sc4	4	Y	0.005	-0.007	0.068	83	17
5-stage	Arch1_sc5	6	Y	0.002	-0.010	0.044	95	5
5-stage	Arch1_sc6	8	Y	0.000	-0.010	0.108	88	12
5-stage	**Arch1_sc7**	**10**	**Y**	**0.001**	**-0.010**	**0.051**	**95**	**5**
5-stage	**Arch1_sc8**	**12**	**Y**	**-0.003**	**-0.011**	**0.045**	**99**	**1**
5-stage	Arch1_sc9	14	Y	-0.002	-0.010	0.044	94	6
5-stage	Arch1_sc9	16	Y	-0.002	-0.011	0.042	94	6

Table 17. Summary of χ^2/df values generated in the comparison of simulated data representing the PCFG and the larger ENP population. Scenarios highlighted in bold type produced results which were not consistent with those based on the empirical data.

$\chi^2/df_{obs} = 1.42$

Matrices	Scenario	Immigration (Inds/Yr at K)	With pulse?	Median	Min	Max	Prop.< than observed	Prop.> than observed
9-stage	**Arch1_sc1**	**0**	**Y**	**2.65**	**1.57**	**3.66**	**0**	**100**
9-stage	**Arch1_sc2**	**1**	**Y**	**2.05**	**1.41**	**3.49**	**1**	**99**
9-stage	Arch1_sc3	2	Y	1.70	1.00	2.87	20	80
9-stage	Arch1_sc4	4	Y	1.41	0.85	2.13	54	46
9-stage	Arch1_sc5	6	Y	1.19	0.74	1.71	83	17
9-stage	Arch1_sc6	8	Y	1.11	0.77	1.69	91	9
9-stage	**Arch1_sc7**	**10**	**Y**	**1.07**	**0.66**	**1.51**	**97**	**3**
9-stage	**Arch1_sc8**	**12**	**Y**	**1.05**	**0.63**	**1.53**	**99**	**1**
9-stage	**Arch1_sc9**	**14**	**Y**	**1.06**	**0.59**	**1.43**	**99**	**1**
9-stage	**Arch1_sc9**	**16**	**Y**	**1.03**	**0.74**	**1.55**	**99**	**1**
9-stage	**Arch1_sc1**	**0**	**N**	**3.23**	**1.87**	**4.73**	**0**	**100**
9-stage	**Arch1_sc2**	**1**	**N**	**2.38**	**1.52**	**3.74**	**0**	**100**
9-stage	Arch1_sc3	2	N	1.93	1.25	3.21	9	91
9-stage	Arch1_sc4	4	N	1.47	0.94	2.12	43	57
9-stage	Arch1_sc5	6	N	1.30	0.81	2.02	73	27
9-stage	Arch1_sc6	8	N	1.16	0.71	1.76	84	16
9-stage	Arch1_sc7	10	N	1.14	0.71	1.62	91	9
9-stage	**Arch1_sc8**	**12**	**N**	**1.07**	**0.70**	**1.80**	**95**	**5**
9-stage	**Arch1_sc9**	**14**	**N**	**1.08**	**0.76**	**1.58**	**96**	**4**
9-stage	**Arch1_sc10**	**16**	**N**	**1.04**	**0.71**	**1.77**	**95**	**5**
5-stage	**Arch1_sc1**	**0**	**Y**	**2.87**	**1.50**	**4.41**	**0**	**100**
5-stage	**Arch1_sc2**	**1**	**Y**	**2.16**	**1.07**	**3.90**	**5**	**95**
5-stage	Arch1_sc3	2	Y	1.71	0.92	2.62	18	82
5-stage	Arch1_sc4	4	Y	1.32	0.82	1.89	64	36
5-stage	Arch1_sc5	6	Y	1.20	0.55	1.64	93	7
5-stage	Arch1_sc6	8	Y	1.12	0.68	1.67	94	6
5-stage	Arch1_sc7	10	Y	1.12	0.71	1.67	92	8
5-stage	**Arch1_sc8**	**12**	**Y**	**1.04**	**0.69**	**1.59**	**97**	**3**
5-stage	**Arch1_sc9**	**14**	**Y**	**1.02**	**0.64**	**1.47**	**98**	**2**
5-stage	**Arch1_sc9**	**16**	**Y**	**1.01**	**0.70**	**1.48**	**99**	**1**

Table 18. Measures of haplotypic diversity, number of haplotypes, and F_{ST} values produced in simulations incorporating a split of the PCFG between 1940 and 1990. These simulations utilized a model incorporating pulse migration and no annual immigration into the PCFG. Scenarios highlighted in bold type produced results which were not consistent with those based on the empirical data.

Haplotypic diversity:
PCFG: H_{obs} = 0.945

Year of split	Median_PCFG	Min_PCFG	Max_PCFG	Prop < than PCFG	Prop > than PCFG
1940	**0.863**	**0.591**	**0.925**	**100**	**0**
1950	**0.884**	**0.721**	**0.932**	**100**	**0**
1960	**0.905**	**0.766**	**0.950**	**98**	**2**
1970	0.927	0.821	0.963	80	20
1980	0.939	0.804	0.969	68	32
1990	0.942	0.883	0.969	55	45
Number of haplotypes					
PCFG: Nb_{obs}=23					
1940	**14**	**7**	**20**	**100**	**0**
1950	**16**	**10**	**23**	**99**	**0**
1960	**17**	**11**	**23**	**96**	**0**
1970	21.5	12	28	65	22
1980	24	15	33	33	57
1990	25	17	34	25	68
F_{ST}					
$F_{ST\ obs}$ = 0.012					
1940	**0.046**	**0.008**	**0.177**	**1**	**99**
1950	**0.036**	**0.011**	**0.104**	**1**	**99**
1960	0.022	0.003	0.077	16	84
1970	0.009	-0.005	0.029	64	36
1980	0.006	-0.003	0.035	84	16
1990	**0.003**	**-0.005**	**0.015**	**97**	**3**

Table 19. Measures of haplotypic diversity, number of haplotypes, and F_{ST} values produced in simulations incorporating a carrying capacity for the PCFG ranging from 500 to 5000 animals. These simulations utilized a model incorporating pulse migration and no annual immigration into the PCFG. Scenarios highlighted in bold type produced results which were not consistent with those based on the empirical data.

Haplotypic diversity:
PCFG: H_{obs} = 0.945

K-PCFG	Median_PCFG	Min_PCFG	Max_PCFG	Prop < than PCFG	Prop > than PCFG
500	**0.876**	**0.714**	**0.937**	**100**	**0**
1000	**0.911**	**0.808**	**0.949**	**96**	**4**
1500	0.922	0.818	0.959	90	10
2000	0.932	0.765	0.966	72	28
3000	0.934	0.841	0.965	73	27
5000	0.945	0.849	0.967	47	53
Number of haplotypes					
PCFG: Nb_{obs}=23					
500	**14**	**7**	**24**	**99**	**1**
1000	**17**	**9**	**23**	**98**	**0**
1500	20	12	27	90	5
2000	20.5	15	28	69	21
3000	22	15	32	51	40
5000	26	16	34	20	73
F_{ST}					
F_{ST}obs = 0.012					
500	**0.037**	**0.013**	**0.111**	**0**	**100**
1000	0.021	0.006	0.058	21	79
1500	0.015	0.002	0.044	39	61
2000	0.012	-0.002	0.041	52	48
3000	0.007	-0.003	0.025	74	26
5000	0.006	-0.004	0.019	91	9

Table 20. Example trajectories for simulations with K_{PCFG} set between 500 and 5000. Note that scale of y-axis differs across figures.

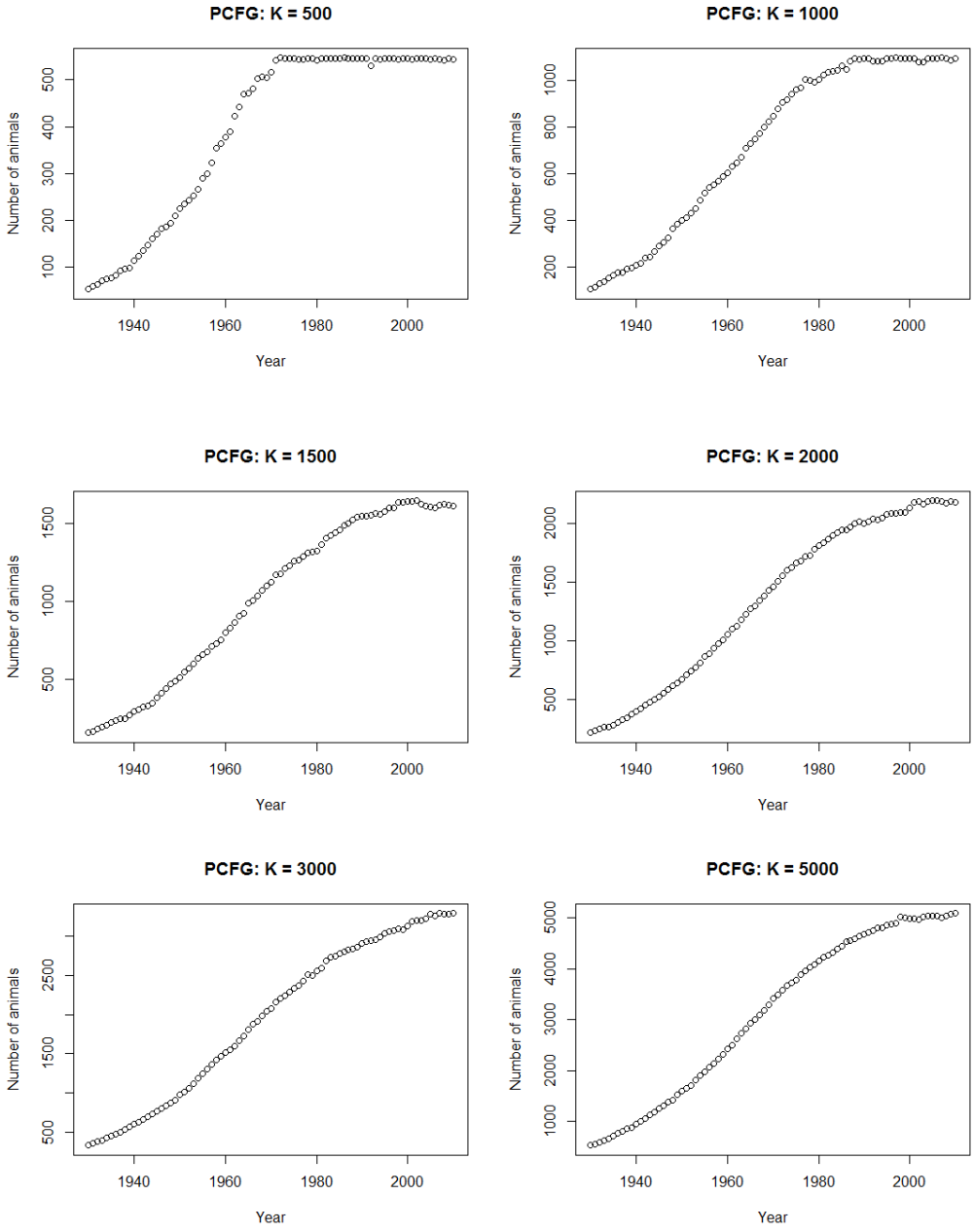


Table 21. Median PCFG abundance in 2010 for scenarios with K_{PCFG} set between 500 and 5000.

K_{PCFG}	N_{2010} (median and 90% range)
500	501 (466 – 542)
1000	998 (923-1063)
1500	1496 (1391-1588)
2000	1994(1864-2080)
3000	3002(2831-3128)
5000	4945 (4790-5095)

Table 22. The expected number of immigrants/year at the cross-over point under the scenarios with and without pulse immigration. The cross-over is derived by calculating the point at which 50% of the simulation replicates produce values for each summary statistic that are higher than that for the empirical data.

Matrices	Timing of split	Pulse migration	Number of haplotypes	Haplotypic diversity	F_{ST}	Φ_{ST}	χ^2/df
9-stage	Post-whaling split	Y	3.77	7.82	3.84	1.67	3.76
9-stage	Post-whaling split	N	4.35	10.25	4.25	2.11	4.47
5-stage	Post-whaling split	Y	6.76	-----	3.39	1.37	3.39

Appendix:

This appendix includes additional tables and figures aimed at understanding how well the model underlying our simulations is mimicking reality and/or the IR trial structure.

Table A1. Generation time estimates as calculated using different maximum ages for both 5-stage TOSSM and 9-stage matrices.

	5-stage matrices		9-stage matrices	
Max Age	K	ZPD	K	ZPD
40	19.52	16.92	21.05	20.59
50	21.68	18.74	23.65	23.86
100	26.04	22.25	28.29	32.87
150	26.64	22.69	28.61	34.93
1000	26.71	22.74	28.63	35.27

Table A2. The number of calves produced per year in simulated datasets at K as compared to data derived from photo-identification studies

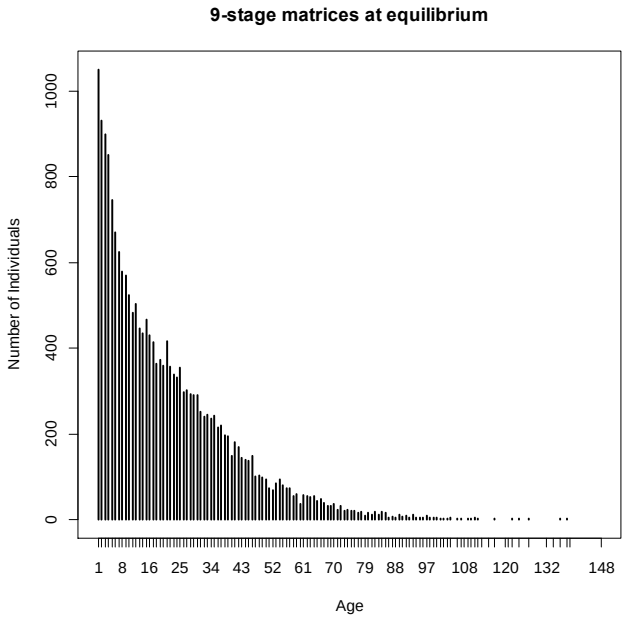
Source	Abundance (median with range):	Number of calves/yr	% Calves
5-stage matrices:	197(156-218)	11 (2-31)	6%
9-stage matrices:	195 (161-217)	10 (2-23)	5%
Photo-identification estimates	194 †	3 (0-9)††	2%

†Annex F, IWC 2011

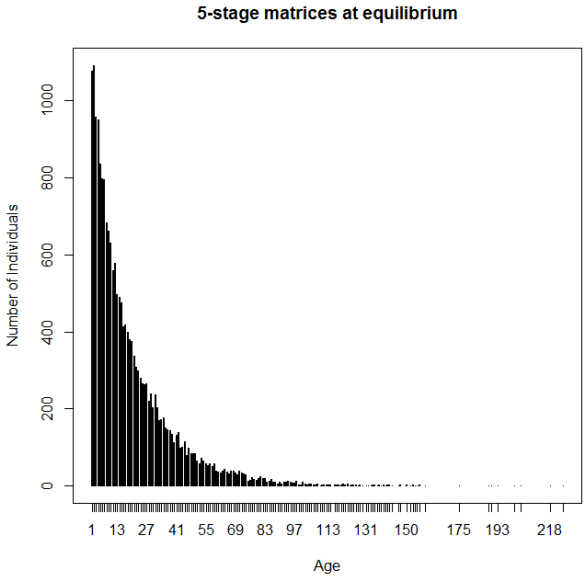
†† Calambokidis *et al.* 2008 (data from 1998-2008)

Figure A1. Age distribution in simulated datasets (note different x-axis scales):

a) Nine-stage matrices:



a.) Five-stage matrices:



Delineating Patterns of Male Reproductive Success in the Western Gray Whale (*Eschrichtius robustus*) Population

AIMEE R. LANG [1], DAVID W. WELLER [1], RICHARD G. LEDUC [1], ALEXANDER M. BURDIN [2, 3], AND ROBERT L. BROWNELL, JR [4].

[1] Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, La Jolla, California 92037, U.S.A

[2] Kamchatka Branch of Pacific Institute of Geography, Far East Division - Russian Academy of Sciences, Petropavlovsk, Kamchatka, 683000, Russia

[3] University of Alaska Fairbanks, Fairbanks, Alaska 99775 U.S.A

[4] Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, Pacific Grove, California 93950, U.S.A

Contact email: aimee.lang@noaa.gov

ABSTRACT

Monitoring of the critically endangered western gray whale population on its primary feeding ground off Sakhalin Island, Russia, has led to the collection of genetic samples from 83% of animals photographically identified from this area. The high proportion of sampled animals provides a rare opportunity to learn more about the mating system of a baleen whale species as well as to identify factors potentially influencing this small population's recovery. Utilizing a panel of 13 microsatellite loci, paternity analysis was conducted to identify breeding males and assess the distribution of male reproductive success. Using biopsy samples from 57 mother-calf pairs and 42 candidate males, putative fathers were identified for 46 to 53% of calves sampled in the population between 1995 and 2007. Although most males were assigned paternity of only one calf, a mild skew in the distribution of reproductive success was identified, with some males siring three to four calves over the 12 seasons of the study. Eighteen putative fathers were identified, and analysis of relatedness patterns among those calves which were not assigned a father suggested that an additional 15 males may be contributing to reproduction in the population. The relatively low success rate of the paternity analysis, in comparison to expectations derived from the percentage of photographically identified animals which have been sampled, indicates that some reproductive males may not use the Sakhalin feeding area on a regular basis. While the high percentage of "missing fathers" in this small population is puzzling, these results provide evidence that many of the animals identified on the Sakhalin feeding ground interbreed, presumably while sharing a common migratory route.

INTRODUCTION

Little is known about the mating systems of most species of baleen whales. Differences in the reproductive cycles of males and females suggest that mysticetes, like the majority of mammals, are polygynous (Clutton-Brock 1989, Mesnick and Ralls 2009). In most baleen whale species, females are restricted to producing a calf every two to three years due to the energetic constraints imposed by gestation and lactation, while males have potential reproductive rates that are much higher. These differences result in a skew in the number of reproductively available females relative to reproductively active males (*i.e.*, the operational sex ratio), increasing the extent to which males must compete for females and permitting variance in male reproductive success to develop. As has been proposed for aquatically mating pinnipeds (Bartholomew 1970), however, the degree of polygyny which can be established in baleen whales is likely

limited by the marine environment in which they breed, as females are highly mobile and resources are difficult to defend.

Much of the information available on mysticete mating systems has been derived from behavioral observations and the collection of physiological data. In humpback whales (*Megaptera novaeangliae*), the use of alternative mating tactics by males, including physical competition for access to females as well as "escorting" of females (Pack *et al.* 1998, Clapham 1996), has been documented and suggests a mechanism by which differential reproductive success might be generated in this species. In North Atlantic right whales (*Eubalaena glacialis*), males aggregate in large active groups and appear to compete for access to a female (Kraus and Hatch 2001). In addition, right whales, along with bowhead and gray whales, have high testes-to-body weight ratios, indicating that sperm competition is an important strategy utilized by males (Brownell and Ralls 1986). The existence of both pre- and post-copulatory competition for fertilization in this species suggest that male reproductive success may not be evenly distributed across individuals.

While these studies have proven valuable in elucidating male mating strategies, they do not provide information on which males in a population successfully breed or how male reproductive success is allocated among individuals, which can have important implications for the maintenance of genetic diversity in small populations. The effective size of a population is determined not only by the number of animals contributing to successive generations, but also by the distribution of reproductive success among those individuals. High variance in reproductive success acts to decrease the effective size of the population (Hedrick 2005), thereby increasing the rate at which genetic diversity is lost. In addition, identifying reproductive pairs within populations can increase our understanding of the role that mate choice may play in inbreeding avoidance (*e.g.,* Archie *et al.* 2007) as well as of the relationship between offspring fitness and parental relatedness (*e.g.,* Amos *et al.* 2001).

Genetic analysis of paternity has the potential to provide detailed information on the reproductive success of individual males. In baleen whales, these analyses have thus far been limited to humpback (Clapham and Palsboll 1997, Nielsen *et al.* 2001, Cerchio *et al.* 2005) and North Atlantic right whales (Frasier *et al.* 2007). In studies of both species, the genetic results contributed valuable insight into patterns of reproduction which were not readily apparent based on previous studies. In humpback whales, the distribution of male reproductive success deviated from that predicted under random mating, but the variation was lower than expected given the apparent skew in the operational sex ratio and the degree of male competition observed (Cerchio *et al.* 2005). In North Atlantic right whales, males demonstrated high variance in reproductive success when compared to other aquatically-mating marine mammals, although the variance was low relative to those breeding terrestrially (Frasier *et al.* 2007). These results support the idea that sperm competition creates differential reproductive success among males, but that the lack of control over resources and mates in the aquatic environment limits the degree of polygyny which could develop (Frasier *et al.* 2007). Results from this study also suggested that the low level of genetic variability in this species may be influencing reproductive success. Calves for which both parents were identified had significantly higher levels of genetic diversity than expected under random mating, indicating that successful mating only occurs between individuals that are genetically dissimilar (Frasier 2005).

In gray whales, behavioral observations of multiple males mating with a female suggest a polygynous or promiscuous mating system (Jones and Swartz 1984). While mating behavior has been observed in all seasons, fertilization is thought to primarily occur during the southbound migration (Rice and Wolman 1971). Information from fetal growth rates suggests that females come into estrus during an approximately three-week period extending from late November to early December at the start of the southbound migration. Most females are thought to conceive during this period, although some females may ovulate approximately 40 days later when on or near the wintering grounds. Increased testes weight and the larger seminiferous tubules of males on the southbound migration, as compared to those of northbound and summer feeding males, also support a peak in spermatogenic activity in late autumn to early winter (Rice and Wolman 1971).

As aforementioned, the high testes weight to body weight ratios found in gray whales suggest that this species utilizes sperm competition as a strategy for males to obtain successful fertilizations (Brownell and Ralls 1986), raising the possibility that, like North Atlantic right whales, some variance in male

reproductive success may exist. Genetic paternity analysis would provide information valuable in assessing this possibility. Such a study would be difficult to conduct in the eastern gray whale population, given its large size and the relatively small proportion of animals which have been sampled. However, the population of gray whales found in the western North Pacific, which is both small and well-sampled, presents a valuable opportunity to conduct such an analysis. This population of whales was nearly extirpated by commercial whaling, which continued through at least 1966 (Brownell and Chun 1977, Weller *et al.* 2002). Unlike its eastern counterpart, which currently numbers approximately 22,000 animals (Punt and Wade 2010), the western population has remained severely depleted and is estimated to contain approximately 130 individuals of one year or older (Cooke *et al.* 2008). Western gray whales are listed as Critically Endangered by the IUCN (Baillie *et al.* 2004). Anthropogenic threats potentially jeopardizing the population's recovery include extensive oil and gas development on the population's primary feeding area (Weller *et al.* 2002, Reeves *et al.* 2005) and mortality of whales associated with entrapment in fishing gear during their migration past Japan (Brownell *et al.* 2007).

Much of what is known about this small population of whales has been derived from long-term studies on their primary feeding ground located in the coastal waters of northeastern Sakhalin Island, Russia. Following a pilot study in the summer of 1995, a monitoring program was initiated in 1997 and continues to date. Extensive photo-identification records collected as part of this effort have shown that western gray whales exhibit a high degree of seasonal site fidelity to the Sakhalin feeding area (Weller *et al.* 1999, 2008a). This site fidelity, in combination with the population's small size, has facilitated the collection of genetic samples from a high percentage (~83%) of animals identified on the feeding ground. Analysis of these samples using both mitochondrial DNA (mtDNA) and a panel of microsatellite markers has shown that the western population is genetically distinct from the much larger eastern gray whale population (LeDuc *et al.* 2002, Lang *et al*. 2010).

Given the high percentage of sampled animals and the availability of extensive sighting records for most individuals, genetic analysis of paternity in the western gray whale population will not only contribute to our understanding of mysticete mating systems but may also provide information important in assessing factors influencing the population's recovery. The low number of known reproductive females (n=24 between 1995 and 2007) has raised concern for the population's capacity for growth and recovery (Weller *et al.* 2002, 2008a). Little has been known, however, about the number of males which are breeding in the population, or how reproductive success is distributed among these animals. Although previous studies have suggested that the western gray whale population has retained relatively high levels of genetic diversity (Lang *et al*. 2010), information about factors potentially influencing the effective size of the population may provide insight into the past and future maintenance of genetic diversity in this population.

In addition, limited information is available about the movements of western gray whales outside of their feeding range. The wintering ground(s) for this population is suspected to be off the southern coast of China, but the location has yet to be confirmed. Sightings, strandings, and entrapments suggest that gray whales migrate along both the eastern and western coasts of Japan, as well as along mainland Asia (Brownell *et al.* 2008). Although photo-identification records have identified one of the animals entrapped off the Pacific coast of Japan as an animal known to utilize the Sakhalin feeding ground (Weller *et al.* 2008b), thus far this is the only established link between a feeding area and a migratory pathway. Given that mating is thought to occur primarily while on migratory routes, the use of paternity analysis to identify pairs of interbreeding animals will provide information on which animals have utilized the same areas for migration and potentially overwintering.

Finally, questions have been raised about the isolation of this small population. Although the eastern and western populations have traditionally been considered geographically separate, in recent years gray whales have been sighted in feeding areas located off the eastern coast of Kamchatka. Some of these whales are known to have visited the Sakhalin feeding area, while others are of unknown origin (Tyurneva *et al.* 2009). These sightings have raised speculation about possible overlap among feeding regions for the eastern and western populations. In addition, although genetic studies have confirmed that eastern and western gray whale populations are distinct, the level of nuclear differentiation between the two populations is relatively low, suggesting that some intermixing of eastern and western animals could be occurring (Lang *et al*. 2010). Such intermixing could entail the use of the Sakhalin feeding area by eastern

whales which then return to the eastern Pacific, or it might include some limited amount of interbreeding between the two populations. Although the lack of extensive sampling of the eastern population limits comparisons across populations, the proportion of reproduction that can be attributed to animals sampled off Sakhalin will provide some insight into the extent and nature of any interbreeding which may be occurring.

Between 1995 and 2007, 57 mother-calf pairs and 42 males of unknown age were sampled on the feeding ground off Sakhalin. These samples represent 90% of identified mother-calf pairs, and 83% (n=142) of all animals identified on the Sakhalin feeding ground during the study period. Using these samples and a suite of 13 microsatellite markers, a genetic paternity assessment was conducted for this population. The primary objectives of this work were to identify the number of males contributing to reproduction in the western population and to evaluate the distribution of reproductive success among these males. The results of the assessment not only expand our knowledge of mating systems of baleen whales, but also increase our understanding of factors potentially affecting the recovery of the western gray whale.

METHODS

Sample collection

Following a Russian-American pilot effort in 1995, a collaborative Russia-U.S. research program was established in 1997 which focuses on individual monitoring of western gray whales using photo-identification and genetic sampling (Weller *et al.*, 1999, 2002). Field studies are carried out annually during summer months on the primary feeding ground off the northeastern coast of Sakhalin Island, Russia. Surveys (n=337) of this area have led to the photographic identification of 169 whales; genetic samples for 141 (83.4%) of the identified whales have been collected through biopsy-darting (Weller *et al.* 2008).

The genetic sample set includes samples collected from 57 animals which were first identified as calves (approximately 6-8 months of age) on the feeding ground and which are linked to known and genetically sampled mothers. Animals were identified as calves based on their small body size (approximately one third that of an adult), and, in most cases, their constant affiliation with a particular adult whale (Weller *et al.* 1999). For 54 of the calves, identification of the mother was first established via behavioral observations and confirmed by genetic analysis. Three calves were already separated from their mothers when first identified; in these cases the mother was identified using genetic parentage analysis alone.

The sex of all animals was determined using molecular methods (detailed in Lang *et al*. 2010). Forty-two animals were identified as males of unknown age and were included as candidate fathers in the analysis. Males first identified as calves which may have reached sexual maturity during the study period were also included as potential candidate males. Although it is not known at what age male western gray whales first reproduce, the earliest estimates of age at sexual maturity in eastern gray whales is five years (IWC, 1993). Therefore, male calves were included as potential candidates for those years in which they would have been at least five years of age and potentially capable of reproduction in the preceding season when fertilization would have occurred. To incorporate the changing number of candidates as calves from earlier years of the study became potentially sexually mature, paternity analysis was run separately for each year of the study.

Analysis

Samples utilized in the study had been genotyped at 13 microsatellite loci for use in the previous study; the protocols used to produce this data are detailed in Lang *et al*. 2010. Paternity was assessed using the likelihood-based approach as implemented in CERVUS v3.0 (Marshall *et al.* 1998, Kalinowski *et al.* 2007). The objective of this analysis was to identify the candidate father which was statistically the most likely to be the true parent of the calf. The likelihood for each candidate was calculated using information on the allele frequencies in the population, such that a candidate male which shared a rare allele at a given locus with the calf was considered to be more likely to be the true father than a candidate sharing a common allele with the calf. The number of mismatches between the genotype of the father and the genotype of the calf (after removal of the maternal contribution to the calf's genotype) was also utilized in the likelihood analysis.

Simulations were used to generate critical values allowing confidence in the assignments to be evaluated. These simulations used the allele frequency data from the population being analyzed to generate simulated genotypes for parent-offspring pairs and unrelated individuals. The simulated data were then used to calculate the likelihood of parentage for the true parent as well as for each of the unrelated candidate parents for the simulated offspring. For each candidate identified as the most likely parent (whether or not it represented the true parent), the difference in likelihood scores between that individual and the next most likely individual, referred to as Δ , was recorded. The distribution of Δ scores where the identified parent was the true parent with the distribution of scores where the identified parent was an unrelated individual was then compared to determine a critical value, such that the identified Δ was sufficiently large to distinguish true parents from unrelated parents at a specified (e.g. 95%) level of confidence.

One of the strengths of the CERVUS analysis is that it is able to account for potential errors in the dataset. Genotyping errors, mutations, or null alleles may create mismatches between the genotypes of candidate fathers and offspring, such that the true father might be falsely excluded when such factors are not taken into account. By incorporating an estimated error rate into the simulations run by CERVUS, the potential for such false exclusions is reduced. Here we ran the CERVUS analysis utilizing two different error rates. The first analysis assumed that no errors were present in the dataset, but this differs from a strict exclusionary approach in that likelihood scores were used to differentiate between candidate parents when more than one male had genotypes which matched that of the mother-calf dyad at all loci. The second analysis utilized an error rate of 0.01, allowing candidates to be assigned as putative fathers which had genotypes mismatching that of the mother-calf dyad at up to two loci. Additional parameters used in the simulations included 1) the number of simulated genotypes = 10,000, 2) proportion of loci typed = 0.99 (the true proportion), 3) minimum number of loci typed = 12, and 4) proportion of candidate males sampled=0.50. Given that the error rate and the proportion of sampled males are not known, additional simulations to explore the effects that these parameters may have had on the results are described in the Supplementary Information. Results were evaluated at both the strict (95%) and relaxed (80%) levels of statistical confidence. The allele frequencies utilized for the likelihood calculations and simulations incorporated only the genotypes of non-calves, to avoid skewing the allele frequency distribution by inclusion of known relatives.

The pool of candidate males changed during some years of the study, as males first identified as calves and known to be $\geq$ 5 years of age became incorporated in the analysis. As such, the simulations used to calculate critical values were run separately for years with different pools of candidate males, such that while the proportion of candidate males sampled (0.50) was held constant throughout the study, the number of candidates was updated to reflect the changing number of sampled males. The total number of candidate males used in the CERVUS simulation was set by multiplying the number of sampled males by two in accordance with the assumption that 50% of candidates had been sampled.

To provide insight into the reproductive success of unsampled males, the program DADSHARE (www.zoo.cam.ac.uk/zoostaff/amos, see Hoffman *et al.* 2003) was used to estimate the number of putative sires for the calves for which all sampled candidates were excluded. This program inferred paternal sibships by calculating pairwise paternal relatedness coefficients among unassigned offspring using the relatedness coefficient of Queller and Goodnight (1989). A clustering algorithm (UPGMA) was then used to produce a dendrogram linking the most closely related individuals and sorting offspring into groups compatible with having a single father (e.g. paternal half-siblings). In addition, Monte Carlo simulations were used to explore the pattern which would be produced if 1 to K fathers sired the offspring, with K representing the total number of offspring being assigned (e.g., the pattern produced if each offspring had a different father). The average r-values and standard deviations generated in the simulated scenarios were compared with the observed average r-values presented in the dendrogram. In order to evaluate how this method compares with direct parentage assignment, DADSHARE was run both with a dataset containing only those calves which were not assigned a putative father by the paternity assessment analysis as well as with a dataset including only those calves which were assigned putative fathers in the previous analyses.

A simulation-based approach, similar to that employed in previous parentage analyses conducted for mysticetes (Cerchio *et al.* 2005, Frasier *et al.* 2007), was used to evaluate how the observed patterns of

male reproductive success compared with those expected if all candidate males had an equal probability of fathering calves within a year (e.g., if mating were random). To make the results of the simulation comparable to those generated in the CERVUS analysis, simulations were based on the number of sampled candidate males included in each year of the analysis as well as the number of paternities which were assigned for those years. For each year of the analysis, candidate males were randomized, and then fathers were selected with replacement for the number of calves which were assigned paternity in that year. This process was repeated for each year of the study, and the number of calves fathered by each male was summed across years to generate the expected distribution of reproductive success for the study period under the expectation of random mating. This process was repeated 1000 times to generate the mean expected number of sampled males which were assigned paternity of zero, one, two, three, four or more calves under random mating.

To facilitate comparisons of male reproductive success with other species, the standardized variance (SV = variance/mean) in reproductive success was calculated as implemented in previous studies (e.g., Coltman *et al.* 1998, Frasier *et al.* 2007) and using both the results of the paternity analysis and results from the simulations based on random mating. This measure was based only on the reproductive success of males which were assigned as putative fathers of at least one calf during the study. The standardized variance in reproductive success is considered to be zero in truly monogamous species and to increase with the extent of polygyny (Boness *et al.* 1993).

Results

Genetic profiling

Summary statistics for the microsatellite loci used in the study are shown in *Table 1*. The total exclusionary probability of the multilocus genotypes used in the paternity analysis, as calculated by CERVUS when one parent is known, was high at 0.9999. The probability of identity (P_{ID}, Paetkau and Strobeck 1994) was estimated to be 2.83×10^{-13}, indicating that the loci utilized in the study provided high power to resolve relationships between individuals. The more conservative $P_{ID\text{-}sib}$ (Evett and Weir 1998) was also calculated to account for the possible presence of related individuals within the dataset. This estimate was low (1.38×10^{-5}), suggesting that the data would be able to distinguish between any full siblings included as candidates. Rechecking of ~20% of all genotypes did not identify a substantial source of error.

Paternity assignment

When no mismatches were allowed between the genotype of candidate males and that of the mother-calf dyad (hereafter referred to as the "stringent criterion"), paternities were assigned for 26 (45.6%) of the 57 calves. All paternities were assigned at the 95% confidence level. One calf had a genotype which matched that of two candidate males; for the remaining 25 calves only one possible match was identified. No putative fathers were identified for the remaining 31 calves.

Incorporating an error rate of 0.01 (later referred to as the "relaxed" criterion), the CERVUS analysis supported all of the assignments previously made and identified putative fathers for an additional four calves, such that paternity was resolved for 52.6% of calves in the study. The four additional assignments included putative fathers with one (n=2) to two (n=2) mismatches with the genotypes of the mother-calf dyads. All CERVUS assignments were supported at the 95% confidence level, with the exception of the one calf whose genotype matched that of two candidate males with no errors, which was assigned at 80% confidence. Those calves which were not assigned putative fathers by the CERVUS analysis mismatched all potential candidates at ≥ 2 loci; for the majority (79%) of these calves, mismatches for ≥ 3 loci were present with all candidates.

The success of the paternity assignment varied greatly across the 12 years of the study (*Table 2*). Excluding years in which only one calf was sampled, the proportion of paternities assigned per year ranged from one year in which no paternities were assigned to years (n=3 using the relaxed criterion) in which putative fathers were assigned to two thirds of sampled calves.

The paternity assignment also varied greatly across the reproductive females included in the study (*Table 3*). Excluding females which only had one offspring during the study, the average proportion of calves with assigned fathers per female was 0.54 (relaxed criterion) and assignment success ranged from having no calves assigned putative fathers (n=3 females) to having all calves born during the study assigned putative fathers (n=5 females).

Male reproductive success

When no errors were allowed, 17 males were assigned paternity of the 26 calves, for an average of 1.5 (±0.72SD) calves per male (*Table 4*). Average reproductive success was slightly higher when calculated from analysis incorporating error, with 18 males assigned paternity for 30 calves and an average of 1.7 (±0.91SD) calves per male. In both cases, the majority of males (59% and 65% of assigned males for the stringent and relaxed analyses, respectively) were assigned paternity of only one calf each, although a small number of males were assigned paternity of 3-4 calves during the 12 seasons of the study.

These estimates of reproductive success do not incorporate males which were not assigned paternity of any calves. Although the number of candidate males varied across years of the study, 57-69% of candidate males were not assigned paternity of any calves over the twelve years of the study. Inclusion of these males would reduce estimates of average reproductive success to 0.47-0.71 calves per male.

As expected, none of the 13 males of known age (*i.e.*, first identified as calves, ranging from 5 to 11 years old during the season of fertilization) were identified as putative fathers during the study (*Table 5*). These males, as well as some proportion of the males of unknown age, were not sexually mature for all or part of the study. Of those males which were identified as putative fathers, all except one (only identified using the relaxed criterion) were identified prior to the 2000 season, and the majority (n=14, 77.8%) had been first identified by the end of the second season of the study (*Table 6*). All except two of the males were sighted at least once for six or more years of the study, with 14 males sighted for at least 8 of the 12 years of the study (*Table 6*). For the majority of assigned paternities (n=26 between 1999 and 2007), the putative father was identified on the feeding ground in the season prior to conception (77% of paternities) and/or the season following conception (73% of paternities).

Only one male was assigned paternity of 2 calves in any one season. Excluding this case, the average interval between successful reproductions was 2.8 years (relaxed criterion) to 3.75 years (stringent criterion). Although the maximum interval between assignments was six years, there were three males which were assigned as putative fathers early in the study and which were not assigned any additional calves for the following 8 to 11 seasons. Although some calves may have been lost before reaching the feeding ground, this finding suggested that intervals between successful mating may be even longer than illustrated with our dataset. The longest time span over which a male in the study was considered reproductively active was nine years, during which the male was assigned as the putative father of three calves.

In the seven to nine cases (stringent and relaxed criteria, respectively) in which a reproductive female had more than one calf assigned to a putative father, there was only one case in which the same father was assigned more than one calf of the same female. Female Q had three calves during the study, and all three calves were assigned to the same male (I) under the relaxed criterion. One of these calves mismatched the assigned father at two of the 13 loci and was only assigned to the male in the relaxed analysis. One of the other two assignments for calves of this female was the case where the genotype of the calf matched that of two different putative fathers with no errors. Although male I was assigned as the most likely father, relatedness analysis (data not shown) suggests that the two putative fathers may represent a parent-offspring pair. Given that this was the only case in which more than one putative father had a genotype which matched that of a calf at all loci, the paternity analysis seemed to generally perform well at discriminating between relatives. However, it is possible that in at least this case the candidate male with the highest likelihood of being the true father shared a different relationship to the calf.

DADSHARE estimated that 15 males were likely to account for the 27 calves not assigned fathers in the CERVUS analysis. Average reproductive success among these 15 males was 1.8 calves per male. Relative

to the paternity analyses, a larger proportion of these unsampled males (53%) were assigned paternity for two calves each during the study (*Graph 1*), suggesting these males may have greater reproductive success on average than those males which were sampled. When the DADSHARE analysis was run using only those calves which were assigned to putative fathers, 18 putative fathers were needed to account for the 30 calves, which corresponds exactly with the number of putative fathers identified in the "relaxed" CERVUS analysis. Similar to the results for the unassigned calves, however, the distribution of reproductive success among these 18 males was somewhat different than the observed pattern, with more males assigned as the putative father of two calves during the study. Differences in reproductive success between the sampled and unsampled males may be an artifact of differences in the resolution of the two methods.

At least some of these unsampled males may be accounted for among the 28 animals which have been photographically identified on the Sakhalin feeding ground but which have yet to be genetically sampled. One of these is presumed to be a female based on its close and prolonged affiliation with a calf during the one season it was sighted, and nine are animals first identified as calves (≤ 9 years of age at the end of the study) and may not have been reproductively mature for much, if any, of the study period. This leaves at least 18 animals of unknown sex or age which have been identified on the feeding ground but are not represented in the sample set. Although some proportion of these animals may be males contributing to reproduction in the population, based on the overall sex ratio of the population (58% male, Weller *et al.* 2008a), it is unlikely that all of the missing males are included in this group of animals. However, obtaining samples from these animals could potentially increase the success of the paternity assessment.

When the observed results were compared with those generated via the simulation of random mating (*Graph 2, Graph 3*), the average number of calves per father was significantly higher in both the relaxed ($p \leq 0.014$) and the stringent ($p \leq 0.037$) analysis. These results were due to significantly fewer than expected candidate males which were assigned only one offspring in the analysis ($p \leq 0.036$, stringent criterion; $p \leq 0.039$, relaxed criterion). The average numbers of males assigned paternity of two calves were similar between the simulated and observed results, while the average number of males assigned three calves over the study period was higher in the observed than the simulated results, although the differences were not significant. In addition, the number of males which were not assigned the paternity of any calves during the study was significantly higher than would be expected under random mating for both the stringent- and relaxed- criterion analyses ($p \leq 0.037$ and $p \leq 0.007$, respectively).

The standardized variance calculated from the results of the paternity analysis (SV_{obs}=0.42) was higher than that calculated from the data simulated under expectations of random mating (SV_{exp}=0.27). When compared to other mysticete studies, the SV_{obs} was most similar to the value calculated in the study of paternity in North Atlantic right whales (SV_{RW}=0.35; Frasier *et al.* 2007) and was higher than that calculated for the humpback whale population (SV_{HW}= 0.23; Cerchio *et al.* 2005).

DISCUSSION

Paternity assessment

Approximately half (46-53%) of the calves sampled on the Sakhalin feeding ground were assigned putative fathers which had been identified and sampled in the same area. Using the stringent criterion, all assignments were supported at the 95% confidence level, and the panel of loci utilized in this study provided sufficient resolution to discriminate between all possible candidates using a simple exclusion approach in all except for one case. Even when the more relaxed criterion was applied, all except one of the assignments was supported with high confidence (95%), and only four additional paternities were assigned. Assignment success was in relatively close agreement for both criteria, and it is likely that the true patterns of paternity are encompassed within this range of estimates.

Similar paternity assignment success rates have been generated in other studies of mysticete mating systems, including those conducted for humpback whales in the Mexican Pacific (32.5 to 49.6 %, Cerchio *et al.* 2005) and for North Atlantic right whales (41.4 to 62.1%, Frasier *et al.* 2007). Although sampling in the humpback whale population was not as complete, it is notable that in both our study and the North

Atlantic right whale study, in which an estimated 74% of animals which were considered alive had been sampled, a very high proportion of photographically identified individuals had been sampled. As such, the success rates of the paternity assignments were somewhat less than might be expected given the overall pattern of sampling. As discussed below, this pattern may have implications for our understanding of the population's status.

Distribution of male reproductive success

A mild skew in male reproductive success was detected over the 12 seasons covered by the study. Although most (56-59%) of the putative fathers identified were assigned paternity of only one calf each, this proportion was lower than that predicted in the simulations based on random mating. While not statistically significant, more males than expected were assigned paternity of three to four calves during the study, suggesting that some males achieved higher reproductive success than others. These results are consistent with those observed in both humpback whales and right whales, both of which demonstrated mild skews compared to random mating expectations (Frasier *et al.* 2007, Cerchio *et al.* 2005). However, in all cases the skew was slight, with most males siring only one calf during each of these studies. While the differences in reproductive success among males were relatively small over the course of the study, continuation of this pattern over the lifespan of these individual males would result in a substantially higher reproductive advantage for some males. However, if male reproductive success varied with age, the advantage gained by individuals during the study period would level out over time.

Based on testes to body size ratios, both gray and right whales are thought to utilize sperm competition (Brownell and Ralls 1986). The standardized variance of reproductive success, a measure often used for comparisons across species, was found to be high in North Atlantic right whales relative to values found in other aquatically mating species (Frasier *et al.* 2007), including a population of humpback whales (Cerchio *et al.* 2005). These results suggested that sperm competition may result in higher variance in reproductive success when compared to tactics employed by some other marine mammals (Frasier *et al.* 2007). The standardized variance estimated for western gray whales was comparable to that found in North Atlantic right whales, providing further support for the role of sperm competition in generating variance in reproductive success among males.

A high proportion of sampled males were not assigned any offspring during the 12 seasons of the study. These findings may suggest that many of the animals of unknown age were too young to successfully compete for mating opportunities. Rice and Wolman (1971) found that 24% of the animals from their sample were sexually immature and estimated that the total proportion of immature animals in the eastern gray whale population was approximately 44-61%. If the results of the paternity analysis are combined with the results of the DADSHARE analysis, the proportion of males (53-54%) that are potentially too young to reproduce falls within the range estimated by Rice and Wolman (1971). It is important to note, however, that successful fertilization not only necessitates that males are sexually mature but also that they are able to successfully compete for fertilization opportunities. Therefore, estimates derived from the paternity analysis are not necessarily representative of the proportion of animals which have not reached sexual maturity. In addition, this estimate assumes that the unsampled males are only those which are contributing to reproduction; if some proportion of non-breeding males has also not been sampled off Sakhalin, this percentage would be lower.

The results suggest a lack of mate fidelity among breeding pairs, with only one female with more than one calf assigned to the same male. These findings agree with expectations based on morphology and behavior. Similar results have been found in paternity analyses in humpback whales (Clapham and Palsboll 1997) and right whales (Frasier *et al.* 2007).

Identification of reproductive males

The paternity assignment identified 17 to 18 males as putative fathers, and analysis of relatedness patterns among the calves with unassigned paternities suggested that approximately 15 additional reproductive males have yet to be sampled. Twenty-four females were determined to be the mother of at least one calf in the western population between 1995 and 2007 (Weller *et al.* 2008a). Combining this information suggests

that approximately 57 animals are capable of reproduction. These numbers are slightly higher than previous estimates (Weller *et al.* 2002), which indicated that the number of mature individuals was approximately 39-49 animals if the population was growing and 55 animals if the population was stable. These estimates were based on parameters (*e.g*., percent of immature animals) derived from the eastern gray whale population and on the western population's size in 1999. Integrating information on the number of putative fathers with the number of females known to reproduce provides a more direct assessment of the number of animals contributing to reproduction in the population, including those which may not be regularly sighted on the primary feeding ground. Although slightly higher than previous estimates of the number of mature animals, the estimate incorporating the results of the paternity analysis supports the need for continued concern over the small size of the population. In particular, the low number of reproductive females may limit the population's growth and recovery (Weller *et al.* 2008a).

Although one of the putative fathers was not identified until the last year of the study, all other males identified as putative fathers were identified early in the study. These animals demonstrated a high degree of seasonal site fidelity to the primary feeding area, indicating that at least this subset of reproductive males are regular visitors to the Sakhalin area. Although some of the unsampled males may be represented among those animals which have been sighted on the feeding ground but not yet sampled, it seems likely that at least some of the "missing fathers" are animals which do not utilize the Sakhalin feeding ground on a regular basis.

The majority of the putative fathers had four of the five most common haplotypes found in the western population. Only two (one of which was identified only in the relaxed analysis) of the nine males which have haplotypes considered to be rare in the western population were identified as putative fathers. These "rare haplotype males" have been hypothesized to represent possible dispersers from the eastern population (Lang *et al*. 2010), although additional analyses evaluating this hypothesis have yet to be conducted. However, these results suggest that the majority of these "rare haplotype males" may not be currently contributing to reproduction in the population.

No males of known age were identified as putative fathers during the study; therefore, no conclusions about the minimum age at which males attain reproductive success can be derived from these results. Based on whales taken off central California under special permits between 1959 and 1969, the age of sexual maturity for both males and females was estimated to range between six and 12 years of age, with a median of nine years (Rice and Wolman 1971, Rice 1990). However, age at sexual maturity is not necessarily representative of age of first reproduction, particularly for males which may need to compete for successful fertilization. The lack of assigned fathers among the known-age males suggests that the age of first reproduction in males may be later than in females. Despite similar limitations in sample size, two females of known age (seven and eleven), out of 17 possible through the 2009 season, have been identified with calves (Bradford *et al.,* submitted). In right whales, paternity analysis suggested that most males do not attain their first successful mating until they were almost twice as old as the average age of fertilization for females (~15 years in males as compared to ~8 years for females; Frasier *et al.* 2007). Although no direct evidence was provided in this study, the lack of paternities assigned to males of known age (≤ 11 yrs) suggests that a similar pattern may be true in western gray whales.

Conservation implications

Despite the high proportion of sampled individuals, the paternity analysis was only able to identify putative fathers for about half of the animals first sighted as calves on the Sakhalin feeding ground. Some of the "missing fathers" may be accounted for by the animals which have been sighted off Sakhalin but not genetically sampled. However, these results suggest that many of the males which are contributing to reproduction in the population may not be regular visitors to the Sakhalin feeding ground, raising questions about the identity and habitat use patterns of these individuals.

A potential explanation for the high proportion of unassigned paternities in the western gray whale population is that some gene flow with the eastern gray whale population may be occurring. Previous work has demonstrated that the eastern and western populations are genetically distinct (LeDuc *et al.* 2002, Lang *et al*. 2010); however, the low level of nuclear differentiation identified between the two populations raised

the possibility that some limited degree of interchange may occur (Lang *et al*. 2010). Such interchange might be characterized by mixing of animals from the two populations on the feeding ground, or might involve some degree of interbreeding. If gene flow between eastern and western populations occurs on a regular basis, then the percentage of candidate fathers that have been genetically sampled would be greatly reduced and a lower assignment success would be expected. Running the paternity analysis with the eastern males included did not identify any additional paternities (see Supplementary Information), but given the very small percentage (<1%) of the eastern population that has been sampled, this result is not very meaningful. However, although genetic drift acts strongly to maintain distinctiveness in small populations, the degree of interbreeding needed to account for the unassigned paternities (~50% of the reproduction in the population) would be likely to dissolve differentiation between the two populations.

If we assume that mating occurs primarily while on migratory routes as has been described in eastern gray whales, two other considerations are important. First of all, if any of the males identified off Sakhalin are animals which originated from the eastern Pacific, then they have a high probability of already being sampled. Therefore, interpopulation breeding between animals of eastern origin and females sampled off Sakhalin can only be used as an explanation for the "missing fathers" if the eastern males demonstrate lower levels of fidelity to the Sakhalin feeding ground and/or utilize other feeding areas but migrate along routes commonly used by Sakhalin animals. Secondly, interbreeding with the eastern population could occur if reproductive females which utilize the Sakhalin feeding area then return to the eastern Pacific to overwinter. Given the increased energetic demands of pregnancy and lactation, females are generally considered to be less likely candidates for dispersal than are males. In addition, of the 18 females which had multiple calves during the study period, the majority (83%, n=15) had at least one calf which was assigned a putative father among the animals sampled off Sakhalin, linking these breeding pairs to the use of common migratory routes during at least some seasons of the study.

An alternate explanation for the unassigned paternities, however, is that many of the males which are contributing to reproduction in the western population utilize other areas in the western Pacific to feed and are rarely found in the waters off Sakhalin. Similar reasoning was invoked to explain the relatively low paternity assignment success observed in North Atlantic right whales, in which only 51% of fathers were identified despite presumed high rates of sampling (69% of identified males; Fraser *et al.* 2007). The discrepancy between the number of assigned paternities and the proportion of whales which were thought to be sampled led the authors to conclude that the size of the North Atlantic right whale population is slightly larger than previously estimated. In addition, information from paternity analysis, in combination with photo-identification records suggesting that as many as one-third of the identified animals were "missing" during a given season (*i.e*., could not be accounted for within areas known to be utilized by this species), supported the existence of additional habitat(s) utilized by North Atlantic right whales but not yet located by researchers.

The results of the paternity analysis in the western gray whale population may suggest a similar pattern. Although it is possible to account for the "missing fathers" among animals identified but not sampled while on the Sakhalin feeding ground, it is unlikely that such a high proportion of the unsampled animals are reproductive males. However, sightings of animals identified as western gray whales have been made in other areas of the Okhotsk Sea (Weller *et al.* 2002), as well as the southwestern Bering Sea (Weller *et al.* 2003) and southeastern Kamchatka (Tyurneva *et al.* 2009). In addition, a relatively high proportion (n=39 of 78; 50%) of the whales sighted off southeastern Kamchatka have not been sighted on the Sakhalin feeding ground (Tyurneva *et al.* 2009). Although these individuals may be of eastern origin, they may also represent western gray whales which use the Sakhalin area infrequently or not at all. These observations suggest that at least some animals in the western population may range more widely during summer and may not have been identified on the Sakhalin feeding ground.

Patterns of relatedness among the unassigned calves suggest that the "missing fathers" may number approximately 15 different animals. Current population assessment models, which indicate that the population contains approximately 130 animals, assume that all western gray whales are sighted off Sakhalin, although not necessarily in all seasons (Cooke *et al.* 2008). The results of the paternity analysis suggest that this assumption may be violated, although the relatively small number of "missing fathers", some of which may be accounted for by photographically identified but not sampled individuals, likely

wouldn't change estimates of the population's size or trajectory dramatically. However, these results raise questions about the proportion of animals of other classes which may also not be accounted for in current estimates. Although little is known about the sex of most animals sighted in other parts of the Okhotsk Sea and eastern Kamchatka, sightings of mother-calf pairs between 1995 and 2008 have been largely confined to the waters of the primary feeding ground off Sakhalin, with only one sighting of a female with a calf in other parts of the range (Tyurneva *et al.* 2009). This female had previously been identified with a calf while utilizing the Sakhalin feeding ground. Thus, although females may range more widely during some seasons, they appear to exhibit particularly strong fidelity to the primary feeding ground in years when they have produced a calf. As such, the proportion of sampled to unsampled reproductive females is likely to be higher than the ratio suggested for males. Interestingly, a male bias has already been documented to exist among those western gray whales which have been sampled, such that approximately 60% of animals first identified (and sampled) as adults or subadults on the Sakhalin feeding ground are males. Results of the paternity analysis suggest that this male bias could be more pronounced than previously estimated.

Conclusions

Much of our understanding of the role that males play in the mating system of baleen whales is based on general patterns derived from behavioral and physiological data as well as predictions based on known differences in the reproductive cycles of males and females. While genetic analyses can provide valuable information on the distribution of reproductive success among males, in many species such studies are limited by the difficulty of collecting a sample set that is representative of population patterns. Due in large part to its small size and the high degree of site fidelity demonstrated by individuals, the western gray whale population is one of the most thoroughly sampled of all mysticete populations, providing a rare opportunity to learn more about the mating system of baleen whales. The findings presented here indicate that the distribution of reproductive success in this small population is similar to that described in North Atlantic right whales. Such comparisons suggest that sperm competition may create differential reproductive success among males, but that the degree of skew is mild in comparison to terrestrially mating mammals. Longer-term studies are needed, however, to determine how differential reproductive success over the relatively short time span of this study compares with patterns produced over the lifespan of individuals.

The lower-than-expected success rate in the paternity assignment for western gray whales raises many questions and suggests that the structure of this population may be more complicated than previously thought. In particular, the results presented here suggest that some animals which are part of the western population may not routinely visit the Sakhalin feeding area. Although this group of "missing fathers" may be small in number, they play a significant role in the reproduction of the population. As such, increasing our understanding of the habitat use and behavior of these animals is important. Genetic sampling of animals identified in other areas of the western Pacific, particularly those which have been sighted off Kamchatka but have not been identified as animals utilizing the Sakhalin feeding area, is one avenue that may elucidate habitat use of animals outside of the primary feeding area. Genetic analysis could be used to determine if these animals are any of the "missing fathers", and genetic assignment tests could be used to better understand if these animals originated from the eastern or western populations.

Although the relatively high proportion of calves which could not be assigned fathers is puzzling, assignment of putative fathers for approximately 50% of sampled calves provides strong evidence for intrapopulation breeding among animals demonstrating fidelity to the western feeding ground. Most females had at least one calf which was assigned a putative father from among the animals sampled off Sakhalin, suggesting the use of common migratory routes among these animals and the putative fathers which were identified. In the future, combining the results of the paternity analysis with genetic assignment tests may provide additional information on the extent and nature of any dispersal which may be occurring between the eastern and western populations.

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Table 1. Diversity of the microsatellite loci utilized in the parentage analysis as calculated in CERVUS. The number of alleles (k), observed (H_{obs}) and expected (H_{exp}) heterozygosities, and polymorphic information content for each locus are shown. No loci were found to be out of Hardy-Weinberg equilibrium. The probability for non-exclusion of a parent pair, the probability of identity (assuming Hardy-Weinberg equilibrium), and the probability of identity assuming full siblings are represented in the data area are also shown.

Locus	**k**	**H_{Obs}**	**H_{Exp}**	**PIC**
D17t	14	0.846	0.896	0.881
EV14t	8	0.701	0.752	0.71
EV37	16	0.923	0.856	0.835
EV94t	9	0.782	0.754	0.708
Gata028	5	0.795	0.751	0.702
Gata098	6	0.615	0.604	0.562
Gata417	7	0.688	0.641	0.569
Gt023	7	0.654	0.685	0.632
RW31	9	0.859	0.832	0.805
RW48	5	0.39	0.414	0.386
SW10t	9	0.808	0.783	0.748
SW13t	8	0.649	0.648	0.58
SW19t	7	0.744	0.648	0.595
Overall	8.5	0.73	0.71	0.67

Non-exclusion probability (parent pair):	7.00×10^{-8}
Probability of identity:	2.83×10^{-13}
Probability of identity (sibling):	1.38×10^{-5}

Table 2. Paternities assigned for western gray whale calves in each season of the study, including the year in which the calves were born, the number of sampled males included as candidates for each year, the number of sampled mother-calf (M-C) pairs, and the number and percentages of paternities assigned under the stringent and relaxed criteria. Unless otherwise noted, all paternities were assigned at 95% confidence.

Year	No. of sampled males	No. of sampled M-C pairs	Paternities Assigned			
			Stringent		Relaxed	
			No. Assigned	%	No. Assigned	%
1995	42	3	1	33	1	33
1997	42	1	1	100	1	100
1998	42	5	1	20	2	40
1999	42	1	1	100	1	100
2000	42	2	0	0	0	0
2001	44	6	3	50	3†	50
2002	44	6	3	50	4	67
2003	46	10	5	50	5	50
2004	49	6	4	67	4	67
2005	50	5	1	20	2	40
2006	53	3	1	33	1	33
2007	55	9	5	56	6	67
Total	55	57	26	46	30	53

†One paternity resolved at 80% confidence

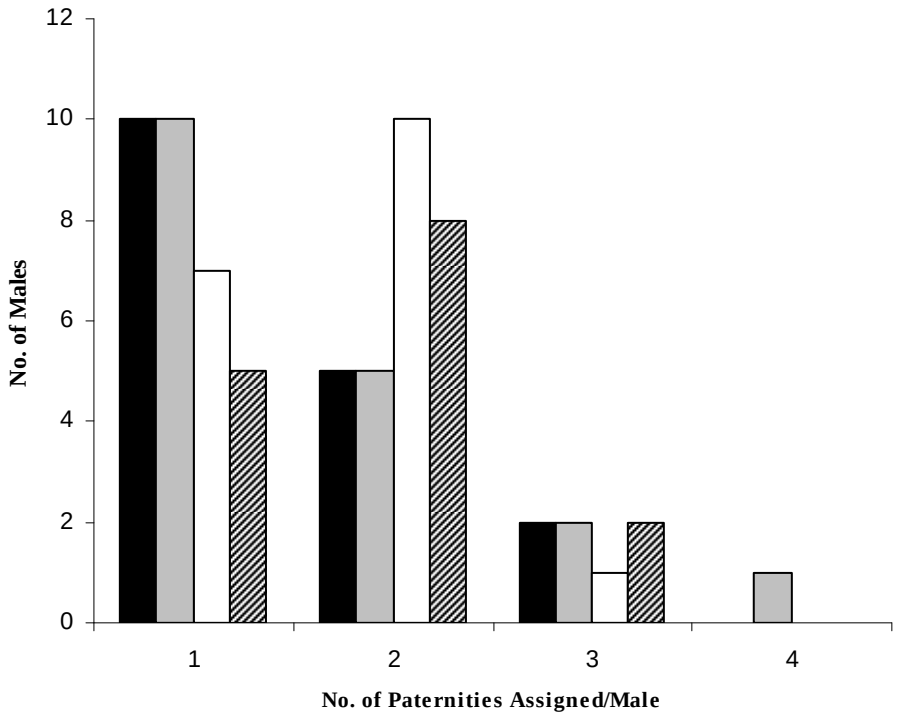
Table 3. Paternities assigned for calves of each reproductive female, including the number of sampled offspring for each reproductive female, and the number and percentage of offspring which were assigned a putative father in the analysis under both the stringent and relaxed criteria. Unless otherwise noted, all paternities were assigned at 95% confidence.

Mother's ID	No. of sampled offspring	Stringent		Relaxed	
		No. Assigned	%	No. Assigned	%
A	1	0	0	0	0
B	4	1	25	2	50
C	3	1	33	1	33
D	4	3	75	3	75
E	2	1	50	2	100
F	3	0	0	0	0
G	5	1	20	1	20
H	5	3	60	3	60
I	2	2	100	2	100
J	2	2	100	2	100
K	1	0	0	0	0
L	2	0	0	0	0
M	2	1	50	1	50
N	4	2	50	2	50
O	1	1	100	1	100
P	2	1	50	1	50
Q	3	2	67	3	100
R	3	1	33	1	33
S	3	3	100	3	100
T	2	0	0	0	0
U	2	1	50	1	50
V	1	0	0	1	100
Total	57	26	0	30	0.53

†One paternity resolved at 80% confidence

Table 4. Distribution of reproductive success among the putative fathers identified in the paternity analysis. Included are the candidate father's ID, his mtDNA haplotype, the year in which he was first photographically identified, and the number and birth year of the offspring he was assigned under the stringent and relaxed criteria analyses. Mean reproductive success for all fathers, along with the standard deviation, is shown at the bottom of the table.

			Stringent	Relaxed	
Father ID	**Year Identified**	**Father's Haplotype**	**No. of Offspring**	**No. of Offspring**	**Year(s)**
A	1994	A	2	2	2002, 2004
B	1995	B	1	1	2004
C	1997	A	1	1	2007
D	1995	D	1	1	1999
E	1997	A	3	3	1997, 2002, 2006
F	1995	B	1	1	2007
G	1997	B	1	1	2003
H	1997	D	1	1	2003
I	1995	A	2	4	1998, 2001, 2002, 2003
J	1995	C	1	1	2003
K	1997	A	3	3	2002 & 2007 (2)
L	1998	J	1	1	1998
M	1995	B	1	1	1995
N	1994	D	2	2	2004 & 2005
O	1999	B	2	2	2001 & 2003
P	1999	B	2	2	2001 & 2007
Q	1995	A	1	2	2004, 2005
R	2007	Q		1	2007
Average:			1.5	1.7	
SD:			0.72	0.9	



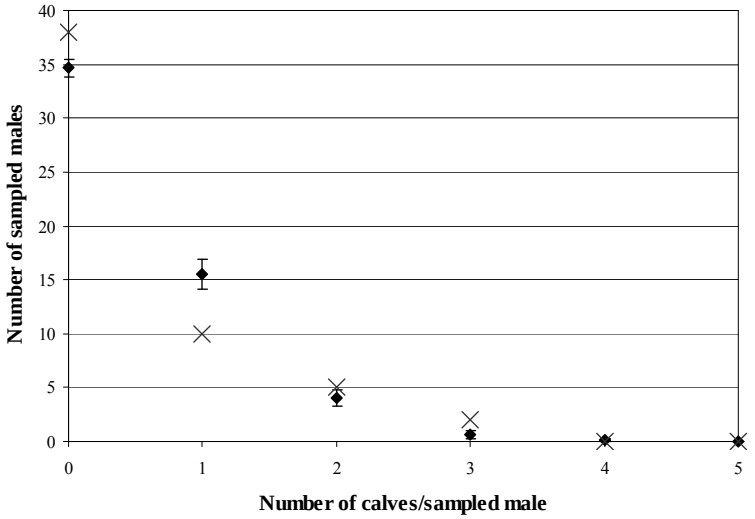
Graph 1. Comparison of the number of males which were assigned one, two, three, and four offspring in the stringent CERVUS analysis (shown in black), the relaxed CERVUS analysis (shown in gray), and the DADSHARE analysis using only those calves which were assigned putative fathers in the relaxed analysis (shown in white), and the DADSHARE analysis using only those calves which were not assigned putative fathers in the relaxed analysis (black and white pattern).

Table 5. Number of known age males for each year of the study. Included are the year of each study, the number of mother calf (M-C) pairs sampled in each year, the number of paternities assigned, the number of males in each age category (5 to 11) for each year, and the total number of known age males included in the paternity analysis for each year. Age categories refer to the approximate age of the male in the season during which fertilization would have occurred.

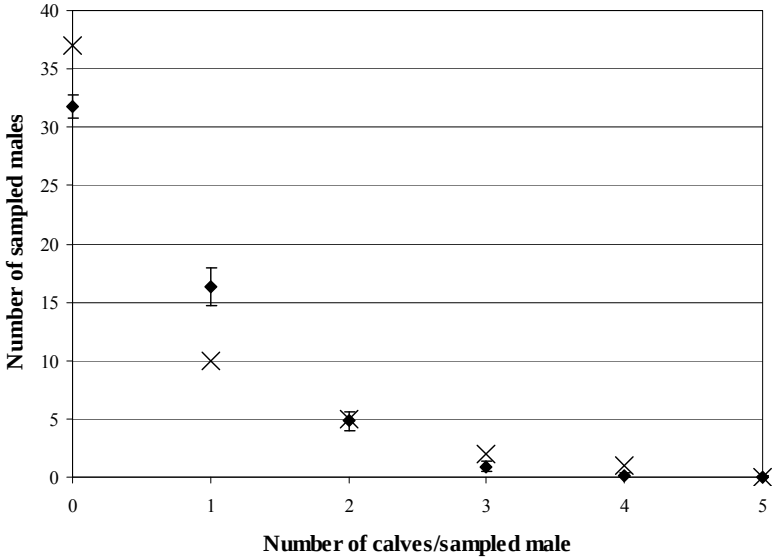
Year	No. of M-C pairs	No. of assigned paternities	Approximate age of males during reproduction (Year -1)							No. of known age males
			5	6	7	8	9	10	11	
2001	6	3	2							2
2002	6	3		2						2
2003	10	5	2		2					4
2004	6	4	3	2		2				7
2005	5	1	1	3	2		2			8
2006	3	1	3	1	3	2		2		11
2007	9	5	2	3	1	3	2		2	13

Table 6 Sighting patterns of males identified as putative fathers in the paternity analysis. Included are the father's ID number and the date on which he was first photographically identified. Years in which the male was sighted at least one are shaded in gray; numbers in each cell refer to the number of calves identified in each season which were assigned to that father. The * symbol is used to denote offspring only assigned under the relaxed criteria. The percentage of years that each candidate male was sighted on the Sakhalin feeding ground of all years of the study following his initial identification is also shown.

ID	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	% of years sighted
A							1		1				100%
B									1				92%
C												1	82%
D				1									67%
E		1					1				1		100%
F												1	83%
G								1					73%
H								1					91%
I			1			1*	1*	1					100%
J								1					83%
K							1					2	73%
L			1										80%
M	1												75%
N									1	1			69%
O						1		1					44%
P						1						1	67%
Q									1	1*			58%
R												1*	100%
Total	1	1	2	1		3	4	5	4	2	1	6	30



Graph 2. Graph comparing the expected distribution of paternities based on simulations of random mating with the observed results for the stringent criterion analysis. Expected values, with error bars representing standard deviations, are shown with black diamonds, while the observed values are displayed with an X.



Graph 3. Graph comparing the expected distribution of paternities based on simulations of random mating with the observed results for the relaxed criterion analysis. Expected values, with error bars representing standard deviations, are shown with black diamonds, while the observed values are displayed with an X.

Genetic Differentiation Between Western and Eastern (*Eschrichtius robustus*) Gray Whale Populations Using Microsatellite Markers

AIMEE R. LANG [1], DAVID W. WELLER [1], RICHARD G. LEDUC [1], ALEXANDER M. BURDIN [2, 3], AND ROBERT L. BROWNELL, JR [4].

[1] Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, La Jolla, California 92037, U.S.A
[2] Kamchatka Branch of Pacific Institute of Geography, Far East Division - Russian Academy of Sciences, Petropavlovsk, Kamchatka, 683000, Russia
[3] University of Alaska Fairbanks, Fairbanks, Alaska 99775 U.S.A
[4] Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, Pacific Grove, California 93950, U.S.A

Contact email: aimee.lang@noaa.gov

ABSTRACT

Within the North Pacific, gray whales (*Eschrichtius robustus*) are recognized as distinct eastern and western populations. Although both populations were severely reduced by whaling, the eastern population is generally considered to have recovered while the western population has remained highly depleted. Previous studies have documented genetic differentiation between the two populations on the basis of mtDNA haplotype frequencies. Since mtDNA represents only maternal inheritance patterns, the present study used bi-parentally inherited microsatellite markers (n=13) to measure differentiation between populations as well as to compare levels of nuclear genetic diversity retained in each. Mean levels of genetic diversity, as measured by the microsatellites, were similar between the eastern and western populations, indicating that the western population has retained relatively high levels of nuclear genetic diversity despite its small size. Comparison of microsatellite allele frequencies confirmed that eastern and western populations are genetically distinct. Although highly statistically significant, the level of differentiation between the two populations is relatively low, and sex-specific analyses suggest that some amount of male-biased dispersal may occur between populations. While these results suggest some movements between the eastern and western populations may take place, the maintenance of genetic differences between the two populations supports their recognition as separate eastern and western populations. Future efforts should focus on elucidating the nature and extent of any dispersal which is occurring in order to better understand factors potentially influencing the recovery of the small western population.

INTRODUCTION

Although gray whales (*Eschrichtius robustus*) once inhabited the North Atlantic Ocean (Mead and Mitchell 1984), the current distribution of the species is limited to the eastern and western margins of the North Pacific (Rice and Wolman 1971). Within this region, gray whales are recognized as having distinct eastern and western populations. Eastern gray whales winter in the lagoons and adjacent waters of Baja California, Mexico and then migrate north along the west coast of North America to feed in the Bering and Chukchi Seas during summer (Rice and Wolman 1971), with a small number of animals remaining in more southern waters between northern California and southeastern Alaska during summer months (Darling 1984, Calambokidis *et al.* 2002). For western gray whales, the primary feeding ground is in the coastal waters off northeastern Sakhalin Island, Russia (Weller *et al.* 1999, 2002). The location of the wintering ground(s) for

this population remains unknown, but limited information from sightings, strandings, and catches shows that some animals winter in the coastal waters of southern China (Wang 1984, Henderson 1990, Zhu 1998).

Both gray whale populations were greatly reduced by intensive commercial whaling during parts of the 19th and 20th centuries, but the two populations have exhibited different trajectories in abundance following exploitation. Commercial whaling for eastern gray whales ceased in 1936 (Brownell and Swartz 2006), and the population's size has increased since that time (Rugh *et al.* 2005). Eastern gray whales were removed from the U.S. List of Endangered and Threatened Wildlife and Plants in 1994, and recent abundance estimates indicate that the population contains approximately 22,000 animals (Punt and Wade 2010). In the western population, however, hunting continued through at least 1966 (Brownell and Chun 1977). This population was reduced to a much smaller size than the eastern populations and was considered by some to be extinct as recently as the 1970s (Bowen 1974). Today western gray whales exist only as a small remnant population. Recent population assessment utilizing a Bayesian individually-based stage-structure model and photo-identification data collected between 1994 and 2007 projected a median non-calf population size of 130 individuals in 2008, assuming current demographic and population trends continue (Cooke *et al.* 2008). This population was listed as Critically Endangered by the IUCN in 2000 (Weller *et al.* 2002, Baillie *et al.* 2004), and its continued survival is jeopardized by problems associated with small population size (reviewed in Clapham *et al.* 1999), as well as by a wide range of potential anthropogenic threats, including the rapid expansion of oil and gas development on its summer feeding ground off Sakhalin Island, Russia (Weller *et al.* 2002, Reeves *et al.* 2005, IISG 2006) and mortality due to net entrapment while on the migratory route off Japan (Brownell *et al*. 2007, Weller *et al.* 2008b).

Concern for the conservation status of the western population led to the initiation of a joint Russia-U.S. research program in 1995. This program is based on the summer feeding ground off Sakhalin Island, Russia and has incorporated both photo-identification studies and biopsy sampling (Weller *et al.* 1999, 2002). Photo-identification research has shown that most whales demonstrate high rates of annual return and pronounced seasonal site fidelity to the Sakhalin feeding ground (Weller *et al.* 1999, 2002). The majority (83% of identified whales (n=169) have also been genetically sampled, allowing a male bias (58% males) to be documented among sampled individuals (Weller *et al.* 2002, 2008). This male bias is particularly pronounced in individuals first identified as calves, of which 66% are males (Weller *et al.* 2008).

Biopsy samples collected between 1995 and 1999 have been used to show that the eastern and western populations are genetically distinct based on mitochondrial DNA (mtDNA) haplotype frequencies (LeDuc *et al.* 2002). This study found that western gray whales have retained a relatively high number of mtDNA haplotypes for such a small population. Genetic differentiation between the eastern and western populations was based on differences in the frequency distributions of haplotypes within each population. While haplotypes were apportioned relatively evenly among the eastern gray whale samples, the haplotype distribution found within the western gray whale samples was highly skewed, with two haplotypes found in very high frequencies and the remaining haplotypes identified in only one or two individuals (LeDuc *et al.* 2002).

The work presented here used thirteen microsatellite markers to further examine population structure of gray whales. Unlike mtDNA, which is maternally inherited and provides information about historic gene flow of females only, microsatellites are nuclear bi-parentally inherited markers and reflect gene flow of both males and females. The primary goal of this study was to examine genetic differentiation between eastern and western populations using microsatellites, as well as to assess factors which might contribute to that differentiation. Secondarily, levels of nuclear genetic diversity were compared between the two populations to determine if substantial genetic variability has been lost in the much smaller western population and could thus be affecting its ability to recover. Finally, since additional western gray whale samples have been collected since the LeDuc *et al.* (2002) study, further analysis of population structure and genetic diversity using mtDNA was also conducted.

MATERIALS AND METHODS

Sample collection and DNA extraction

One hundred forty-two western gray whale samples were collected between 1995 and 2007 via biopsy darting of free-ranging whales on the population's feeding ground off Sakhalin Island, Russia. All except for one of the western gray whale samples are linked to a photographically identified animal, and this sample set represents 83.4% of all animals (n=169) identified on the western feeding ground through 2007. One hundred thirty-seven eastern gray whale samples obtained from the archive at the Southwest Fisheries Science Center were used for comparison to the western population. These samples were taken primarily from stranded animals (n=105), with some samples obtained from directed subsistence takes (n=12), fisheries bycatch (n=3), and biopsies (n=17) from free ranging whales. Collection locations ranged from southern California north to the Chukotka Peninsula in Russia.

DNA had been previously extracted for 120 of the eastern gray whale samples and 45 of the 142 western gray whale samples (those collected between 1995 and 1999) for use in an earlier study (LeDuc *et al.* 2002). For the remaining samples, whole genomic DNA was extracted using either the QIAGEN DNeasy™ tissue kit or the Corbett Robotics X-tractor Gene robot with the recommended protocols.

Molecular sexing and mtDNA control region sequencing

For those samples (n=114) not analyzed in the prior study by LeDuc *et al.* (2002), molecular sexing and mtDNA control region sequencing were conducted. For all of the eastern gray whale samples as well as the western gray whale samples which were collected prior to the 2006 season (n=94), a polymerase chain reaction (PCR) was used to determine sex utilizing primers described in Fain and Lemay (1995) and following the methods described in Gilson *et al.* (1998). For western gray whale samples collected in 2006 and 2007 (n=20), the protocol described in Morin *et al.* (2005) was used to determine the sex of individuals.

PCR was used to amplify a 523-base-pair fragment from the mtDNA control region using the primers 5'-TACCAAATGTATGAAACCTCAG-3' (H00034, Rosel *et al.* 1995) and 5'-CCTCCCTAAGACTCAAGGAAG-3' (L15812, Escorza-Trevino *et al.* 2005). Amplification products were cleaned through purification columns (QIAquick, Qiagen) and then sequenced using standard protocols with ABI-PRISM® Dye-DeoxyTerminator Big Dye™ v3.1 (Applied Biosystems) and the same primers. Following ethanol precipitation, sequenced products were run on an ABI 3100 or ABI3130 capillary sequencer. Consensus sequences for both strands were generated using ABI SEQSCAPE v2.5 software.

Microsatellite genotyping

Thirteen microsatellite loci isolated from other cetacean species were used to genotype the samples (*Table 1*). Reactions were performed in 25-uL volumes containing approximately 100 ng of genomic DNA and 2.5 uL of 2.0 mM $MgCl_2$ buffer, 1.5 uL of 10 mM dNTPs, 0.75 uL of each primer (at 10uM concentrations, with the forward primer of each pair fluorescently labeled), and 0.25 uL Taq. The thermal cycling profile included an initial hot start of 94°C for 2 min followed by 35 cycles of 94°C for 45 s, 1 min at the annealing temperature (see *Table 1*), and 1.5 min at 72°C, with a final 5-min extension at 72°C. Amplified products were mixed with a size standard and loaded onto an ABI 3100 or ABI 3130 sequencer. Sizing and binning of allele fragments using ABI GENESCAN and GENOTYPER analysis software were automated and relied on the use of internal lane standards, with subsequent manual evaluation of all labeled peaks.

Microsatellite scoring errors and identification of replicate samples

Prior to inclusion in this study, photo-identification data collected during biopsy sampling was used to identify and remove any duplicate samples (*i.e.,* samples taken from the same individual) from the western population sample set. Genotypic data were used to search for duplicates within the eastern gray whale sample set using MS Excel Toolkit v3.1 (Park 2001); one duplicate was identified and removed prior to

analyses, leaving a total of 136 eastern gray whale samples. Microsatellite data were also examined for signs of large-allele dropout and null alleles using MICRO-CHECKER v2.2.1 (van Oosterhout *et al.* 2004).

Genetic variability within populations

ARLEQUIN v3.01 (Excoffier *et al.* 2005) was used with the mitochondrial control region data to calculate standard indices of genetic variation (nucleotide diversity, π, and haplotype diversity, h; Nei 1987) for each population. Genetic diversity at the nuclear level was characterized by generating the number of alleles, observed heterozygosity, and expected heterozygosity for each microsatellite locus in each population using ARLEQUIN. Within each sample set, a Markov-chain approximation of an exact test, as implemented in GENEPOP v3.4 (Raymond and Rousset 1995a), was used to test for departures from Hardy Weinberg expectations and for linkage disequilibrium between all pairs of loci.

Bottleneck analyses

Populations which have undergone recent bottlenecks are expected to exhibit genetic signatures characteristic of a reduction in effective population size (Cornuet and Luikart 1996, Luikart and Cornuet 1998, Luikart et al. 1998, Garza and Williamson 2001). One such signature is a transient excess of heterozygosity (H_e) relative to that expected in a population of constant size, which results from the rapid loss of rare alleles contributing little to overall heterozygosity (Cornuet and Luikart 1996). Here we utilized the program BOTTLENECK v1.2 (Piry *et al.* 1999) to determine if the gray whale microsatellite data demonstrated evidence of population bottlenecks. As recommended (Piry *et al.* 1999), a two-phase model assuming 95% single-step mutations and 5% multiple-step mutations was employed, with the variance among multiple steps set to 12. The distribution of gene diversity at equilibrium was estimated using a coalescent process with 10,000 simulations, and a one-tailed Wilcoxon test was used to determine if an excess of heterozygosity, relative to that expected in populations at equilibrium, was present (Cornuet and Luikart 1996).

The loss of rare alleles during a population bottleneck may also result in gaps in the size distribution of microsatellite alleles. This can be measured as the mean ratio (M) of the number of alleles to the allele size range across all loci (Garza and Williamson 2001); bottlenecked populations demonstrate reduced M values. Here we used ARLEQUIN to calculate M for both gray whale populations and then compared our values to those reported for reduced and stable populations by Garza and Williamson (2001).

Genetic differentiation among populations:

Two approaches were used to assess the degree of genetic differentiation between the two sampling regions. In the first approach, samples were divided *a priori* into populations based on the geographic location in which they were collected. The extent of genetic differentiation between populations was then examined using both mtDNA sequences and microsatellite data. For mtDNA data, an analysis of molecular variance (AMOVA, Weir and Cockerham 1984, Excoffier *et al.* 1992) was used to generate frequency-based (F_{ST}) estimates of differentiation using the program ARLEQUIN (20,000 permutations were used to test for significance). For microsatellite loci, genetic differentiation was examined using an AMOVA (ARLEQUIN) and allelic frequencies (with 20,000 permutations to test for significance) to generate F_{ST} values (Weir and Cockerham 1984). Modified exact tests based on genotype counts, as implemented in GENEPOP v3.4 (Raymond and Rousset 1995b), were also utilized to measure levels of differentiation. Significance was tested using 10,000 permutations. Since the western gray whale sample set included 57 mother-calf pairings, analyses of genetic differentiation were repeated after removal of the sample representing the calf in each pair, in order to avoid biasing the results by including known first-degree relatives.

As an alternative to *a priori* stratification of samples by geographic location, population structure was also explored using a Bayesian model-based clustering approach (STRUCTURE v2.2, Pritchard *et al.* 2000) with the microsatellite data. STRUCTURE assumes that within a set of samples there are K populations, each of which is characterized by allele frequencies at each locus. The program then divides all samples into K genetically distinct clusters by assigning individuals to putative populations such that Hardy-

Weinberg and linkage disequilibrium are minimized within each group. Five independent runs of K=1-5 were performed with a burn-in period of 50,000 iterations followed by 100,000 Markov-chain Monte Carlo repetitions, using a model based on admixture with correlated allele frequencies (Falush *et al.* 2003). After averaging across runs, the log probability of the data given K (Ln P(X|K) was used as the criterion to infer the number of clusters (K) most compatible with the our data.

Detection of sex-biased dispersal

The potential for sex-biased dispersal between populations was investigated using the microsatellite data with the methods described by Goudet *et al.* (2002) and implemented in FSTAT v2.9 (Goudet 2001). Since the signal of sex-biased dispersal disappears with mating (Goudet *et al.* 2002), animals first sampled as calves in the western population were omitted prior to analysis. This program generates a number of statistics aimed at identifying patterns of sex-biased dispersal. The statistics utilized here were 1) F_{st}, the proportion of genetic variation among populations; 2) the mean corrected assignment index (mAIc) and 3) the variance around the assignment index (vAIc) (Favre *et al.* 1997, Mossman and Waser 1999). The p values were estimated using 10,000 randomizations, and a one-tailed test was utilized based on the expectation that, as in most mammals, dispersal is biased toward males. F_{st} and mAIc are expected to be higher in the more philopatric sex, while vAIc should be lower (Goudet *et al.* 2002).

To further explore the potential for sex-biased dispersal between populations, sex-specific estimates of genetic differentiation were generated using the methods outlined above with both the mtDNA and microsatellite data. In addition, values of cluster membership (Q) produced by the STRUCTURE model assuming K=2 clusters were compared between males and females.

RESULTS

Genetic diversity

Forty haplotypes defined by 39 variable sites were identified from the 278 gray whale samples. Thirty-five haplotypes were found among the eastern gray whale samples, while 22 haplotypes were found in the western gray whale sample set. Seventeen haplotypes were shared between the two populations. The frequency of haplotypes in each population is shown in *Table 2*. When all samples were combined, nucleotide diversity (π) was 0.018 (SD=0.0092), while haplotypic diversity (h) was 0.89 (SD=0.012). When subdivided by population, nucleotide diversity was relatively similar in both populations (π=0.016 ±0.0081SD, eastern population; π=0.018 ±0.0093SD, western population), while measures of haplotype diversity were higher in the eastern (h=0.95 ±0.006SD) than the western (h=0.77±0.025SD) population (*Table 3*). Sex-specific diversity measures indicated that although haplotypic diversity was similar between the male (h=0.96) and female (h=0.95) subsets of the eastern population, lower levels of haplotype diversity were found among the western female subset (h=0.77) when compared to the western male subset (h=0.83).

No signal of large-allele dropout or null alleles was identified by MICROCHECKER for any locus in either of the two populations. No deviation from Hardy-Weinberg Equilibrium was detected in either population after controlling for the False Discovery Rate (FDR, Benjamini and Hochberg 1995). After correcting for the FDR, only one loci combination was found to be in significant linkage disequilibrium in the eastern population. However, significant linkage disequilibrium was detected for eight loci combinations in the western population. Given that the same loci pairs were not in disequilibrium in both populations, it is unlikely that this result was derived from physical linkage. Linkage disequilibrium can result from inclusion of related individuals within a sample set. Therefore, known relatives were removed and the tests were rerun on the remaining genotypes. Six loci combinations remained out of linkage disequilibrium after controlling for the FDR.

After averaging across loci, measures of microsatellite diversity were higher in the eastern population (H_o=0.74, H_e=0.74, K=9.8) than in the western population (H_o=0.71; H_e=0.70, A=8.8); however, these differences were relatively small (*Table 4*). A total of 18 private alleles were observed in the eastern population, while only 5 private alleles were found in the western population.

Statistical analysis of the microsatellite allele frequency data using the program BOTTLENECK did not detect evidence of a recent (2-4N_e generations) bottleneck in either population. Under the model utilized, heterozygosity excess was not observed in the eastern (Wilcoxon test, *P*=0.989) or the western population (Wilcoxon test, *P*=0.999). In addition, the calculated *M* values (0.823±0.15and 0.808±0.17) in the eastern and western populations, respectively) were more consistent with those described for stable populations and were considerably higher than the upper bound (0.70) that Garza and Williamson (2001) derived for reduced populations.

Genetic differentiation among populations

Significant genetic structuring between eastern and western populations on the basis of both mtDNA haplotypes and microsatellite allele frequencies was observed (*Table 5*). Similar results were also observed for the microsatellite data when genetic differentiation was assessed using the exact test; the overall results were significant ($p \leq 0.001$), with 11 of the 13 loci showing significant differences when analyzed independently (data not shown). These comparisons remained significant ($P \leq 0.001$) after known relatives (n = 57 calves which had sampled mothers) were removed from the analysis (*Table 5*); however, only three of the thirteen loci showed significant differences when analyzed independently.

STRUCTURE analyses (Pritchard *et al.* 2000, Falush *et al.* 2003) supported the presence of two populations (P ~1.0), with a clear increase in the log-likelihood of the data for K = 2 when compared to that for other numbers of clusters (*Table 6*). The probability that the data contained only one cluster was < 0.001, suggesting that eastern and western populations are not panmictic. When Q values, which represent the proportion of each individual's genotype that can be attributed to each of the clusters, were used to assign individuals into clusters, 80% (n = 109 of 136) of animals sampled in the east were grouped into the same cluster while 65% (n = 92 of 142) of animals sampled in the west were grouped into a cluster (*Figure 1*). However, average source population Q values were relatively low for both populations; they averaged 0.69 (± 0.209SD) for animals sampled in the east and 0.60 (± 0.296SD) for animals sampled in the west.

Sex-specific comparisons

Sex-specific estimates of differentiation were much more marked among females than among males. Using mtDNA haplotype frequencies (*Table 5*), both the male and female comparisons were highly significant, although the F_{st} value estimated for females (F_{st} = 0.078) was more than twice as high as that estimated for males (F_{st} = 0.033). Interestingly, while the male-specific comparisons remained significant (P = 0.029) in the microsatellite exact test, F_{st} estimates based on microsatellite allele frequencies suggested no significant differences between eastern and western males. The sex-biased dispersal tests in FSTAT also supported greater philopatry among females when compared to males. While difference in males and females were not significant for the mean assignment index (*P* = 0.365) or the variance in the mean assignment index (*P* = 0.9262), females demonstrated significantly higher F_{st} values (*P* = 0.0176).

Results of the STRUCTURE analysis provided further evidence that male-biased dispersal may be occurring. After removing animals first identified as calves, average Q values were similar between eastern males (Q_{EM} = 0.70 ± 0.211SD) and females (Q_{EF} = 0.67 ± 0.208SD, *P* = 0.26, t-test); 80% and 87% of males and females were assigned to their source population. In contrast, average Q values were lower for western males (Q_{WM} = 0.47 ± 0.339SD) than for western females (Q_{WF} = 0.63 ± 0.250; *P* = 0.010, t-test). Only 40% of western males had $Q \geq 0.50$ for the cluster representing the western population, in contrast to 75% of western females.

DISCUSSION

Genetic variability

Populations reduced to small sizes can suffer from a loss of genetic diversity, which in turn may compromise their ability to respond to changing environmental conditions (Willi *et al.* 2006) and negatively influence long-term viability (Spielman *et al.* 2004, Frankham 2005). Although little is known

about the level of genetic diversity maintained in the western gray whale population prior to its depletion by commercial whaling, comparison of the levels of diversity found in this small population with those maintained in the much larger population in the eastern Pacific can provide some insight into whether reduced genetic diversity may influence its recovery. Previous studies utilizing mtDNA indicated that while the western gray whale population had retained a relatively high number of mtDNA haplotypes and levels of nucleotide diversity which were concordant with those found in the eastern population, the population had reduced haplotype diversity when compared to its eastern counterpart (LeDuc *et al.* 2002). Our results, using an extended sample set that included ~83% of photographically identified western gray whales, support these earlier findings. As previously noted, the reduced haplotype diversity found in the western population was not a reflection of the number of haplotypes present but rather of the skewed distribution of those haplotypes (LeDuc *et al.* 2002). This skew was even more marked with the added samples. While the frequencies of the two most common haplotypes changed little, new low frequency haplotypes were added, with 14 of the 22 western gray whale haplotypes being found in only one or two animals.

While approximately half (49%) of the mtDNA haplotypes identified in the eastern population were shared with animals sampled in the western North Pacific, a much larger proportion (77%) of the mtDNA haplotypes found in the western population were also identified in eastern animals. Given the relatively thorough sampling of animals on the western feeding ground, it is likely that most if not all haplotypes present in that area have been identified, indicating that the mtDNA haplotypes found only in the eastern Pacific are likely to be unique to that population. In contrast, the low proportion of animals sampled in the eastern population suggests that those haplotypes currently identified only among western animals (n=5) might also be discovered in the eastern population with additional sampling.

Although the relationship between population size and mtDNA diversity is not straightforward (Bazin *et al.* 2006; Nabholz *et al*. 2008), the number of haplotypes (n=22) found in the western gray whale population is surprising given its small size and history of exploitation. In a similar study of endangered North Atlantic right whales (*Eubalaena glacialis*), which are thought to number approximately 400 individuals, only five haplotypes have been documented (n = 180 samples, Malik *et al.* 2000). While sampling in other populations has been less comprehensive, similar patterns have been found in other small mysticete populations, including the Okhotsk Sea bowhead whale population (*Balaena mysticetus*), in which only four different haplotypes were found (n = 25 samples, LeDuc *et al.* 2005), as well as the Sea of Cortez fin whales (*Balaenoptera physalus*), in which three haplotypes have been identified (n = 56 samples, Berube *et al.* 2002). The number of haplotypes found in the western gray whale population is more consistent with numbers found in larger populations, such as the stock of right whales (*Eubalaena australis*) breeding off South Africa, which contains 21 haplotypes (n = 41 samples, Patenaude *et al.* 2007) and has an estimated abundance of 3400 animals (Best *et al.* 2005).

Although the number of haplotypes currently found in the western population is higher than might be expected, this pattern may not persist into the future. Eleven of the 14 haplotypes found in low frequencies have been identified only in a single male. Although little specific information is available on gray whale longevity, they are generally thought to live for approximately 40 to 60 years. It is possible that some of these "rare haplotype" males could be animals that escaped being killed by whalers which hunted gray whales until at least 1966. Given the maternal inheritance pattern of mtDNA, and assuming that these males are indeed the only animals in the population with these haplotypes, the eventual loss of these individuals has the potential to substantially decrease levels of mtDNA diversity in the future.

The level of nuclear genetic diversity found in the western population was slightly lower than, but very similar to, that found in the much larger eastern population. The number of microsatellite alleles found exclusively in the eastern population, however, was markedly higher than the number found in the western population. Given that the western population has been relatively thoroughly sampled, these results suggest that the western population's depletion and continued small size may have resulted in the loss of rare alleles from the population. No genetic signature of a bottleneck was detected in the western population using the microsatellite data. However, simulations have shown that detection of bottlenecks using genetic methods is dependent on a wide range of conditions, including duration of the bottleneck, mutation rate, pre-bottleneck size, and post-bottleneck recovery (Williamson-Natesan 2005), and many studies have failed to

detect the genetic signature of a bottleneck even when demographic data indicate population size collapse (*e.g.*, Queney *et al.* 2000, Spong and Hellborg 2002).

Overall, the western population appears to have retained relatively high genetic diversity despite its history of exploitation and continued small population size. In other populations, the maintenance of genetic diversity in the face of population decline has been attributed to long generation times (Dinerstein and McCracken 1990, Hailer *et al.* 2006, Lippe *et al*. 2006), which are characteristic of baleen whales and may have buffered the population against the rapid loss of variation. However, the relatively high level of genetic diversity that appears to have been maintained in the western population could also be the result of dispersal of eastern animals onto the western feeding ground. Even at low levels, dispersal has been shown to obscure bottleneck signatures (*e.g.,* Kellar *et al.* 2001, Busch *et al.* 2007) and genetically "rescue" populations from the loss of genetic diversity (Vila *et al.* 2003). Further exploration of this possibility is detailed below.

Population structure

The inclusion of additional samples to analyses employing mtDNA supported the previous conclusion that the two populations are genetically distinct (LeDuc *et al.* 2002). Nuclear differentiation estimates further confirm differences between the two populations and indicate that genetic separation between populations is not derived solely from female philopatry. These measures of differentiation remained significant after known first degree relatives (*i.e*., the calf from sampled mother-calf pairs) were removed from the dataset, suggesting that such differences are not solely an artifact of the inclusion of highly related individuals in the analysis.

Although highly significant, the degree of nuclear differentiation, as measured by F_{ST} values, between the two populations is relatively small. This pattern of differentiation is similar to that found in North Pacific bowhead whale populations, which also demonstrate a significant but small degree of differentiation between a smaller western population inhabiting the Okhotsk Sea and a much larger eastern population in the Bering-Chukchi-Beaufort Seas (LeDuc *et al.* 2005). The relatively small but highly significant genetic differences observed in gray whales, particularly when combined with the similar pattern observed in North Pacific bowhead populations, suggests that past Arctic environmental changes may have played a role in influencing patterns of historic mixing and separation of eastern and western animals. Both stranding records and radio-carbon dating of remains have indicated that changes in sea ice distribution may have mediated bowhead whale distribution in the Canadian Arctic (Dyke *et al.* 1996, SaVelle *et al.* 2000). Within the North Pacific, Arctic-wide cooling and glaciation brought on by the "Little Ice Age" (~400-750 years ago) may have resulted in a southern shift in sea ice distribution and reduced sea level (Overpeck *et al.* 1997), potentially facilitating mixing between eastern and western whales. Sea ice expansion during the Neoglacial (~4700 to 2500 years ago) may also have limited access to parts of the Bering Sea and has been hypothesized to have altered the distribution of North Pacific pinnipeds and cetaceans (Crockford and Frederick 2007).

A second explanation for the low level of differentiation is that some limited gene flow could be occurring between the two populations. Given the small size of the western population, it seems likely that even minimal gene flow from the eastern to the western population would quickly homogenize allele frequencies. However, genetic drift also acts more strongly on small populations, allowing differences between populations to develop more rapidly. As such, genetic drift could be acting to counterbalance some restricted degree of genetic interchange between populations.

A third scenario which might also explain our results involves dispersal of whales between feeding areas without genetic exchange. Since breeding in gray whales is thought to primarily occur along migratory corridors (Rice and Wolman 1971), movement between feeding regions does not necessarily imply gene flow between the populations. Given that all of the western gray whale samples were obtained on the feeding ground, low differentiation levels could potentially be generated by a small number of eastern gray whales traveling to the western gray whale feeding ground during summer months and consequently being sampled while mixed with members of the western population. If these eastern dispersers visit the western

feeding ground but return to the eastern Pacific to breed, such extralimital movements would act to reduce measured levels of genetic differentiation between populations in the absence of significant gene flow.

Some support for a limited degree of dispersal and/or gene flow between populations can be derived from the results of the sex-specific comparisons. If the observed low level of differentiation were due to recent divergence, similar patterns of differences should be observed for males and females. Contrary to this expectation, all measures of differentiation were at least twice as high for female-only versus male-only comparisons. In addition, although comparisons between males remained significant for mtDNA, the F_{st}-based comparison of microsatellite allele frequencies did not identify significant differences among males, suggesting that some degree of male-biased dispersal may be occurring between populations. Such a pattern could also provide an explanation for the large proportion of mtDNA haplotypes (11 of 22) in the western population which are represented only by a single male. Given the higher diversity and number of mtDNA haplotypes found in the eastern population, any dispersers from the east would have a relatively high probability of carrying haplotypes considered "rare' in the west (LeDuc *et al.* 2002). Eight of the eleven haplotypes carried by only a single male in the west were also found in the east; given the low proportion of sampled animals in the east, it is plausible that the other three haplotypes would also be identified among eastern animals with additional sampling.

Although the analyses summarized here are not able to discriminate between gene flow and feeding ground dispersal, a combination of genetic assignment tests and parentage analysis in the future may be useful to distinguish between these two possibilities. In addition, simulation modeling could be utilized in the future to determine the degree of gene flow or feeding-ground dispersal which could occur while still allowing the two populations to maintain genetic distinctiveness.

Conclusions and conservation implications

The results presented here support past work indicating that eastern and western populations are genetically distinct, further highlighting the need for continued conservation and expanded protection of the critically endangered western gray whale population. Although highly statistically significant, the level of differentiation between the two populations is relatively low, which may reflect recent divergence of the two populations, perhaps mitigated by past environmental changes, but could also suggest that some limited degree of dispersal and/or gene flow may occur between the two populations. Discrimination between these proposed explanations is important, given that each scenario could have different effects on the recovery of the critically endangered western population. If a restricted amount of gene flow is taking place, that interchange could be important in providing "genetic rescue" for the western population, helping to maintain relatively high levels of genetic diversity in a small population which would otherwise likely suffer from inbreeding and a subsequent loss of fitness. However, if dispersal between feeding grounds without any gene flow is occurring, then any eastern dispersers are not contributing to the gene pool but could be artificially inflating our estimates of both genetic diversity and population size, which would suggest that the western population is even more vulnerable than currently thought. Given the wide range of threats, including entrapment in fishing nets as well as expanding oil and gas development, which challenge the recovery of the western gray whale population, further exploration of possible mechanisms of intermixing is needed to better understand the dynamics of this critically endangered population.

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Table 1. Microsatellite loci used in the study. Includes the species for which primers were initially designed, size of repeats, annealing temperature (T_a), size range, and reference listing primer sequences.

Locus	Source Species	Repeat Size (bp)	T_a (°C)	Size Range (bp)	Reference
DlrFCB17t*	*Delphinaptera leuca*	2	54	183-213	Buchanan *et al.* 1996
EV14t*	*Megaptera novaeangliae*	2	55	138-156	Valsecchi and Amos 1996
EV37	*Megaptera novaeangliae*	2	55	183-231	Valsecchi and Amos 1996
EV94t*	*Megaptera novaeangliae*	2	52	209-237	Valsecchi and Amos 1996
Gata028	*Megaptera novaeangliae*	4	54	159-187	Palsboll *et al.* 1997
Gata098	*Megaptera novaeangliae*	4	54	67-103	Palsboll *et al.* 1997
Gata417	*Megaptera novaeangliae*	4	54	198-222	Palsboll *et al.* 1997
Gt023	*Megaptera novaeangliae*	2	54	94-116	Palsboll *et al.* 1997
RW31	*Eubalaena glacialis*	2	54	114-136	Waldick *et al.* 1999
RW48	*Eubalaena glacialis*	2	55	112-124	Waldick *et al.* 1999
SW10t*	*Physeter macrocephalus*	2	55	119-151	Richard *et al.* 1996
SW13t*	*Physeter macrocephalus*	2	55	168-196	Richard *et al.* 1996
SW19t*	*Physeter macrocephalus*	2	55	122-142	Richard *et al.* 1996

* The sequence for the reverse primer has been modified from the original design by the addition of a tail (Brownstein *et al.* 1996)

Table 2. Frequency of mtDNA haplotypes in each population.

	# of Individuals	
Haplotype	**East**	**West**
A	15	51
B	10	44
C	13	9
D	7	5
E	4	3
F		1
G	9	2
H	1	2
I		1
J		1
K	5	
L	6	1
M	6	2
N	5	1
O	1	
P	2	
Q	1	1
R	7	
S	1	
T	7	1
U	3	
V	3	1
W	1	
X	6	
Y	3	1
Z	2	1
27	2	
28	2	3
29	2	
30	3	
31	1	
32	1	
33	1	1
34	1	
35		7
36	2	
37	1	
38		3
41	1	
42	1	
Total	136	142

Table 3. Genetic diversity estimates based on mtDNA control region sequences. Includes number of individuals (n), number of haplotypes (k), haplotype diversity (h) and percent nucleotide diversity (π). For haplotype diversity and nucleotide diversity, standard deviations are included in parentheses.

Population		n	k	h	π (%)
East	All	136	35	0.95 (±0.006)	1.57(±0.810)
	Females	49	23	0.95 (±0.014)	1.41 (±0.744)
	Males	87	30	0.96 (±0.008)	1.66 (±0.856)
West	All	142	22	0.77 (±0.025)	1.82 (±0.932)
	No known relatives	84	22	0.82 (±0.030)	1.83(±0.937)
	Females*	36	10	0.77 (±0.050)	1.89 (±0.984)
	Males*	42	15	0.83 (±0.041)	1.82 (±0.944)
Both		278	40	0.89 (±0.012)	1.81 (±0.922)

* Excludes animals first identified as calves

Table 4. Microsatellite data for gray whales. Includes number of alleles per loci (k), expected heterozygosities (H_e), observed heterozygosities (H_o), and number of private alleles (K_p). The overall results include averaged values over all loci for k, H_e, and H_o, and the sum of all private alleles for K_p.

	East				West			
Locus	**K**	**H_e**	**H_o**	**K_p**	**K**	**H_e**	**H_o**	**K_p**
D17t	15	0.89	0.90	1	15	0.88	0.85	1
EV14t	9	0.81	0.78	1	9	0.76	0.74	1
EV37	17	0.88	0.89	1	17	0.85	0.91	1
EV94t	11	0.79	0.74	2	9	0.75	0.75	0
Gata028	8	0.78	0.82	3	5	0.75	0.78	0
Gata098	10	0.65	0.65	3	7	0.63	0.61	0
Gata417	7	0.71	0.71	0	7	0.63	0.65	0
Gt023	9	0.72	0.76	1	8	0.68	0.68	0
RW31	10	0.82	0.83	1	9	0.82	0.85	0
RW48	5	0.40	0.42	0	5	0.36	0.34	0
SW10t	9	0.77	0.76	1	9	0.75	0.77	1
SW13t	8	0.63	0.67	1	8	0.67	0.68	1
SW19t	10	0.71	0.67	3	7	0.64	0.67	0
Overall	9.8	0.74	0.74	18†	8.8	0.70	0.71	5†

Table 5. Analysis of molecular variance (AMOVA) and pairwise comparisons among gray whale populations from microsatellites and mtDNA control region sequences. Significant P values (<0.05) are shown in bold. Comparisons using only females and only males did not include known relatives.

Comparison	**Microsatellites**			**mtDNA**	
	Genotype frequency			**Haplotype frequency**	
	F_{ST}	F_{ST} probability	Exact test probability	F_{ST}	F_{ST} probability
All individuals	0.009	**≤ 0.001**	**≤ 0.001**	0.068	**≤ 0.001**
No known relatives	0.005	**≤ 0.001**	**≤ 0.001**	0.045	**≤ 0.001**
Females	0.013	**≤ 0.001**	**≤ 0.001**	0.078	**≤ 0.001**
Males	0.002	0.117	**0.039**	0.033	**≤ 0.001**

Table 6. Results of STRUCTURE analyis using a model incorporating admixture with correlated allele frequencies. Includes the inferred number of genetic clusters (K), the estimated log likelihood value (after averaging across runs) for the data given K (Ln P(X|K)), and the posterior probability of K (Pr (K|X)). The value of K with the highest posterior probability is shown in bold. Details about the parameters incorporated in each model are described in the text.

K	**Ln P (X|K)**	**Pr (K|X)**
1	-11612.18	~0
2	**-11469.22**	**~1**
3	-11682.32	~0
4	-11808.74	~0
5	-12214.70	~0

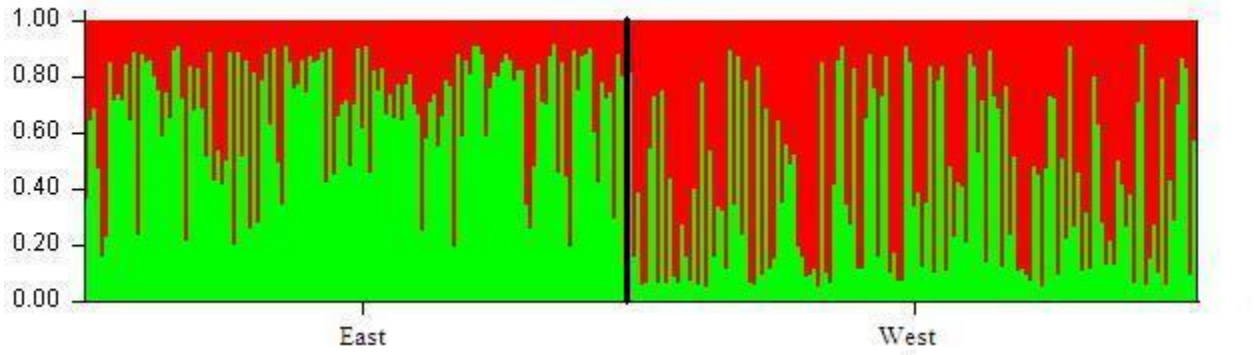

Figure 1. STRUCTURE barplot for K=2 using a model based on admixture with correlated allele frequencies. Individuals are represented by vertical bars, and the different colors of the bars represent the proportion of admixture (*Q*), or ancestry, from a each inferred genetic cluster. Individuals are grouped according to the population in which they were sampled, and the black line denotes the boundary between animals sampled in the eastern and western Pacific.

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Genetic analysis of stock structure and movements of gray whales in the eastern and western North Pacific

A.R. Lang[1], D.W. Weller[1], R. LeDuc[1], A. M. Burdin[2], V.L. Pease[1], D. Litovka[3], V. Burkanov[2, 4], R.L. Brownell, Jr.[5]

[1] Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, CA USA

[2] Kamchatka Branch of the Pacific Geographical Institute, Russian Academy of Sciences, Petropavlovsk-Kamchatsky, Kamchatka, Russia

[3] Marine Mammal Laboratory, Chukotka Branch of FGUP-TINRO, Anadyr, Chukotka, Russia

[4] National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration, Seattle, WA USA

[5] Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Pacific Grove, CA USA

ABSTRACT

Previous studies have documented genetic differentiation between gray whales in the eastern and western North Pacific on the basis of both mtDNA haplotype and microsatellite allele frequencies. In these studies, the eastern North Pacific (ENP) population of gray whales has been represented by a sample set comprised primarily of samples from animals that stranded along the migratory route. Recent studies assessing population substructuring of gray whales within the ENP have resulted in the collection and analysis of additional samples from ENP gray whales feeding north of the Aleutian Islands (n=106 sampled individuals). Here we update previous assessments of genetic differentiation between ENP and western North Pacific (WNP) gray whales using these additional ENP samples and samples collected from whales (n=142 individuals) feeding off the northeastern coast of Sakhalin Island, Russia. In addition, comparison of the mtDNA haplotype, sex, and genotypes (8 to 13 loci) of all analyzed samples (n=380) was used to identify samples with identical genetic profiles, and these genetic matches were used to infer movements of individuals between areas. Consistent with the results of previous studies, significant levels of differentiation were found between WNP and ENP gray whales using both mitochondrial (e.g., Sakhalin versus Chukotka, F_{ST} = 0.082, p<0.0001; Φ_{ST} = 0.037, p<0.001) and nuclear (e.g., Sakhalin versus Chukotka, F_{ST} =0.010, p=0.001; F_{ST}' = 0.037, p=0.001) markers (n=8 loci). Seven pairs of samples shared identical genetic profiles, including one match between an animal sampled off the coast of San Diego and an animal taken in the Chukotka hunt, four matches between animals biopsied on the Sakhalin feeding ground and animals biopsied off southeastern Kamchatka, and two matches between animals biopsied on the Sakhalin feeding ground and animals biopsied off the coast of southern California. While the significant levels of genetic differentiation support demographic independence and a degree of reproductive isolation between whales feeding in the WNP and the ENP, the putative movements detected here, in combination with information derived from photo-identification comparisons and telemetry studies, suggest that some of the animals summering off Sakhalin overwinter in the ENP in at least some years. Given that recent records document gray whales in Japanese waters during winter and spring, these results suggest that population structure in gray whales may be more complex than previously believed, such that not all of the animals which feed off Sakhalin share a common wintering ground, or that some animals may switch between wintering grounds. Thus, the number of gray whales remaining in the WNP year-round may be lower than previously thought, highlighting the need for additional studies focusing on identifying migratory routes and wintering ground(s) used by gray whales in the WNP.

INTRODUCTION

Like many species of baleen whales, gray whales (*Eschrichtius robustus*) exhibit seasonal movements between high- latitude summer feeding grounds and low- latitude wintering areas. The current distribution of this species is limited to the eastern and western margins of the North Pacific (Rice & Wolman 1971), where two populations are recognized. Although both populations were greatly depleted by commercial whaling, the population in the eastern North Pacific (ENP) currently numbers ~19,000 animals, (based on surveys in 2006/2007; Laake *et al*., 2009). Most animals in the ENP population feed in the waters of the Bering, Beaufort, and Chukchi Seas during summer and early fall and then migrate south to the lagoons and coastal waters off Baja California, Mexico to spend the winter months. However, a small number of animals (~200, Calambokidis *et al*., 2010), referred to as the Pacific Coast Feeding Group (PCFG) of gray whales (IWC, 2010), demonstrate consistent return to more southern waters between northern California and southeastern Alaska during the summer feeding season (Darling, 1984; Calambokidis *et al*., 2002, 2010). Recent genetic studies have demonstrated significant mtDNA differentiation between the PCFG and ENP gray whales feeding in areas north of the Aleutians (Lang *et al*., 2011), as well as between the PCFG and a sample set comprised primarily of whales which stranded along the migratory route in the ENP (Frasier *et al*., 2011). No significant differentiation in nuclear markers was identified, however, suggesting that PCFG whales may interbreed with animals feeding north of the Aleutians (Lang *et al*., 2011).

The population of whales in the western North Pacific (WNP) was reduced to much lower numbers than its eastern counterpart during commercial whaling. This population has been estimated to contain only about 130 animals of age one or older (Cooke *et al,* 2008) and is currently listed as Critically Endangered by the IUCN (Weller *et al.,* 2002; Baillie *et al,* 2004). Much of what is known about this population is derived from combined photo-identification and genetic studies of individuals on the population's primary feeding ground in the coastal waters of northeastern Sakhalin Island, Russia (Weller *et al.*, 1999; Weller *et al.*, 2008a; LeDuc *et al.*, 2002; Lang *et al.*, 2010). Photo-identification studies have documented seasonal site fidelity and annual return of individuals to this feeding area (Weller *et al.*, 1999). Reproductive females are known to utilize the Sakhalin feeding ground year after year when they are accompanied by calves as well as when they are pregnant or resting, and the return of many individuals first identified as calves accompanying their mothers has been documented (Weller *et al.*, 2009). Some of the whales feeding in the coastal waters off Sakhalin are also known to utilize feeding areas slightly offshore, as well as off the southern and eastern coast of Kamchatka (Tyurneva *et al*., 2010; Burdin *et al*., 2011). The whales identified off Kamchatka include some mother-calf pairs also identified on the Sakhalin feeding ground (Tyurneva *et al*., 2010). However, not all of the whales photographed off Kamchatka have been identified off Sakhalin, and their population affiliation is unknown.

Genetic samples have been collected from 83 % (n=142) of the whales identified on the Sakhalin feeding ground between 1995 and 2007 (Lang, 2010). Comparison of this sample set with samples collected from whales in the eastern North Pacific (ENP) have supported recognition of the two populations as distinct, with differentiation in both mtDNA haplotype and microsatellite allele frequencies (LeDuc *et al.*, 2002; Lang *et al.*, 2010). Assessment of the paternity of animals first identified as calves on the Sakhalin feeding ground between 1995 and 2007 (n = 57 sampled mother-calf pairs) resulted in the assignment of putative fathers for 46-53% of the calves, supporting interbreeding among animals that feed off Sakhalin but also raising questions about the identity of the unassigned fathers (Lang, 2010).

Little is known about the location of migratory routes and wintering ground(s) currently used by the whales that feed off Sakhalin. The coastal waters of southeastern Russia, the Korean Peninsula, and Japan are thought to have been used as migratory corridors historically, and some evidence exists suggesting that the coastal waters of southern China may have been used as wintering grounds (reviewed in Weller *et al.*, 2002). Aside from sightings of whales in feeding areas, the majority of recent records of gray whales in the WNP are of sightings, strandings, and entrapments in the coastal waters of Japan (see details in Kato *et al*., 2010). Although little is known about the identity of most of the whales recorded off Japan, photographs of one animal which was entrapped off the Pacific coast of Japan in January 2007 were matched to an animal first

photographed as a calf on the Sakhalin feeding ground in 2006, providing the first known link between the Sakhalin feeding ground and a migratory route in the western North Pacific (Weller *et al*., 2008b).

In October 2010, a team of scientists from Russia and the United States deployed a satellite tag on a gray whale off the coast of Sakhalin Island[1]. The tagged individual ("Flex") was a 13 year-old male that had been first identified as a calf off Sakhalin in 1997 and subsequently demonstrated repeated return to the Sakhalin feeding ground. "Flex" was tracked for ~4 months, during which time he traveled from the feeding ground off Sakhalin Island to the western coast of the U.S.[1, 2, 3]. Subsequent comparison of photographs of "Flex" collected off the coast of Sakhalin with photographs collected by Cascadia Research Collective in the Pacific Northwest revealed that Flex had previously been photographed off the coast of Vancouver Island in April 2008 (Weller *et al*., 2011). The satellite track and photographic record of "Flex" have since raised questions about the potential for movements of gray whales between the eastern and western North Pacific.

Prior analyses of genetic differentiation between ENP and WNP gray whales have been based on an ENP sample set in which the majority of samples were collected from animals which stranded along the migratory route (LeDuc *et al*., 2002; Lang *et al.,* 2010). As part of recent efforts to better understand the potential for substructure in ENP gray whales (Lang *et al*., 2011), additional samples were collected and analyzed from gray whales utilizing feeding grounds north of the Aleutians. This sample set provides the opportunity to update previous assessments of genetic differentiation between eastern and western gray whales and will allow direct comparisons to be made between animals utilizing feeding areas in the ENP and in the WNP. The expanded data set will also be used to identify samples with identical genetic profiles, which may provide information on movements of animals both within and between the eastern and western North Pacific.

METHODS

Sample Collection

The collection location for all samples utilized in the study is shown in Figure 1. Within the WNP, samples were collected between 1995 and 2007 via biopsy-darting of 142 individual whales on the feeding ground off Sakhalin Island, Russia. All except one of these samples are linked to a photographically identified animal, and this sample set represents 83% of all animals (n=169) identified on the Sakhalin feeding ground through 2007. Additional samples were collected via biopsy darting of whales between Kamenistaya Bay and Asacha Bay on the southeastern coast of Kamchatka, Russia during the summer months of 2004 (n=3 samples) and 2010 (n=12 samples).

Within the ENP, samples were collected from 228 individuals. Table 1 shows the year of sample collection as well as the collection method, with samples subdivided into those collected from animals south of the Aleutians ("CA->AK") and those collected on the northern feeding ground(s) ("N of Aleutians").

Lab Processing:

Details on protocols for extraction, sequencing, molecular sexing, and genotyping of the samples collected off Sakhalin Island and samples collected in the ENP between California and the Aleutians are provided in Lang *et al*. 2010. These samples were genotyped at 13 loci, including D17t, EV14t, EV37, EV94t, Gata028, Gata098, Gata417, Gt023, RW31, RW48, SW10t, SW13t, and SW19t.

Protocols used for generating data for the samples collected north of the Aleutians and those collected off of the coast of southeastern Kamchatka are described in Lang *et al*. 2011. These samples have been genotyped at 8 loci, including EV14t, EV94t, Gata028, Gt023, Gata417, RW31, SW13t, and SW19t. Genotypes for the additional five loci included in Lang *et al.* 2010 are currently being generated. Analysis of genetic diversity

[1] http://www.iucn.org/wgwap/?6614/International-scientists-track-endangered-whale-to-discover-breeding-grounds[1]
[2] http://mmi.oregonstate.edu/Sakhalin2010
[3] http://www.sevin.ru/menues1/index_rus.html?../ExpeditionsRAS/Gray_whale/Gray_whale.html

and differentiation for nuclear markers used only the eight microsatellite loci which have been generated for all samples, although the calculation of probabilities associated with identifying genetic matches utilized the 13-loci dataset when available.

Analysis

Sample Stratification

Samples were separated into strata for analysis based on the geographic location of sample collection. Within the WNP, samples were subdivided into two strata. All samples collected from animals off the northeastern coast of Sakhalin Island were included in the Sakhalin stratum; the composition of this stratum is identical to that utilized in Lang *et al*., 2011. Samples collected from whales off the southeastern coast of Kamchatka were included in a southeastern Kamchatka stratum.

Within the ENP, samples were first classified into two broad-scale strata, with all samples from feeding grounds north of the Aleutians included in the "north of Aleutians" stratum and all samples from animals obtained along the migratory route between southern California and southeastern Alaska included in the "CA->AK" strata. The "north of the Aleutians" stratum is identical in composition to the "North" stratum utilized in Lang *et al*., 2011. The "CA->AK" stratum is similar in composition to the stratum used to represent ENP gray whales in previous comparisons (LeDuc *et al*., 2002; Lang *et al*., 2010; Frasier *et al*., 2011); however, all samples which were collected from animals north of the Aleutians were removed and were retained in the "north of the Aleutians" stratum. Although all samples included in the "CA->AK" stratum were obtained from regions utilized as part of the migratory route in the ENP, the region between northern California and southeastern Alaska is also used as a feeding ground by the PCFG whales. While none of the samples included in the "CA->AK" stratum were known to be from PCFG whales (i.e., none of these samples were included in the "South" or "PCFG" strata utilized in Lang *et al*., 2011), it is possible that some PCFG whales could be included in this stratum.

Little is known about whether or not additional substructuring occurs among whales feeding in different areas within the larger "north of the Aleutians" feeding ground. To avoid inadvertently using a stratum that may contain unrecognized structure, samples collected north of the Aleutians were further subdivided into the "Chukotka" and "Barrow" strata. These strata are the same as those used in Lang *et al*., 2011, and additional details on the rationale for this stratification system are included in that manuscript.

The Microsoft EXCEL program MS_TOOLKIT (Park, 2001) was used to identify samples with genotypes that matched at all loci. The mtDNA haplotype and sex of animals with identical genotypes were used to confirm all identified matches. For those samples that shared identical genetic profiles and were collected within the same region (i.e., were included in the same stratum), one of each pair of matching samples was removed prior to analysis.

Genetic Diversity

For the mtDNA, haplotypic diversity (h) and nucleotide diversity (π) were calculated using Arlequin 3.5.1.2 (Excoffier *et al.,* 2005). For the 8-loci microsatellite dataset, the number of alleles per locus and observed and expected heterozygosities were calculated using custom R-code (eiaGenetics, available upon request[1]). Deviations from Hardy-Weinberg equilibrium (HWE) were assessed for each microsatellite locus using Genepop (version 4.0.11, Rousset 2008). Both the probability test (Guo & Thompson, 1992) and the test for heterozygote deficiency (Rousset and Raymond 1995) were conducted using the program defaults for the Markov chain parameters (10,000 dememorization steps, 20 batches, 5000 iterations/batch). Genepop was also used to test for linkage disequilibrium (LD) for each pair of loci.

Genetic Structure

Pairwise estimates of genetic divergence were calculated using both F_{ST} and Φ_{ST} (based on pairwise differences between sequences as the measure of genetic distance) for the mtDNA data as implemented in Arlequin 3.5.1.2 (Excoffier *et al.,* 2005). Statistical significance was assessed using 20,000 permutations.

Fisher's exact test (Raymond & Rousset, 1995) was also used to test for mtDNA differentiation between strata using 100,000 replications to test for significance.

For the 8-loci microsatellite dataset, F_{ST} (Weir & Cockerham, 1984), normalized F_{ST}, Jost's D (Jost, 2008), and a χ^2 test were used to assess genetic differentiation. These tests were implemented using custom code (eiaGenetics[4]) written in the statistical program language R (R Core Development Team, 2009). Statistical significance was determined from 10,000 permutations of each data set.

Movements

As aforementioned, the EXCEL add-in MS_TOOLKIT (Park, 2001) was used to identify samples with genotypes that matched at all loci, and the mtDNA haplotype and sex of animals with identical genotypes were used to confirm all identified matches. Although the majority of the genetic matches detected were collected from animals within the same region, several were collected from animals in different areas and may represent movements of individuals. The program GENECAP (Wilberg & Dreher, 2004) was used to calculate the probability of identity using the microsatellite genotypes. The probability of identity (PID) is defined as the probability that two individuals drawn randomly from the dataset will have the same genotype at multiple loci. This statistic was initially calculated under the assumption of Hardy-Weinberg equilibrium (PID_{HW}, Paetkau & Strobeck, 1994). However, such estimates may be biased in the presence of population structure. Calculations assuming the presence of full siblings within the dataset (PID_{SIB}) are considered more conservative (Waits *et al.* 2001) and were calculated using the formula of Evett & Weir (1998).

The match probability (*e.g.*, individual probability of identity) is defined as the probability that given the genotype of one individual, a second individual will have the same genotype. For the genetic matches between samples collected in different areas, the match probability was calculated for all identified pairs of duplicate genotypes both under the assumption of Hardy-Weinberg equilibrium and assuming that the two individuals were full siblings (Woods *et al.,* 2009).

RESULTS

Population Structure –

Forty mtDNA haplotypes defined by 38 variable sites were identified among the 377 gray whale samples for which mtDNA sequences were produced (Table 2). Haplotype diversity (*h*) was high in all of the ENP strata (*h* = 0.952-0.967) but was reduced in the WNP strata (*h*=0.77, Sakhalin; *h*=0.80, southeastern Kamchatka). Nucleotide diversity (π) was also similar across all strata, although slightly higher in the WNP strata (1.8-1.9%) than in the ENP strata (1.2 – 1.6%).

The number of individuals with each haplotype in each stratum is shown in Table 3, with data for the PCFG stratum taken from Lang *et al*., 2011. Within the Sakhalin stratum, two haplotypes were found in very high frequencies, with 36% of sampled animals having haplotype 1 and 31% having haplotype 2. Within the ENP strata, no haplotypes were found in frequencies greater than 14%. The three highest frequency haplotypes in the PCFG stratum were found in 10% and 13% of individuals.

Within the Sakhalin stratum, the number of known mother-calf pairs with each haplotype, relative to the total number of animals with each haplotype, is shown in Figure 2. Of the 51 animals with haplotype 1, 59% were part of a known mother-calf pair, while 66% of the individuals with haplotype 2 (n=44) were animals from a known mother-calf pair. With one exception, all haplotypes that were identified in more than two sampled animals in the Sakhalin stratum are composed of at least one known mother-calf pair.

The median-joining network shows the relationship among mtDNA haplotypes and their frequency in each

[4] Contact E. Archer @Eric.Archer@noaa.gov

stratum (Figure 3). MtDNA haplotypes identified among animals feeding off Sakhalin are dispersed throughout the network, and no phylogeographic pattern is apparent.

Measures of microsatellite diversity for each stratum after averaging across the eight loci common to both datasets are shown in Table 4. Nuclear diversity was similar across all strata. None of the tests for HWE were significant after the correction for multiple tests was applied. Significant linkage disequilibrium was found for two pairs of loci (one in the "Sakhalin" stratum and one in the "north of the Aleutians" stratum) after the correction for multiple tests was applied. No significant LD was found for these two loci pairs in any of the other strata, so these loci were retained for the analysis.

The results of the mtDNA comparisons are shown in Table 5. All comparisons between ENP strata and the Sakhalin stratum were highly significant ($p<0.001$). No significant differentiation was found when the CA->AK stratum was compared to either Chukotka ($F_{ST}=0.010$, $p=0.0883$; $\Phi_{ST}<0.001$, $p=0.5009$; χ^2 $p=0.5466$) or the combined set of all samples collected north of the Aleutians ($F_{ST}=0.005$, $p=0.1488$; $\Phi_{ST}=0.001$, $p=0.3477$; χ^2 $p=0.4049$).

Similar results were found in the microsatellite comparisons (Table 6). With one exception (Sakhalin versus all samples collected north of the Aleutians, Jost's $D = 0.0004$, $p = 0.1169$), all other comparisons between the ENP strata and the Sakhalin stratum were highly significant ($p<0.001$ to $p=0.002$). No significant differentiation was identified when strata within the ENP were compared.

Genetic Matches

Of the 380 samples genotyped, seven pairs of samples were identified that were collected in different areas and that shared identical microsatellite genotypes, mtDNA haplotypes, and sexes. These genetic matches included four matches between samples collected from the Sakhalin feeding ground and samples collected from southeastern Kamchatka, one match between an animal sampled off San Diego, California and an animal killed in the Chukotka hunt in Russia, and two matches between animals sampled off Sakhalin and animals sampled off the coast of southern California (Figure 1). The average probability of identity based on allele frequencies of all sampled animals was 1.35×10^{-8} (PID_{HW}) and 7.50×10^{-4} (PID_{SIB}) for the 8-loci dataset.

The individual match probabilities are shown in Table 7. For the 8-loci dataset, the individual match probabilities ranged from 6.74×10^{-4} to 1.24×10^{-3} (P_{SIB}) and 9.10×10^{-10} to 1.16×10^{-8} (P_{HW}). There were no samples that mismatched at only 1 allele but two pairs of samples were identified that mismatched at only 2 alleles and had identical mtDNA haplotypes and sexes. However, both pairs were part of the Sakhalin dataset analyzed in Lang *et al*. 2010, and when the 13-loci genotypes were compared the two pairs differed at 6 and 7 loci. Genotypes for the additional five loci are currently being generated for the Lang *et al*. 2011 dataset.

Although the 8-loci match probabilities assuming HW equilibrium were relatively low, the more conservative P_{SIB} measures are high, suggesting probabilities as great as 1 in 1000 that two individuals could share the same genotype by chance. Although P_{SIB} values are considered overly conservative in most cases (Rewe *et al*., 2011), the genetic matches based on the 8-loci dataset should be considered only preliminary evidence of movements until the matches can be corroborated with the addition of more loci. However, although no photographs exist for the animal(s) included in the San Diego-Chukotka match, photographs were collected of the animals biopsied off Kamchatka. Comparison of these photographs to the Sakhalin photo-identification catalogue maintained by the joint Russia-U.S. research program verified that in all four cases the genetic matches represented samples collected from the same animal.

The two sets of matching samples identified between Sakhalin and southern California were genotyped at 13 loci. For both pairs, the genotypes were heterozygous for 10 of the 13 loci genotyped, and all other samples in the 13-loci dataset had genotypes that mismatched at five (n=1 pair) or more loci. Precautions, including replication of genetic profiles after re-extraction of the DNA from the tissue, were taken to ensure that the matching genotypes were not an artifact of lab error (detailed in Lang, 2010). The power of the microsatellite panel used to discriminate between individuals was high when the 13-loci dataset was analyzed (PID_{HW} =

8.65×10^{-14}; $PID_{SIB} = 1.04 \times 10^{-5}$) and comparable to that used in other studies utilizing genetic tagging to infer movements of individuals between areas (*e.g.,* PIDave = 1.51×10^{-7}, Palsboll *et al.* 1997; PIDsib = 2.8-3.11 x 10^{-5}, Pomilla and Rosenbaum 2005;). The more conservative estimates of the match probabilities (P_{SIB}) calculated from the gray whale microsatellite data suggest that the probability of finding two different animals with these identical genotypes is 1/50,000 (for the match between females) and 1/100,000 (for the match between males). The less conservative measures (P_{HW}) suggest that the probability is almost infinitesimally small. It is likely that the true probability lies somewhere between these two estimates, given that there is evidence for population structure in our data but it is unlikely that many full siblings were represented. Based on these considerations, the probability that the two sets of matching genotypes identified between the eastern and western North Pacific are an artifact of laboratory errors or a lack of resolution in the markers used is small.

Both of the biopsies from the ENP were collected during the same expedition. Sample #3947 was collected on 20 March 1995, and sample #3950 on 23 March 1995. Both samples were taken from whales in the Santa Barbara Channel off southern California, and the timing and location indicates that the samples were likely collected from animals which would have been migrating north after overwintering in the ENP. Although some video was taken during this sampling trip, it proved to be of too poor resolution to be useful in photographic comparisons. Sample #12186 was collected from an animal on the Sakhalin feeding ground on 14 August 1998. Photo-identification records link this whale to an animal that was first identified in that area on 19 August 1995. This male was sighted off Sakhalin during ten of the 12 seasons covered by the study. Sample #50728 was collected from a whale on the Sakhalin feeding ground on 27 August 2004. Photo-identification was used to link this animal to a whale first identified in that area in 1999. This female was then sighted off Sakhalin in all subsequent years of the study. Extensive photo and video documentation exists for both of these animals.

DISCUSSION

Population Structure –

The genetic signal of matrilineal fidelity among the whales sampled off Sakhalin is apparent both in the measures of mtDNA differentiation and in the distribution of haplotypes among individuals. Similar to the results of previous comparisons of samples collected in the WNP with samples obtained primarily from whales on migratory routes in the ENP (LeDuc *et al*., 2002; Lang *et al*., 2010), mtDNA comparisons between the Sakhalin stratum and strata comprised of animals feeding north of the Aleutians were highly significant. The magnitude of mtDNA differentiation between the Sakhalin stratum and the ENP strata (WNP v. North, F_{ST}=0.086, p<0.0001; Fisher's exact test, p<0.0001; WNP v. Chukotka, F_{ST}=0.082, p<0.0001, Fisher's exact test, p<0.0001) is greater than that seen in comparisons between whales utilizing different feeding grounds within the ENP (PCFG v. North, F_{ST}=0.01, p=0.005; Fisher's exact test, p=0.008; PCFG v. Chukotka, F_{ST}=0.01, p=0.012; Fisher's exact test, p=0.030; Lang *et al*., 2011).

As has been previously described (LeDuc *et al*., 2002; Lang *et al*., 2010), the distribution of haplotypes among sampled individuals in the Sakhalin stratum is highly skewed, with two haplotypes found in very high frequencies, representing 36% and 31% of all animals sampled from that area. Given the maternal inheritance of mtDNA, this pattern would be expected if utilization of this area was driven in large part by the continued return over time of a small number of females and their offspring (and eventually their offspring's offspring). Examination of the haplotypes carried by sampled individuals revealed that 16 of the 23 known reproductive females identified between 1995 and 2007 (Weller *et al*., 2008a) share one of these two common haplotypes (Lang, 2010), and known mother-calf pairs comprise a large proportion of animals with the two common haplotypes. Within any of the strata representing the ENP, there were no haplotypes found in frequencies greater than 14% of sampled individuals. This was also true of the PCFG, in which the three highest frequency haplotypes were found in 10 and 13% of sampled animals (Lang *et al*., 2011).

Similar to results of previous comparisons of samples collected in the WNP with those obtained primarily from animals along the migratory route in the ENP (based on n=13 loci, Lang *et al*., 2010), significant levels of

nuclear differentiation were also found between animals feeding north of the Aleutians and those feeding off of Sakhalin. Although highly statistically significant, the magnitude of nuclear differentiation was relatively low, which has lead to speculation that some limited degree of dispersal or gene flow could be occurring between the WNP and ENP populations (LeDuc *et al*., 2002; Lang *et al.*,2010; Lang, 2010). However, the significant differences identified in both the mtDNA and the microsatellite comparisons indicate that the group of animals feeding off Sakhalin is not only demographically independent from animals feeding in the eastern North Pacific, but also that a degree of reproductive isolation is occurring. This differs from what has been reported thus far within the ENP (Lang *et al*., 2011), where comparisons of microsatellite differentiation have suggested that animals feeding in different areas of the ENP may interbreed.

One limitation of this analysis is that all of the WNP samples were collected from animals on feeding grounds. A preliminary mtDNA analysis of six samples collected from gray whales (five females and one of unknown sex) which were stranded or entrapped in Japanese coastal waters found high haplotype (h=0.933) and nucleotide (π=1.85%) diversity (Kanda *et al*., 2010). No significant differentiation was found when these Japanese samples were compared to their samples (n=7) collected from whales taken in the hunt off Chukotka, although the small sample sizes used in the comparison limited the conclusions that could be drawn (Kanda *et al*., 2010). One of the whales included in the analysis was the animal that was entrapped off the Pacific coast of Japan in January 2007 and that had previously been identified off Sakhalin. This animal has a haplotype (Haplotype 2 or B) which is common among animals sampled off Sakhalin. Although one of the other samples analyzed had a haplotype (Haplotype 1 or A) that is found in high frequencies among animals sampled off Sakhalin, the other four animals had haplotypes which have been identified in only one or two animals sampled off Sakhalin.

Movements –

Within the WNP, comparison of the genetic profiles of sampled animals indicates that four of the ten whales biopsied off southeastern Kamchatka were also sampled while on the Sakhalin feeding ground. These four genetic matches, which were confirmed photographically, include samples collected from two animals (one male and one female) first identified as calves on the Sakhalin feeding ground in 2007, indicating that these animals would have been ~3 years old when they were sampled off Kamchatka in 2010. The mother of one of these calves is also the mother of one of the animals first identified as a calf off Sakhalin and later photographed in the ENP (Weller *et al*., 2011). The other two samples were collected from males first identified as non-calves off Sakhalin in 1994 and 1995. One of these males has also been photographed in the ENP (Weller *et al*., 2011). The remaining six samples could not be matched to the genetic profiles of whales sampled off Sakhalin. These samples may represent animals that do not utilize the Sakhalin feeding ground, or they could be from animals known to feed off Sakhalin but from which no genetic sample has been collected. These results are consistent with patterns identified in photo-identification comparisons between southeastern Kamchatka and Sakhalin, in which 61 of the 116 animals identified off Kamchatka between 2004 and 2009 had also been sighted on the Sakhalin feeding ground (Tyurneva *et al*., 2010). Photo-identification work has also documented the use of the southeastern Kamchatka area by young whales (Tyurneva *et al*., 2010; Burdin *et al.*, 2011).

The detection of two pairs of matching samples between the ENP and WNP was more surprising. If these genetic matches do represent movements of individuals, they suggest that these animals, both of which are known to demonstrate fidelity to the western Pacific during the feeding season, have overwintered in the eastern Pacific for at least one season. Although the results presented here, as well as those from previous studies (LeDuc *et al*., 2002; Lang *et al*., 2010), have confirmed that the eastern and western gray whale populations are genetically differentiated, the relatively low level of differentiation observed at nuclear markers suggested that some degree of dispersal of eastern animals onto the western feeding ground may occur (Lang et al. 2010, Lang, 2010). In the past, this dispersal was hypothesized to have been mediated largely by males, as supported by observations that the majority of haplotypes found in only one or two individuals are represented only by males (LeDuc *et al*., 2002; Lang *et al*., 2010) as well as by the lower levels of differentiation found when only males were compared between ENP and WNP strata (Lang, 2010). However, the putative movements associated with these genetic matches suggest that both males and females

may travel between these two areas. Other factors, such as age and oceanographic conditions, may also influence any movements.

In addition, the female associated with sample #50728 is a known reproductive female and was identified (both behaviorally and genetically) as the mother of three calves between 2003 and 2007. Although two of her calves were not assigned a putative father among the sampled western animals in the paternity analysis, her 2007 calf was assigned a putative father that has been sighted regularly on the Sakhalin feeding ground (Lang, 2010). The paternity analysis assigned the male associated with sample #12186 as the putative father of a calf born in 2007 (Lang, 2010). This calf was one of the two animals first identified as calves off of Sakhalin which were genetically and photographically matched to the southeastern coast of Kamchatka in 2010. This evidence suggests that both of the whales sampled off Sakhalin interbred at least one time with other animals which feed in the WNP.

Even if all 130 of the animals which feed off Sakhalin were to have visited the eastern Pacific during the study period, it would seem unlikely that one of the western animals would have been sampled given the size of the eastern population and the relatively low proportion of animals sampled in the eastern Pacific. If samples obtained from stranded or harvested animals in the ENP prior to 1995 (n=24) are excluded, samples were obtained from only 203 individuals in the ENP during the period of time (*i.e.*, in 1995 or later) in which an animal identified on the western feeding ground could have feasibly been sampled (Table 1). Only 48 of these samples were collected via biopsy-darting, while the rest were collected from animals which were stranded, hunted, or taken in fishing gear. The probability of sampling one of ~130 Sakhalin animals among an estimated 19,000 eastern gray whales is approximately 1/150; assuming the two events are independent, the probability of capturing two Sakhalin animals is approximately 1/22500. These probabilities would be even lower if only a small number of the animals identified in the WNP travel to the ENP.

However, if the genotype matches do represent dispersal of whales between Sakhalin and the ENP, the short time span over which the two samples were collected in the ENP raises questions about the independence of the two events. One possible explanation is that some segregation takes place on the migratory route relative to the feeding location. Southbound migration timing has been correlated with feeding ground origin in North Atlantic humpback whales (Stevick *et al.,* 2004), which utilize two different feeding areas but a common breeding area in the West Indies. Animals that fed in the Gulf of Maine and eastern Canada had earlier mean sighting dates in the West Indies than did animals known to feed in Greenland, Iceland, and Norway, suggesting that the migration from feeding area to breeding area might be segregated. Although stratification of the gray whale migration relative to age, sex, and reproductive status is known to occur (Rice & Wolman 1971), no additional mechanisms for segregation have been identified.

Weller *et al*. (2011) presents the results of a comparison between the Sakhalin photo-identification catalogue and a catalogue of whales photographed in the Pacific Northwest that is maintained by Cascadia Research Collective. The results of this photographic comparison were similar in several regards to the findings from the genetic comparison. Six animals that were photographed off Sakhalin were also identified in the Pacific Northwest during months (late April and early May, when field efforts in this area are relatively low) when the animals would have been migrating north. Three of the animals were photographed on one day, while the other three were photographed on another day, further suggesting that some segregation with respect to feeding ground origin may occur on the northbound migration. The combined findings indicate that, despite the low probability of sampling or photographing one of ~130 Sakhalin animals while the majority of the 19,000 whales comprising the eastern population are migrating, as many as eight animals have been either photographed or sampled despite relatively low field effort. These results suggest that the potential for photographing or sampling a Sakhalin whale, at least while on the northbound migration, is higher than would be expected based on the assumption of random intermixing of animals with eastern versus western summer destinations.

While estimates of genetic differentiation support demographic independence and a degree of reproductive isolation between whales feeding in the WNP and the ENP, information from tagging[1], photo-identification comparisons (Weller *et al*., 2011), and genetic comparisons suggest that some of the animals summering off

Sakhalin overwinter in the ENP in at least some years. Conception in gray whales is thought to primarily occur during a three week period from late November to early December (Nov 27 – Dec 13), although if no conception occurs during this first period, a second estrus may occur about 40 days later when whales are on or near their wintering grounds (Rice & Wolman, 1971). Rugh *et al.* (2001) estimated that the median (peak) sighting date for the southbound migration in the ENP is 12 December for Unimak Pass, Alaska, suggesting that many animals from the ENP are north of the Aleutians during the first mating period. With the exception of the 13 year-old male ("Flex") that was tagged off Sakhalin this past fall and remained off northeastern Sakhalin until early December[5], little is known about the current migratory timing of and route(s) used by any whales traveling between Sakhalin and the ENP. However, it is plausible that animals making this journey would be relatively far west during the first mating period, suggesting a mechanism by which some degree of reproductive isolation could develop between animals feeding off Sakhalin and those feeding in eastern areas even if they shared a common wintering destination.

Recent records of gray whales off Japan, however, indicate that some whales remain in the WNP during winter months. Since 1955, there have been 19 reports of gray whales in Japanese waters, most of which (n=13) occurred in 1990 or later (Kato *et al*., 2010). These reports span the months of November through August, although the majority (n=11) were recorded between March and May, when animals would likely be migrating north. At least one of the whales, an approximately one year old female that was entrapped off the coast of Honshu in January 2007, is known to have also visited Sakhalin with her mother the summer prior to her entrapment (Weller *et al*., 2008b). Although it is not known what proportion of the other gray whales reported in Japanese waters were also animals that visited Sakhalin, this link indicates that not all of the gray whales feeding off Sakhalin show fidelity to wintering destinations in the ENP.

These observations suggest that population structure in gray whales may be more complex than previously thought, such that animals utilizing the Sakhalin feeding ground may not all share a common wintering ground. Photo-identification and genetic studies of humpback whales in the North Pacific have revealed similar, albeit more complicated, patterns (Calambokidis *et al*., 2008; Baker & Steel, 2010). Significant differences in mtDNA haplotype frequencies (overall F_{ST} = 0.179) have been used to define 7 different "eco-stocks" among the feeding grounds. Differences in both mitochondrial and nuclear DNA have also been used to delineate five reproductive units or "breeding stocks" on the wintering grounds (overall F'_{ST} = 0.034 for nuclear comparisons, Baker & Steel, 2010). However, some feeding grounds (e.g., Kodiak) are comprised of individuals from different breeding stocks (Calambokidis *et al*., 2008).

Conclusion

Although questions remain about the movements of Sakhalin gray whales when they are not on the feeding range, the significant mtDNA and nuclear genetic differences between animals utilizing the Sakhalin feeding ground and those summering in the ENP support the continued recognition of the Sakhalin animals as a distinct unit. Additional satellite tagging of Sakhalin gray whales, along with continued collection and analysis of photo-identification and genetic data, especially from Japan, is needed to address these questions. If some proportion of the animals that feed off Sakhalin overwinter in the ENP, then the number of animals remaining in the WNP year-round may be smaller than previously estimated, and the impact of potential threats to this group of animals may be greater than predicted. As such, learning more about migratory routes and wintering grounds in the WNP should be a priority of future work.

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[5] http://mmi.oregonstate.edu/Sakhalin2010

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Figure 1. Map showing collection locations for samples analyzed in the study. Lines link recapture locations of genetic matches but do not denote movement tracks of animals. Text above lines indicates the number of matching genotypes between areas.

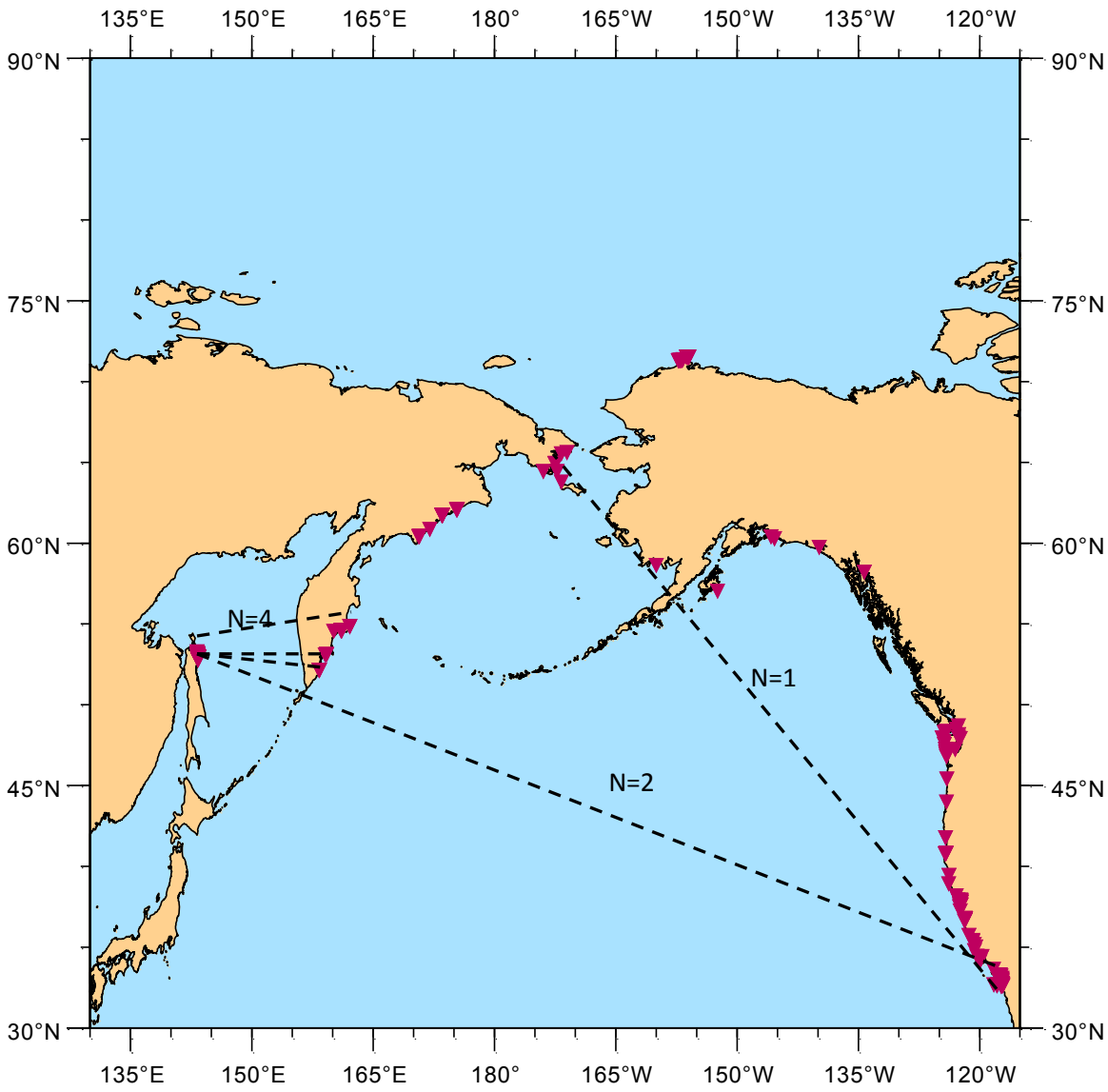

Table 1. List of genetic samples used in the study which were collected from gray whales in the eastern North Pacific. The year of sample collection, source of tissue, and designated strata are shown

YEAR	Biopsy		Strand		Fishery	Harvest	Total
	CA->AK	N of Aleutians	CA->AK	N of Aleutians	CA->AK	N of Aleutians	
?						1	1
1979			1				1
1990			1				1
1992			5				5
1993			2				2
1994			2			12	14
1995	6						6
1996			1				1
1997			4	1			5
1998			13		1		14
1999			13	1	1		15
2000			41	1			42
2001	2		1	1		25	29
2002			3				3
2003	2		3			13	18
2004			8	1		11	20
2005	3		1	1	1	9	15
2006	6		1				7
2010		29					29
Total	19	29	100	6	3	71	228

Table 2. Genetic diversity estimates for each strata based on mtDNA control region sequences (523 bp in length). For haplotype diversity and nucleotide diversity, standard deviations are included in parentheses.

Region	Strata	No. of Samples	No. of Haplotypes	Haplotype Diversity (h)	Nucleotide Diversity (π)
ENP	North of Aleutians	103	32	0.952 (+/- 0.008)	0.0141 (+/- 0.007)
	Chukotka	69	27	0.953 (+/- 0.011)	0.0142 (+/- 0.007)
	Barrow	14	11	0.967 (+/- 0.037)	0.0123 (+/- 0.007)
	CA->AK	122	34	0.956 (+/- 0.006)	0.0162 (+/- 0.008)
WNP	Sakhalin	142	22	0.770 (+/- 0.025)	0.0182 (+/- 0.009)
	SE Kamchatka	10	5	0.800 (+/- 0.100)	0.0192 (+/- 0.011)
All		377†	40	0.914 (+/- 0.008)	0.0177 (+/- 0.009)

† "North of the Aleutians" includes samples from both Chukotka and Barrow

Table 3. The number of individuals with each haplotype in each stratum. Data for the PCFG stratum, which is taken from Lang *et al*., 2011, is included for comparative purposes.

	Strata					
MtDNA Haplotype	Barrow	Chukotka	CA->AK	SE Kamchatka	Sakhalin	PCFG
1	2	8	13	3	51	7
2		2	11	4	44	4
3	1	9	9		9	1
4		4	6		5	6
5		1	4		3	1
6					1	
7		4	8		2	6
8		1	1		2	2
9		1			1	
10				1	1	
11	1	2	4			3
12	1	4	5		1	3
13		3	6		2	9
14		1	5		1	7
15	2					
16	1		2			
17			1		1	
18		3	7			2
19			1			
20	2	1	7		1	2
21	1	1	3	1		3
22		1	3		1	
23		4	1			
24		2	5			3
25		4	2	1	1	1
26	1	1	1		1	
27			2			4
28		2	2		3	2
29		2	1			
30			3			1
31		1	1			
32			1			
33		4	1		1	1
34			1			
35	1		1		7	
36	1		2			1
38		1			3	
41			1			
42		1	1			
43		1				
46						1
47						1
Total	14	69	122	10	142	71

Figure 2. Graph showing the distribution of mtDNA haplotypes in the Sakhalin stratum. Known mother-calf pairs with each haplotype are represented in green.

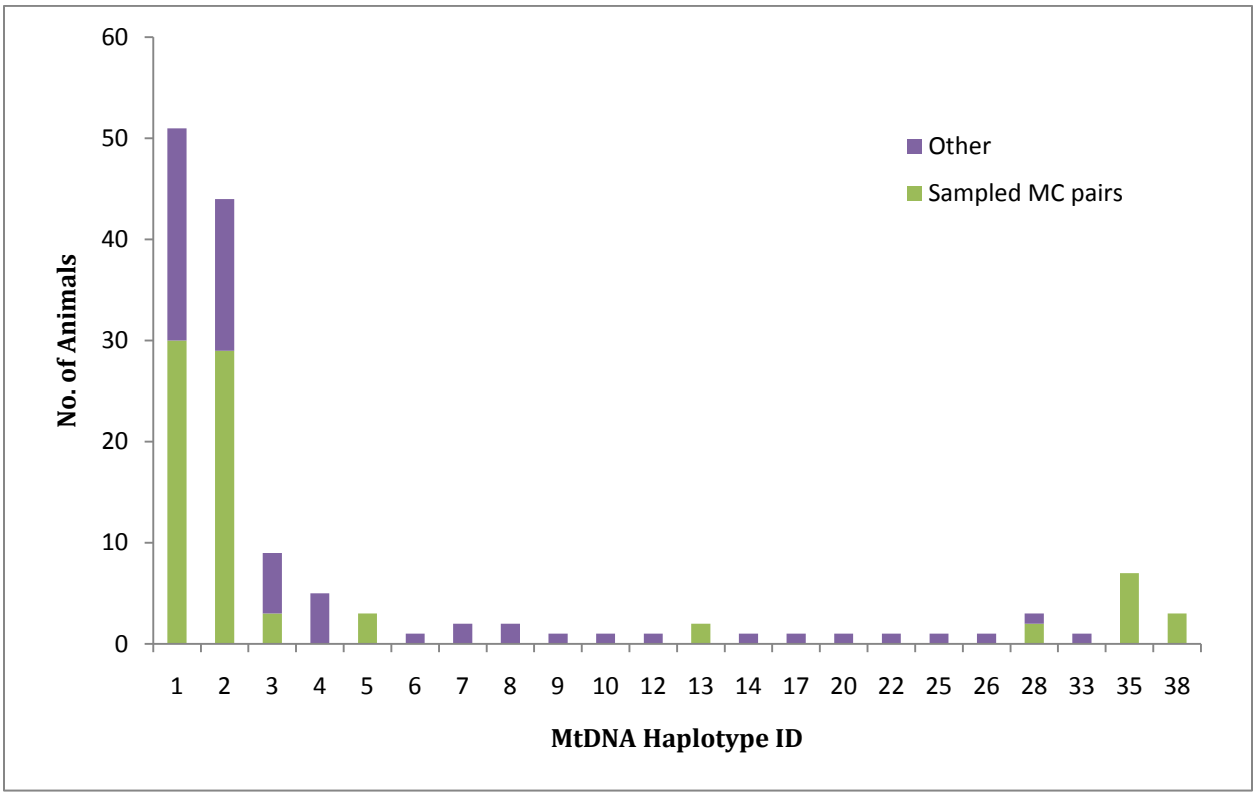

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Figure 3. Median joining network for the mtDNA haplotypes.

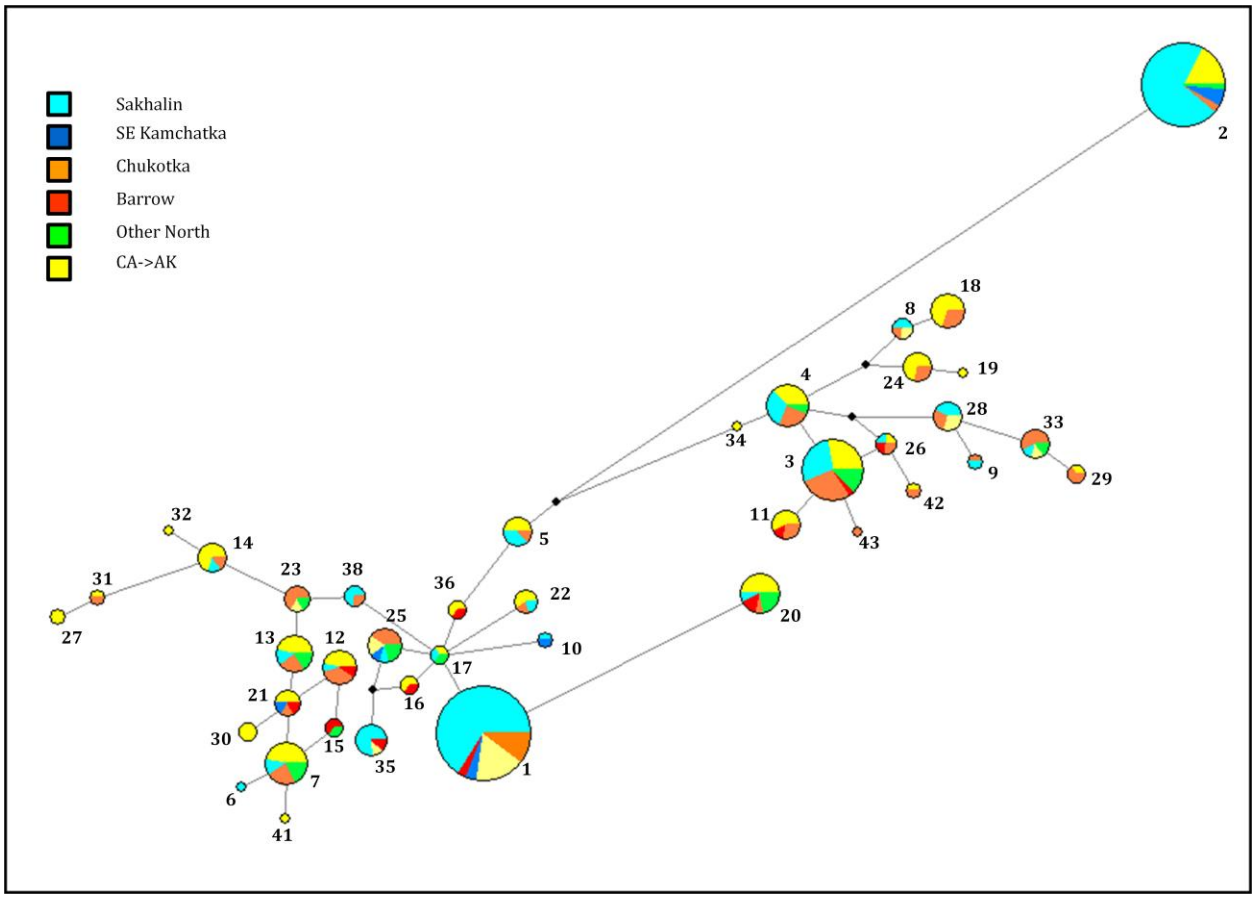

Table 4. Genetic diversity measures for the nuclear DNA data set based on 8 microsatellite loci, including the mean number of alleles, and mean expected and observed heterozygosity.

Region	Strata	No. of Samples	Mean No. of alleles	Mean He	Mean Ho
ENP	North of Aleutians	106	8.25	0.746	0.728
	Chukotka	71	7.88	0.748	0.737
	Barrow	14	5.00	0.723	0.705
	CA->AK	122	8.88	0.746	0.747
WNP	Sakhalin	142	7.75	0.712	0.724
	SE Kamchatka	10	5.13	0.730	0.713
All		380†	9.38	0.739	0.737

† "North of the Aleutians" includes samples from both Chukotka and Barrow

Table 5. Results of MtDNA comparisons across strata, with sample sizes shown in parentheses. Significant p-values are highlighted in bold.

Pairwise Comparison	Φ_{ST}	p-value	F_{ST}	p-value	χ^2 p-value
Sakhalin (142) v. Chukotka (69)	**0.150**	**<0.0001**	**0.082**	**<0.0001**	**<0.0001**
Sakhalin (142) v. North of Aleutians (103)	**0.152**	**<0.0001**	**0.086**	**<0.0001**	**<0.0001**
Sakhalin (142) v. CA->AK (122)	**0.100**	**<0.0001**	**0.065**	**<0.0001**	**<0.0001**
CA->AK (122) v. Chukotka (69)	0.010	0.0883	<0.001	0.5009	0.5466
CA->AK (122) v. North of Aleutians (103)	0.005	0.1488	0.001	0.3477	0.4049

Table 6. Results of microsatellite comparisons (n=8 loci) across strata, with sample sizes shown in parentheses. Significant p-values are highlighted in bold.

Pairwise Comparison	F_{ST}	p-value	F'_{ST}	p-value	Jost's D	p-value	χ^2 p-value
Sakhalin (142) v. Chukotka (71)	**0.010**	**0.0010**	**0.037**	**0.0010**	**0.008**	**0.0020**	**0.0010**
Sakhalin (142) v. N of Aleutians (106)	**0.010**	**0.0010**	**0.037**	**0.0010**	0.000	0.1169	**0.0010**
Sakhalin (142) v. CA->AK (122)	**0.008**	**0.0010**	**0.028**	**0.0010**	**0.018**	**0.0010**	**0.0010**
CA->AK (122) v. Chukotka (71)	-0.001	0.7053	-0.004	0.7123	-0.001	0.7542	0.8951
CA->AK (122) v. N of Aleutians (106)	-0.001	0.8362	-0.005	0.8492	-0.001	0.8661	0.9820

Table 7. Match probabilities, as calculated in GENECAP, for pairs of identical genotypes identified in the gray whale microsatellite data. PHW refers to probabilities calculated assuming Hardy-Weinberg equilibrium, while PSIB refers to probabilities calculated assuming that the two individuals are full siblings. Information on the location and date the sample was collected, the mtDNA haplotype, sex, and number of microsatellite loci compared is included. All samples were collected via biopsy of live whales except where noted.

Labid	Location Sampled	Date Sampled	MtDNA Hap	Sex	No. of Loci Compared	Sib Prob	HW Prob
15164	Sakhalin Island, Russia	8/22/1999	1	M	8	9.07×10^{-4}	2.21×10^{-09}
100791	SE Kamchataka, Russia	7/10/2010	1	M			
72878	Sakhalin Island, Russia	7/27/2007	2	F	8	1.12×10^{-3}	2.21×10^{-08}
100792	SE Kamchataka, Russia	8/26/2010	2	F			
72884	Sakhalin Island, Russia	8/19/2007	2	M	8	1.06×10^{-3}	9.39×10^{-09}
100765	SE Kamchataka, Russia	6/18/2010	2	M			
19050	Sakhalin Island, Russia	8/10/2000	2	M	8	1.24×10^{-3}	1.16×10^{-08}
100790	SE Kamchataka, Russia	7/10/2010	2	M			
100735	Chukotka, Russia	Summer 2001*	12	M	8	6.74×10^{-4}	9.10×10^{-10}
18838	San Diego, CA	1/21/2001	12	M			
3950	Santa Barbara Channel, CA	3/23/1995	2	M	13	2.10×10^{-5}	1.87×10^{-13}
12186	Sakhalin Island, Russia	8/14/1998	2	M			
3947	Santa Barbara Channel, CA	3/20/1995	35	F	13	1.06×10^{-5}	5.43×10^{-15}
50728	Sakhalin Island, Russia	8/27/2004	35	F			

*This sample was collected from a harvested whale.

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Assessment of genetic structure among eastern North Pacific gray whales on their feeding grounds

Aimée R. Lang,[1] Marine Mammal & Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, California 92037, U.S.A. and Ocean Associates Incorporated, 4007 North Abingdon Street, Arlington, Virginia 22207, U.S.A.; **John Calambokidis**, Cascadia Research Collective, Olympia, Washington 98501, U.S.A.; **Jonathan Scordino**, Marine Mammal Program, Makah Fisheries Management, Makah Tribe, Neah Bay, Washington 98357, U.S.A.; **Victoria L. Pease**, Marine Mammal & Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, California 92037, U.S.A.; **Amber Klimek**, Cascadia Research Collective, Olympia, Washington 98501, U.S.A.; **Vladimir N. Burkanov**, National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration, Seattle, Washington 98115, U.S.A. and Kamchatka Branch of the Pacific Geographical Institute, Russian Academy of Sciences, Petropavlovsk-Kamchatsky, Kamchatka 683000, Russia; **Pat Gearin**, Kamchatka Branch of the Pacific Geographical Institute, Russian Academy of Sciences, Petropavlovsk-Kamchatsky, Kamchatka 683000, Russia; **Dennis I. Litovka**, Marine Mammal Laboratory, Chukotka Branch of FGUP-TINRO, Anadyr, Chukotka 689000, Russia; **Kelly M. Robertson**, Marine Mammal & Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, California 92037, U.S.A.; **Bruce R. Mate**, Marine Mammal Institute, Oregon State University, Hatfield Marine Science Center, Newport, Oregon 97365, U.S.A.; **Jeff K. Jacobsen**, Humboldt State University, Department of Biological Sciences, Arcata, California, U.S.A.; **Barbara L. Taylor**, Marine Mammal & Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, California 92037, U.S.A.

Abstract

Although most eastern North Pacific (ENP) gray whales feed in the Bering, Beaufort, and Chukchi Seas during summer and fall, a small number of individuals, referred to as the Pacific Coast Feeding Group (PCFG), show intra- and interseasonal fidelity to feeding areas from northern California through southeastern Alaska. We used both mitochondrial DNA (mtDNA) and 12 microsatellite markers to assess whether stock structure exists among feeding grounds used by ENP gray whales. Significant mtDNA differentiation was found when samples representing the PCFG ($n = 71$) were compared with samples ($n = 103$) collected from animals feeding further north ($F_{ST} = 0.012$, $P = 0.0045$). No significant nuclear differences were

[1]Corresponding author (e-mail: aimee.lang@noaa.gov).

detected. These results indicate that matrilineal fidelity plays a role in creating structure among feeding grounds but suggests that individuals from different feeding areas may interbreed. Haplotype diversities were similar between strata (h_{PCFG} = 0.945, $h_{Northern}$ = 0.952), which, in combination with the low level of mtDNA differentiation identified, suggested that some immigration into the PCFG could be occurring. These results are important in evaluating the management of ENP gray whales, especially in light of the Makah Tribe's proposal to resume whaling in an area of the Washington coast utilized by both PCFG and migrating whales.

Key words: *Eschrichtius robustus*, gray whale, population structure, mitochondrial DNA, microsatellites, demographic independence.

A single stock of gray whales (*Eschrichtius robustus*) is currently recognized in U.S. waters (Carretta *et al*. 2013). This stock, which is referred to as the eastern North Pacific (ENP) stock, is estimated to contain approximately 19,000 individuals (Laake *et al*. 2009). Most of these whales feed in the Bering, Beaufort, and Chukchi Seas during summer and fall and then migrate south along the coast of North America to overwinter in the lagoons and coastal waters of Baja Mexico. However, a small number of individuals feed in more southern waters from northern California through southeastern Alaska during summer and fall (Gilmore 1960; Pike 1962; Hatler and Darling 1974; Darling 1984; Calambokidis *et al.* 2002, 2012). Photo-identification research, which commenced in the early 1970s and continues to date, has identified a subset of whales that have returned to this southern feeding ground in multiple years and account for the majority of sightings in the area during summer and fall months (Hatler and Darling 1974; Darling 1984; Calambokidis *et al*. 2002, 2012). These whales are referred to as the Pacific Coast Feeding Group (PCFG; IWC 2011*a*). Recent estimates of annual abundance suggest that the PCFG includes approximately 200 animals (Calambokidis *et al*. 2012). Although PCFG whales account for the majority of sightings on this southern feeding ground during summer and fall, the area is also used by whales that are encountered in the region following the migration (*e.g.*, after 1 June) but are seen in only one year (Calambokidis *et al*. 2012). These individuals are generally seen for shorter time periods and in a more limited area than are PCFG whales, and they may represent stragglers from the larger group of animals that migrate through the southern feeding ground on their way to feeding areas further north (Calambokidis *et al*. 2012).

The PCFG includes some animals that were first identified as calves with their mothers on the southern feeding ground and that have returned to feed in the area in subsequent years (Calambokidis *et al*. 2012). This pattern of behavior, which is often called matrilineal fidelity, likely results from calves learning the location of suitable feeding/calving grounds from their mothers. Matrilineal fidelity to feeding and/or calving areas has been documented in other baleen whales (*e.g.*, Gulf of Maine humpback whales, Clapham and Mayo 1987; southern right whales, Valenzuela *et al*. 2009). Understanding patterns of matrilineal fidelity may be important in shaping management decisions, as it is thought that the lack of recovery or repopulation of baleen whales in some areas heavily impacted by commercial whaling is related to the loss of knowledge of where suitable habitat is located (Clapham *et al*. 2008).

Concern for PCFG whales has arisen in part from recent interest in the resumption of whaling by the Makah Tribe in northwest Washington, an area used by virtually all migrating whales as well as by foraging whales considered part of the PCFG. The current proposal by the Makah Tribe includes time/area restrictions designed to

reduce the probability of killing a PCFG whale by focusing hunt effort on the much larger group of whales migrating to/from feeding areas further north. However, PCFG whales are present during the migratory season, and it is impossible to ensure that no PCFG whales would be killed. The Makah Tribe also proposes to compare photographs of any whales harvested in the hunt to a photo-identification catalog of known PCFG whales and to suspend the hunt if needed to prevent the number of PCFG whales harvested from exceeding the annual allowable bycatch level for that year (IWC 2011*b*).

Evaluating whether any kills would, over time, have the potential to deplete the PCFG requires an understanding of how individuals are recruited into the group. If recruitment into the area is exclusively internal, such that use of the area is driven by calves learning the location of feeding grounds from their mothers, then a PCFG individual that is removed would not be replaced by immigration. However, if recruitment is largely external, then it is possible that any takes from the PCFG could be offset by immigration into the PCFG by whales that in previous years fed in northern areas. As aforementioned, some PCFG individuals were first identified as calves on the feeding ground and have returned to the area to feed in subsequent years. However, the origin of other individuals is unknown, and "new" (previously unidentified) noncalf whales are identified each year, some of which have returned to the southern feeding ground in subsequent years (Calambokidis *et al*. 2012). Although these whales may be individuals who were "missed" as calves (*e.g.*, not identified as a calf or not photographed that season), they could also represent whales that previously fed further north but now demonstrate fidelity to the PCFG range.

Genetic studies have provided some insight into mechanisms of recruitment into the PCFG. Initial work utilizing a simulation-based approach indicated that if the PCFG originated from a single recent colonization event in the past 40–100 yr, with no external recruitment into the group, detectable mtDNA genetic differentiation would be generated (Ramakrishnan and Taylor 2001). Subsequent empirical analysis, however, failed to detect such a signal when comparing 16 samples collected from PCFG whales using Clayoquot Sound, British Columbia, with samples ($n = 41$) collected from individuals presumed to feed in more northern areas (Steeves *et al.* 2001). More recently, Frasier *et al.* (2011) used mtDNA to compare samples collected from 40 individuals considered part of the PCFG with published data generated from 105 samples collected from ENP gray whales, most of which stranded along the migratory route (LeDuc *et al.* 2002). All haplotypes identified among the PCFG samples were also found in the larger ENP sample set, and haplotype diversity found in the PCFG ($h = 0.93$) was lower than, but similar to, that found among the samples representing the larger ENP population ($h = 0.95$). However, significant differences in estimates of long-term effective size and mtDNA haplotype frequencies were identified between the two groups. These results suggest that matrilineally directed fidelity plays a role in use of this area, and the authors concluded that the PCFG should be recognized as a distinct management unit (Frasier *et al.* 2011).

One limitation of previous genetic studies on the PCFG is that they utilized samples primarily collected from gray whales that stranded while on the ENP migratory route as representative of the larger ENP population in their comparisons. Although the likelihood that any of these stranded animals were part of the PCFG is low given the large size of the ENP gray whale population, this possibility could not be ruled out based on the location where most of the ENP samples were collected. More importantly, the limited number of samples available from the feeding ground(s)

north of the Aleutians precluded previous studies from making a direct comparison between animals utilizing different feeding grounds.

At the end of the feeding season, PCFG whales are thought to join the southbound migration to Mexican waters and have therefore been presumed to interbreed with the larger ENP population (Calambokidis *et al*. 2002, 2012). Earlier genetic studies of the PCFG relied exclusively on mtDNA, however, and the assumption that PCFG whales interbreed with gray whales feeding in other areas was not assessed. Conception in gray whales is thought to occur primarily during a 3 wk period between late November and early December (27 November to 13 December), although if no conception occurs during this first period, a second estrus may occur about 40 d later when whales are on or near their wintering grounds (Rice and Wolman 1971). Rugh *et al.* (2001) estimated that the median (peak) sighting date for the southbound migration is 12 December for Unimak Pass, Alaska, suggesting that many gray whales would be north of the PCFG seasonal range during the first mating period and raising the possibility that some segregation in breeding could occur with respect to feeding ground origin.

Here we contribute to the understanding of stock structure of gray whales by (1) comparing samples collected from gray whales feeding north of the Aleutians with samples collected from PCFG whales to directly address whether structure exists among feeding grounds used by ENP gray whales, and (2) using nuclear markers (n = 12 microsatellites) to test the assumption that PCFG whales interbreed with whales from other feeding grounds. We also increased the number of samples collected from PCFG whales and, for those samples linked to photographed individuals, were able to further refine our representation of the PCFG by incorporating sighting histories of known individuals in the comparisons. Although other scenarios are possible, here we test the following three hypotheses:

(1) No population structure (*e.g.,* panmixia) is present among feeding grounds used by ENP gray whales; individuals move between feeding areas and exhibit random mating. This hypothesis would be supported by a finding of no nuclear or mitochondrial differentiation between samples from PCFG whales and those collected from animals feeding further north.

(2) Utilization of feeding areas is influenced by internal recruitment, with calves following their mothers to feeding grounds and returning in subsequent years. Mating is random with respect to feeding ground affiliation. This hypothesis would be supported by a finding of significant differences in mtDNA haplotype frequencies when comparing samples from PCFG whales with those collected from animals feeding further north, but no significant differences in microsatellite allele frequencies between these groups.

(3) Utilization of feeding areas is influenced by matrilineal fidelity and mating is not random with respect to feeding ground affiliation. This hypothesis would be supported by a finding of significant differences in both mtDNA haplotype and microsatellite allele frequencies.

Methods

Samples

The initial sample set consisted of 277 samples collected between 1994 and 2010, with collection locations ranging from northern California to Barrow, Alaska and

Chukotka, Russia (Fig. 1, Table S1). Although some samples were collected from individuals taken as part of a subsistence hunt off Chukotka ($n = 75$ samples) or from stranded individuals ($n = 17$), the majority of samples ($n = 185$, including all samples collected between northern California and British Columbia, Canada) were collected as biopsies from free-ranging individuals. During biopsy sample collection, efforts were made to obtain a photograph of each biopsied whale. These photographs were compared to a photo-identification catalog maintained by Cascadia Research Collective and containing photo-identification images primarily collected between 1998 and 2009. This catalog focuses on the PCFG whales but also includes some migrating whales that were photographed in the spring (March through May) during their northward migration.

Linking biopsy samples to photographed whales allowed the sighting history of individuals to be evaluated when determining which samples should be used to represent the PCFG whales. As noted earlier, whales utilizing the PCFG's seasonal range fall into two categories: (1) whales that return frequently and account for the majority of sightings, and (2) apparent stragglers from the migration that are sighted in only one year (Calambokidis *et al*. 2012). To ensure that our PCFG stratum was representative of the first category of whales, samples were screened using two criteria: (1) the sample had to be linked to a photo-identified animal, and (2) the photo-identified

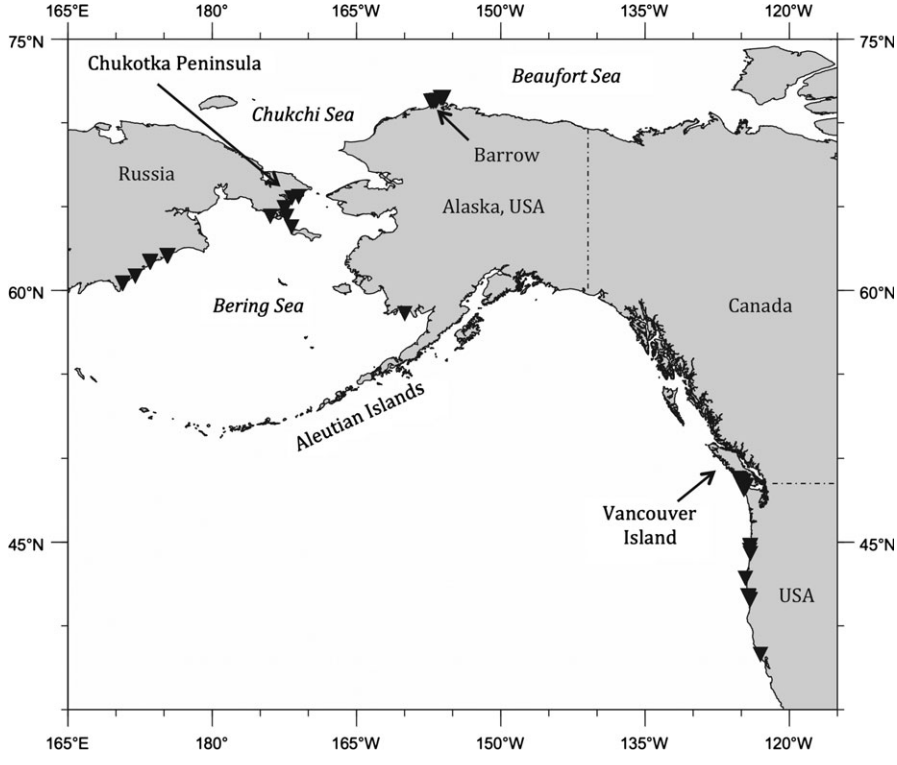

Figure 1. Locations where samples were collected, with key areas mentioned in the text labeled.

animal to which the sample was linked had to have been sighted in two or more years within the defined season (1 June to 30 November) and area (between 41°N and 52°N, in concordance with the boundaries used by the International Whaling Commission's Scientific Committee, IWC 2012) representative of PCFG whales. Samples collected on the southern feeding ground but not meeting these criteria ($n = 36$) were removed prior to data analysis, leaving 113 samples collected from whales considered to represent the PCFG in the sample set.

Samples collected from gray whales on the northern feeding area were stratified in two ways. First, all samples collected from whales that were north of the Aleutian Island chain between June and November were included in a "North" stratum ($n = 128$). This stratification assumes that whales use the northern feeding area in a relatively uniform manner, such that sampling location within this area does not matter. However, little is known about whether gray whales exhibit fidelity to smaller regions within the northern feeding area. If multiple feeding aggregations exist north of the Aleutians, then sampling location within that larger area is important. Although the original design of the study was to have a stratum representing Chukotka, Russia, and a stratum representing Barrow, Alaska, the sample size for the latter ($n = 14$ individuals) was insufficient to characterize genetic frequencies from that area. As such, we were unable to directly address hypotheses about whether additional structure exists north of the Aleutian Islands. However, we did include a comparison of the PCFG stratum to the Chukotka stratum ($n = 75$ samples) to avoid including unrecognized heterogeneity in our representation of animals feeding in the north.

Laboratory Processing

DNA extraction, PCR amplification and sequencing—Genomic DNA was extracted from samples using either sodium chloride protein precipitation (Miller *et al*. 1988) or silica-based filter purification (Qiaxtractor DX reagents, Qiagen, Valencia, CA) following the manufacturers' instructions. Extractions were performed on a JANUS automated work station (Perkin-Elmer, Waltham, MA). MtDNA sequences for eight of these samples had been generated previously for another study (LeDuc *et al*. 2002); however, to provide consistent quality control, these samples were resequenced for our analyses. The 5′ end of the hyper-variable mtDNA control region was amplified from extracted genomic DNA, using the polymerase chain reaction (PCR) and the primers used in the LeDuc *et al*. (2002) study (H00034, Rosel *et al*. 1994; L15812, Chivers *et al*. 2005). DNA was amplified using a 25 μL reaction of ~100 ng DNA, 1× PCR buffer (50 mM KCl, 10 mM Tris-HCl, pH 8.3, and 1.5 mM $MgCl_2$), 0.6 mM dNTPs, 0.3 μM primers, and 0.25 units of Taq DNA polymerase (New England BioLabs, Inc.). The PCR cycling profile consisted of 90°C for 2 min, followed by 35 cycles of 94°C for 50 s, an annealing temperature of 60°C for 50 s, and 72°C for 1 min, then a final extension of 72°C for 5 min. Sequencing of amplified products followed standard techniques (Saiki *et al.* 1988, Palumbi *et al.* 1991), and both strands of the amplified DNA product were sequenced independently on an Applied Biosystems, Inc. (ABI) model 3730 sequencer. If a sample was identified as having a mtDNA haplotype that was not found among any of the other samples, mtDNA amplification and sequencing were replicated to confirm the haplotype identity. All sequences were aligned using Sequencher v4.8 (Gene Codes Corp. 2000), resulting in final sequences that were 523 base pairs long.

Nuclear DNA processing—Twelve microsatellite loci isolated from other cetacean species were used to genotype the samples (see Table S2): EV14, EV37, and EV94

(Valsecchi and Amos 1996); Gata028, Gata098, Gata417, and Gt023 (Palsbøll *et al.* 1997); RW31 and RW48 (Waldick *et al.* 1999); and SW10, SW13, and SW19 (Richard *et al.* 1996). For all reverse primers except those amplifying Gata098 and EV37 (which failed to amplify with modified primers), the primer sequence was modified from the original design by placing the sequence GTTTCTT on the 5′ end to facilitate complete adenylation and thus more consistent scoring (Brownstein *et al.* 1996). Forward primers were fluorescently labeled. Extracted DNA was amplified using a 25 μL reaction of ~100 ng of DNA, 1× PCR buffer (50 mM KCl, 10 mM Tris-HCl, pH 8.3, and 1.5 mM $MgCl_2$), 0.6 mM dNTPs, 0.3 μM primers, and 0.5 units of Taq DNA polymerase (New England BioLabs, Inc.). The PCR cycling profile included 90°C for 2.5 min, followed by 35 cycles of 94°C for 45 s, 1 min at the optimal annealing temperature (see Table S2), and 72°C for 1.5 min, then a final extension of 72°C for 5 min. Only one locus was amplified per reaction, and each PCR product was assessed electrophoretically on a 2% agarose gel for size and quality before loading onto an ABI 3730 Genetic Analyzer. ABI GeneMapper software (version 4.0) was used along with an internal size standard (GeneScan-500 ROX, ABI) to determine allele fragment size. Two positive control samples were included on each plate to ensure consistent sizing between runs.

Sex determination—Samples were genetically sexed by amplification and Real-Time PCR (MX3000p, Stratagene Inc.) of the zinc finger (ZFX and ZFY) genes. Samples from one male and one female for which sex had been determined *via* examination of a stranded animal were included as positive controls in all amplifications. Sex was determined by the amplification pattern: males had two products and females had one (Morin *et al.* 2005).

Analysis

Data review—Quality control and sample tracking procedures, as detailed in Morin *et al.* (2010), were implemented during data generation. A randomly chosen set of samples, representing 13% of all samples processed, was sequenced, sexed, and genotyped a second time, and these records were reviewed for consistency. For the microsatellite data, replicate and original genotypes were compared, and a per-allele error rate was calculated by determining the number of discrepant allele calls divided by the total number of allele calls compared across all loci. In addition, all microsatellite genotypes were scored independently by two experienced genotypers. The allele calls from each genotyper were compared, and calls that did not match were reviewed jointly by both genotypers. Inconsistencies that could not be resolved upon review were treated as missing data.

After genotyping of samples was complete for eight of the twelve loci (EV14, EV94, Gata028, Gata417, Gt023, RW31, SW13, and SW19), the program GENECAP (Wilberg and Dreher 2004) was used to calculate the probability that two randomly chosen individuals would share the same multilocus genotype under both the assumption of Hardy-Weinberg equilibrium (PID_{HW}, Paetkau and Strobeck 1994) and under the more conservative assumption that full siblings may be present within the data set (PID_{SIB}, Waits *et al.* 2001). Samples with identical genotypes, indicating that they may have been collected from the same animal, were flagged for further review. These sample pairs were checked to see if they also shared the same mtDNA haplotype and sex, and, when possible, photo-identification records were used to confirm the genetic match. For all samples that shared identical mtDNA haplotypes, sexes, and nuclear genotypes at the eight loci, one sample from each pair

was removed and then the remaining samples were genotyped at the additional four loci prior to further analysis.

After genotyping at all 12 microsatellite loci was complete, the data set was reviewed to identify samples that were missing data for ≥25% of the markers; these samples were considered to be of poor quality and were removed prior to further analysis. The program MSTOOLS (Park 2001) was used to identify any additional samples whose genotypes matched at eight or more loci (using the full 12 microsatellite data set) and thus might represent duplicate samples that were not detected in the earlier analysis. Deviations from Hardy-Weinberg equilibrium (HWE) were assessed for each locus using Genepop (version 4.0.11, Rousset 2008). Both the probability test (Guo and Thompson 1992) and the test for heterozygote deficiency (Rousset and Raymond 1995) were conducted using the program defaults for the Markov chain parameters (10,000 dememorization steps, 20 batches, 5,000 iterations/batch). Genepop was also used to test for linkage disequilibrium (LD) for each pair of loci. All tests were run for the combined data set as well as for each stratum. The false discovery rate (FDR) adjustment (Benjamini and Hochberg 1995) was used to control for multiple testing when the results of the HWE and LD analyses were assessed.

Genetic diversity—For the mtDNA data, nucleotide (π) and haplotype (h) diversities (Nei 1987) were calculated using Arlequin 3.1 (Excoffier *et al*. 2005). To look for phylogeographic patterns among the mtDNA data, the software package Network 4.5.1.0 (available at http://www.fluxus-engineering.com/sharenet.htm) was used to generate a median-joining network of haplotypes using the algorithm of Bandelt *et al*. (1999). For the microsatellite data, the number of alleles per locus and observed and expected heterozygosities (Nei and Roychoudhury 1974) were calculated using custom code (eiaGenetics[2]) written in the statistical programming language R (R Core Development Team 2009).

Genetic structure—Pairwise estimates of genetic divergence were calculated using both F_{ST} (Weir and Cockerham 1984) and the AMOVA Φ_{ST} (Excoffier *et al.* 1992) for the mtDNA data using Arlequin v3.1 (Excoffier *et al*. 2005). For the Φ_{ST} pairwise distance calculations, the program jModelTest v2.1.4 (Guindon and Gascuel 2003, Posada 2008, Darriba *et al*. 2012) was used to select the best nucleotide substitution model based on the Akaike Information Criterion (AIC). Statistical significance was assessed using 10,000 permutations. Fisher's exact test (Raymond and Rousset 1995) was also used to test for mtDNA differentiation between strata using Arlequin 3.1 (Excoffier *et al*. 2005); 10,000 replications were used to test for significance. For the microsatellite data, F_{ST} (Weir and Cockerham 1984), F'_{ST} (Hedrick 2005, Meirmans 2006), and a χ^2 test were used to assess genetic differentiation using custom R-code (eiaGenetics). Statistical significance was determined from 5,000 permutations of each data set.

RESULTS

Data Review

Fourteen samples (including 11 samples collected from stranded whales) did not produce useable mtDNA sequence data and also failed to amplify at >4 microsatellite

[2]Available on request from E. Archer at eric.archer@noaa.gov.

loci; these samples (identified as "poor quality" samples) were removed from all subsequent analyses and data review (Table S1, S3).

Based on the genotypes of the remaining samples ($n = 227$) at the initial eight loci, the probability of two individuals possessing the same multilocus genotype was 9.08×10^{-9} for unrelated individuals (PID_{HW}) and was 6.97×10^{-4} for full siblings (PID_{SIB}), indicating that the microsatellite loci were adequate for identifying unique individuals. These samples were screened for duplicates (*i.e.*, samples considered to be from the same animal) after genotyping of the first eight loci was complete. Fifty samples had microsatellite genotypes that were identical to at least one other sample in the data set. In all cases, the mtDNA haplotypes and sexes of each pair also matched. Forty-two of the duplicate samples were identified in the PCFG stratum; 74% of these ($n = 31$) were confirmed to be the same animal using photo-identification records. All 50 duplicate samples were removed from further analysis. No movements of animals between regions representing different strata were identified based on genetic matches (*i.e.*, all samples sharing identical genetic profiles were part of the same stratum). The number of unique individuals ($n = 177$) remaining after removal of duplicates is shown in Table S3.

The proportion of missing genotypes at each locus was $\leq 2\%$ for all loci (Table S2). Using the samples randomly selected for replication, a per-allele error rate of 0.11% was detected for the full microsatellite data set. After controlling for the FDR, no loci demonstrated significant deviations from HWE for either the probability test or the test for heterozygote deficiency. One pair of loci (EV94-SW19) showed significant linkage disequilibrium (LD) in the Chukotka and the North strata, while three pairs of loci (EV14-Gt023, EV94-RW48, and EV94-Gata098) demonstrated significant LD in the PCFG stratum. All loci were retained in subsequent analyses.

Further review of the microsatellite data set did not identify any samples that were identical for ≥ 7 loci. Two samples amplified at ≤ 8 loci and were removed from the microsatellite analyses, leaving a total of 175 unique individuals for the microsatellite analyses. These samples did produce useable mtDNA sequence data and were thus retained in that data set.

No discrepancies were identified when the replicated and original mtDNA haplotype sequences were compared. The mtDNA haplotype could not be resolved for three of the 177 individuals, and these individuals were removed from the mtDNA data set but retained in the microsatellite data set. Sex was determined for all of the 177 individuals.

Genetic Diversity

Thirty-six mtDNA haplotypes defined by 36 variable sites were identified among the 174 individuals for which mtDNA haplotypes were resolved (Table 1). Thirty-two (NCBI Accession numbers AF326789-326824) of these haplotypes had been previously identified in LeDuc *et al*. (2002). The frequency of each haplotype in the defined strata (including Barrow) is shown in Table 2. Nineteen haplotypes were shared between the North and the PCFG strata, with four haplotypes found only in the PCFG. For all strata, many haplotypes were found in only one individual ($n = 13$ haplotypes in the North, $n = 12$ haplotypes in Chukotka, and $n = 8$ haplotypes in the PCFG, including three of the haplotypes found only in the PCFG). Haplotype diversity (h) was high in all strata defined for the analysis (0.945–0.953). Nucleotide diversity (π) was also similar among the three defined strata (0.0144–0.0154). The median-joining network shows the relationship among mtDNA haplotypes and their

Table 1. Number of mtDNA control region haplotypes, haplotype diversity (± SE), and nucleotide diversity (± SE) within each stratum.

Strata	No. of samples	No. of haplotypes	Haplotype diversity (h)	Nucleotide diversity (π)
North[a]	103	32	0.952 (± 0.008)	0.0144 (± 0.008)
Chukotka	69	27	0.953 (± 0.011)	0.0145 (± 0.008)
PCFG	71	23	0.945 (± 0.010)	0.0154 (± 0.008)

[a]Samples from Chukotka are included as part of the North stratum.

Table 2. The mtDNA haplotypes identified in the study, their corresponding NCBI accession numbers, and the number of individuals with each haplotype in each stratum.

MtDNA haplotype ID	NCBI accession number	North[a] (n = 103)	Chukotka (n = 69)	Barrow (n = 14)	PCFG (n = 71)
1	AF326789	10	8	2	7
2	AF326790	3	2	0	4
3	AF326791	14	9	1	1
4	AF326792	5	4	0	6
5	AF326793	1	1	0	1
7	AF326795	7	4	0	6
8	AF326796	1	1	0	2
9	AF326797	1	1	0	0
11	AF326799	3	2	1	3
12	AF326800	5	4	1	3
13	AF326801	5	3	0	9
14	AF326802	1	1	0	7
15	AF326803	3	0	2	0
16	AF326804	1	0	1	0
17	AF326805	1	0	0	0
18	AF326806	3	3	0	2
20	AF326808	6	1	2	2
21	AF326809	2	1	1	3
22	AF326810	1	1	0	0
23	AF326811	5	4	0	0
24	AF326812	2	2	0	3
25	AF326813	6	4	0	1
26	AF326814	2	1	1	0
27	AF326815	0	0	0	4
28	AF326816	2	2	0	2
29	AF326817	2	2	0	0
30	AF326818	0	0	0	1
31	AF326819	1	1	0	0
33	AF326821	5	4	0	1
35	AF326823	1	0	1	0
36	AF326824	1	0	1	1
38	KC917326	1	1	0	0
42	KC917327	1	1	0	0
43	KC917328	1	1	0	0
46	KC917329	0	0	0	1
47	KC917330	0	0	0	1

[a]Samples from Chukotka are included as part of the North stratum.

frequency in each stratum (Fig. 2). MtDNA haplotypes from both Chukotka and the PCFG are dispersed throughout the network, and no phylogeographic pattern was apparent.

A summary of nuclear diversity for each microsatellite locus is shown in Table S2. Measures of nuclear diversity for each stratum after averaging across loci are shown in Table 3. As in the comparisons of mtDNA haplotype and nucleotide diversity, nuclear diversity was similar across all strata. Nine alleles were found only among whales that were part of the North stratum (six of these were from Chukotka), and three alleles were identified only among PCFG whales.

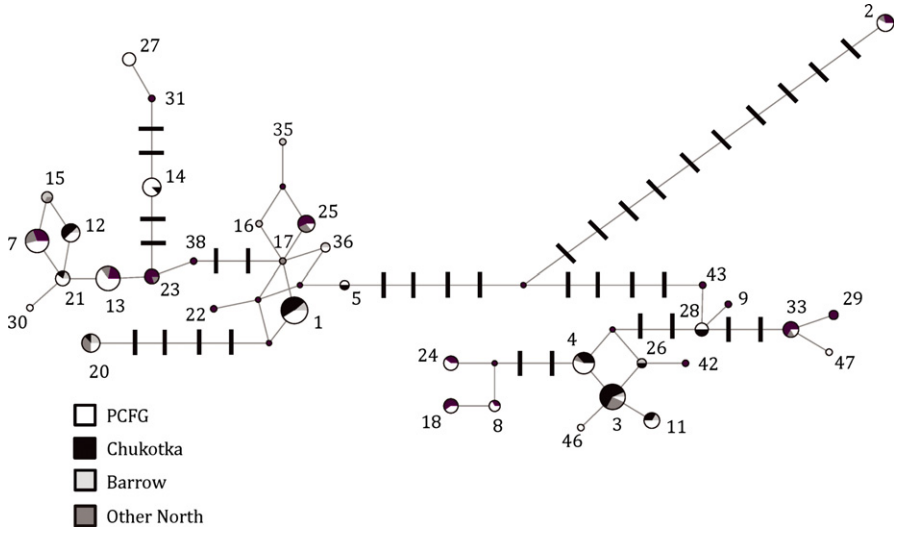

Figure 2. Median-joining network showing relationships among the mtDNA haplotypes. The numbers next to the nodes correspond to the haplotype IDs listed in Table 4. The size of the nodes is proportional to the frequencies of the haplotypes, and each node is shaded to indicate the fraction of individuals with that haplotype from each strata. The small black diamonds (unlabeled) indicate haplotypes that were inferred by the program but were not found among our samples. The length of lines connecting nodes is proportional to the inferred number of mutations separating haplotypes; for all haplotypes separated by more than one mutation, hash marks are used to represent the number of mutational events.

Table 3. Estimates of the number of alleles, observed heterozygosity (H_o), and expected heterozygosity (H_e) averaged across loci within each stratum for the microsatellite data. The genotypes of two samples that were used in the mtDNA analysis were removed because they amplified for ≤8 loci.

Strata	No. of samples	Mean number of alleles	Mean H_o	Mean H_e
North[a]	105	8.75	0.72	0.73
Chukotka	70	8.33	0.73	0.73
PCFG	70	8.00	0.74	0.73

[a]Samples from Chukotka are included as part of the North stratum.

Sex Ratio

All strata were comprised of more females than males, with ratios of 1.4 females per male in each stratum (Table S3). This female bias is similar to that (1.47 females per male) described in Frasier *et al*. (2011). Although the female bias was not significantly different from the expected 1:1 ratio in any of the strata, when all samples were combined the female bias was significantly different from parity ($\chi^2 = 5.43$, $P < 0.05$).

Genetic Structure

The results of the mtDNA comparisons are shown in Table 4a. The Tamura and Nei model of nucleotide substitution (Tamura and Nei 1993) with invariant sites (TrN + I) was selected as the most appropriate model of sequence evolution and was used in calculating Φ_{ST}. When the PCFG stratum was compared with the North stratum, significant differences in mtDNA haplotype frequencies were detected using F_{ST} and the exact test ($F_{ST} = 0.012$, $P = 0.0045$; Fisher's exact test $P = 0.0067$), but no significant differences were found in the Φ_{ST} comparison ($\Phi_{ST} = 0.012$, $P = 0.0740$). Statistically significant differences were detected in all mtDNA comparisons of the PCFG stratum with the Chukotka stratum ($\Phi_{ST} = 0.020$, $P = 0.0386$; $F_{ST} = 0.010$, $P = 0.0348$; Fisher's exact test $P = 0.0254$). None of the comparisons across strata utilizing the microsatellite data were significant (Table 4b).

Discussion

Given that PCFG whales share the same migratory routes and wintering grounds used by other ENP whales, it has generally been thought that PCFG whales interbreed with whales that feed further north (*e.g.,* Calambokidis *et al*. 2002, 2012). Here we were able to test that assumption directly by using microsatellite markers to compare PCFG whales with whales feeding north of the Aleutians. No significant nuclear differences between the two groups were identified, indicating that gray whales feeding in these areas likely represent a single interbreeding population. Significant differences in mtDNA haplotype frequencies were identified between the PCFG and northern feeding whales, however, suggesting that some structure exists among

Table 4. Results of pairwise comparisons across strata using (a) mtDNA and (b) 12 microsatellites. Comparisons that are statistically significant are shown in bold.

Pairwise comparison	Φ_{ST}	*P*-value	F_{ST}	*P*-value	Fisher exact test *P*-value
(a)					
North[a] (103) *vs*. PCFG (71)	0.012	0.0740	0.012	**0.0045**	**0.0067**
Chukotka (69) *vs*. PCFG (71)	0.020	**0.0386**	0.010	**0.0349**	**0.0254**

Pairwise comparison	F_{ST}	*P*-value	F_{ST}'	*P*-value	χ^2 *P*-value
(b)					
North[a] (105) *vs*. PCFG (70)	0.000	0.5269	0.000	0.5271	0.3491
Chukotka (70) *vs*. PCFG (70)	0.001	0.2539	0.003	0.2539	0.3503

[a]Samples from Chukotka are included as part of the North stratum.

feeding grounds used by ENP gray whales. Within the PCFG, this finding is concordant with photo-identification records that indicate that many animals first identified as calves return to the PCFG feeding area in subsequent years (Calambokidis *et al*. 2012). When combined, these findings are consistent with the second proposed hypothesis, and suggest that while mating is random with respect to feeding ground affiliation, utilization of feeding areas is influenced by internal recruitment.

The results of our mtDNA comparisons are similar to those presented in Frasier *et al*. (2011), who also found evidence of maternally driven structure when comparing samples from whales that were considered to represent the PCFG with a sample set comprised primarily of animals that stranded along the migratory route in the ENP. All of the samples utilized in the Frasier *et al*. (2011) study to represent the PCFG were collected from whales in Clayoquot Sound, which is located off the central west coast of Vancouver Island, British Columbia. In contrast, 89% of the samples representing the PCFG in this study were collected from animals in the waters off northern California, Oregon, and Washington, with only 12 samples (11%) collected off southern Vancouver Island. While the majority of PCFG whales photographed off southern Vancouver Island (52%) and northern Washington (60%) have also been sighted off western Vancouver Island, interchange between more distant areas (*e.g.*, comparison of northern California and western Vancouver Island) has been documented less frequently (Calambokidis *et al*. 2012). In addition, while some whales are known to move throughout the range of the PCFG, sightings of other whales are concentrated within subareas (Calambokidis *et al*. 2012), suggesting that individual gray whales may not use the range of the PCFG randomly. Thus while there is likely overlap among the individuals sampled in Frasier *et al*. (2011) and the current study, neither represents random sampling across the range of the PCFG. In the future, the collection of additional samples from whales in the northern portion of the PCFG range and/or integration of our sample set with that utilized by Frasier *et al*. (2011) would provide more evenly distributed sample coverage throughout the range of the PCFG and could provide insight into whether additional substructuring within the PCFG exists.

Despite the fact that the estimated abundance of the PCFG is roughly 1% of that of the ENP population as a whole, the haplotype diversity identified in the PCFG is similar to that found among strata representing the larger ENP population. This high haplotype diversity seems inconsistent with what might be expected if the PCFG was founded by a small number of individuals and has remained isolated (*e.g.*, all recruitment into the group is internal) for many generations. Under such a scenario, the mtDNA haplotypes carried by founders that were males or nonreproducing females would be lost over time, while haplotypes found in successfully reproducing females and their returning offspring would build to higher frequencies, resulting in reduced haplotype diversity in the group. However, the mtDNA haplotype diversity found within the PCFG, as well as the significant but relatively low level of mtDNA differences identified between the PCFG and northern feeding whales, could suggest that colonization of the PCFG range occurred relatively recently. Under this scenario, strong mtDNA differences between PCFG whales and individuals feeding further north may have had insufficient time to develop, and the number and distribution of haplotypes in the PCFG would not have been strongly affected by genetic drift. Little is known about the history and origin of the PCFG. Gray whales have been recorded feeding in the southern portion of the PCFG range as early as 1926, when a single gray whale, which was reported to have been feeding with four other whales, was taken by the Trinidad whaling station off the entrance to the Crescent City Harbor

in July (Howell and Huey 1930). Additional sightings of whales within the PCFG range during summer and fall were reported in the 1940s, 50s, and 60s (Gilmore 1960, Pike and MacKaskie 1969, Rice and Wolman 1971). The repeated return of individual whales to the area was first documented starting in the 1970s (Hatler and Darling 1974, Darling 1984). This time period marked the beginning of photo-identification studies for gray whales, and thus it is unknown if fidelity to the PCFG area occurred prior to this time or if the sightings recorded earlier were of animals that only visited the area during a single feeding season.

It is unclear what oceanographic conditions would have been present during the last century that would have precipitated use of the PCFG feeding area. Pyenson and Lindberg (2011) reconstructed the carrying capacity of gray whales over the past 120,000 yr by quantifying what feeding habitats would have been available during that time. They hypothesized that gray whales survived glacial fluctuations during the Pleistocene by employing generalist filter-feeding strategies that allowed them to take advantage of alternative food sources and feeding areas, similar to foraging strategies and areas used by PCFG whales today (*e.g.*, Darling *et al*. 1998, Dunham and Duffus 2001). More recently, access to the Bering Sea feeding areas would have been limited by heavy ice during parts of the "Little Ice Age" (*ca*. 1450–1850). Even if the PCFG seasonal range was colonized prior to the start of commercial whaling, this group of animals may have been greatly depleted or eliminated prior to the end of commercial whaling. Thus, it is plausible that the PCFG range may have been colonized multiple times in the past as a response to environmental changes and/or to depletion due to whaling.

The low level of mtDNA differentiation and high diversity are also consistent with a scenario in which matrilineal fidelity plays a role in determining use of the PCFG area but in which external recruitment also occurs. Given that the migratory route for whales traveling to the northern feeding ground(s) passes through the PCFG range, such recruitment could take place if migrating whales encounter a productive source of food within the PCFG range, remain in the area for the remainder of the season, and return in subsequent years (Calambokidis *et al*. 2002, 2012). External recruitment would slow the accumulation of genetic differences between PCFG whales and individuals feeding further north. Also, external recruits (at least initially) would likely carry haplotypes not previously identified among PCFG individuals, increasing the number and diversity of haplotypes found as well as the proportion of haplotypes currently shared between the PCFG and the animals feeding north of the Aleutians. Examination of the photo-identification data provides some information relevant to evaluating whether external recruitment into the PCFG could be occurring. Although photo-identification studies of the PCFG started in the early 1970s (Hatler and Darling 1977, Darling 1984), consistent efforts covering a larger portion of the PCFG seasonal range did not begin until 1998 (Calambokidis *et al*. 2012). Between 1998 and 2010, "new" (*i.e.*, previously unidentified) noncalf whales continued to be identified in the PCFG area each year, and many of these whales returned to the area in subsequent years (mean = 11 whales per year, 2002–2009, northern California to northern British Columbia; Calambokidis *et al*. 2012). It is unknown what proportion of these new whales could be immigrants into the group (*e.g.,* external recruits) and what proportion may be animals that were internally recruited but were not identified as calves during their first year (*e.g.*, "missed calves"). Although the number of calves identified on the PCFG range each year is low (mean = 3 calves per year, range 0–9, 2002–2009, northern California to northern British Columbia), calves may wean from their mothers as early as June or July, making them difficult to

identify as calves (*vs*. yearlings or young animals) and leading to underestimates of the number of calves present (Calambokidis *et al*. 2012). Indices of gray whale calf production based on estimates of the number of northbound calves past Piedras Blancas, California, are highly variable and averaged 4.3% (calf estimate/total population estimate, range 1.55%–6.8%) between 1994 and 2000 (Perryman *et al*. 2002). These estimates are likely high relative to the total number of gray whale calves that survive the full migration, as mortality of calves due to killer whale predation is known to occur in areas north of Piedras Blancas, including Monterey Bay, California (see summaries in Jefferson *et al.* 1991, Ford and Reeves 2008), an area that both PCFG and ENP whales traverse while migrating. While it is unknown how these estimates relate to calf production among PCFG whales, applying these indices to a group of 200 animals would result in a mean of 9 calves per year (range 3–13 calves per year).

In addition, comparison of nine whales photographed off Barrow, Alaska in 2006 and 2010 with the photo-identification catalog of animals identified within the PCFG range resulted in two matches (Calambokidis *et al*. 2012). One of these animals was photographed off Vancouver Island during March on a single occasion and thus may have been migrating through the area and would not be considered part of the PCFG. The second animal, however, had previously been sighted in multiple years during summer/fall in the PCFG area. While the significance of this match is difficult to interpret given the limited photo-identification data available from Barrow, it does indicate that at least this one individual has utilized more than one feeding ground during its lifespan.

Based on the genetic results presented here, it is not possible to determine the extent of immigration into the PCFG that could occur while still allowing mtDNA differences to be detected. While dispersal can be indirectly estimated from F_{ST} values (Wright 1931), the assumptions (*e.g.*, equal population sizes, equilibrium) of the underlying model are unlikely to be valid in wild populations (Whitlock and McCauley 1999). In addition, if the PCFG was isolated from the rest of the ENP population in the past, then the underlying level of genetic divergence would be related to the length of time the two groups had been separated and their effective sizes (Nei and Chakravarti 1977). As the underlying level of genetic divergence increases, the amount of recent immigration that could occur without obscuring the signal of mtDNA differentiation also increases. This highlights the fact that there are multiple scenarios (*e.g.,* colonization histories, number of founders, and immigration rates) that could lead to the pattern of mtDNA differentiation seen in the comparisons of the PCFG and the ENP samples. Given the information that is currently available, we are not able to discriminate among these possibilities.

A remaining question is whether additional structure exists within the northern feeding area. If there is no structure on the feeding grounds north of the Aleutians, then the northern strata (both "North" and "Chukotka") could be considered representative of the genetic diversity of whales feeding throughout the northern feeding area and the mtDNA differences observed here would be driven by fidelity of individuals to the PCFG seasonal range. However, if structuring is present among northern feeding areas, then the differences demonstrated here may be influenced by fidelity of individuals in either or both areas (PCFG and Chukotka). While the results of photo-identification studies of the PCFG are consistent with the occurrence of some internal recruitment, the collection of additional samples from northern feeding areas would be valuable in further elucidating the mechanisms creating the observed differences and in evaluating whether structuring is present among whales utilizing the northern feeding grounds.

Implications for Management

Understanding recruitment into the PCFG is relevant to management under the Marine Mammal Protection Act (MMPA). The goal of the MMPA is to maintain population stocks as functioning elements of their ecosystem. The National Marine Fisheries Service (2005) considers stocks to be demographically independent units, such that the population dynamics of the affected group is more a consequence of births and deaths within the group (internal dynamics) rather than of immigration or emigration (external dynamics). This definition is similar to that described for management units by Palsbøll *et al*. (2007) and for a population under the ecological paradigm by Waples and Gaggiotti (2006).

Traditionally, the most commonly used approach to evaluate demographic independence using genetic data has been null hypothesis testing, in which significant divergence of allele frequencies between groups is considered evidence supporting the delineation of separate management units (Moritz 1994). This approach assumes that if the migration rate is large enough to lead to demographic dependence, then genetic comparisons will not be able to reject the null hypothesis. Under this criterion, our findings support recognition of the PCFG of gray whales as demographically independent based on the significant differences in mtDNA between the PCFG and whales feeding further north.

Critical to our understanding of whether two groups are demographically independent, however, is the rate of dispersal between them. As noted in Waples and Gaggiotti (2006), there is no general framework for determining at what dispersal rate populations become demographically correlated, although it has been suggested that demographic correlation occurs when the proportion of immigrants in a group is greater than 10% (Hastings 1993). However, simulations have shown that, at least in cases where multiple microsatellite loci are used, it may be possible to reject panmixia even when dispersal rates are higher than this level (Palsbøll *et al*. 2006, Waples and Gaggiotti 2006). These results suggest that while genetic comparisons like those conducted here can provide insight into demographic connectivity, they should be interpreted carefully and integrated with other available information on the demography of the groups being considered (Lowe and Allendorf 2010).

When the significant mtDNA differences identified between the PCFG and the northern feeding strata are put into context with the other available evidence, questions arise about the balance between internal recruitment and external immigration. The significant mtDNA differences, as well as the observations of animals first identified as calves returning to the PCFG (Calambokidis *et al.* 2012), indicate that internal recruitment into the group occurs. However, the low level of mtDNA differences identified, the similarity in haplotype diversities between the PCFG and other groups thought to represent the larger ENP population, and the continued identification of "new" whales each year (Calambokidis *et al*. 2012) suggest that external immigration into the group may also be taking place. While other explanations (*e.g*., recent colonization and a high rate of "missed" calves) exist that could be consistent with demographic independence of the PCFG, discriminating between these explanations is not currently possible.

Although uncertainty remains, our results indicate that it is plausible that the PCFG represents a demographically independent group and suggest that caution should be used when evaluating the potential impacts of the proposed Makah harvest on this group of animals. Continued monitoring of the PCFG, including the collection of additional photographs and genetic samples, is warranted. Future work

should focus on estimating dispersal rates and levels of internal recruitment in the PCFG. The lack of differentiation in nuclear markers identified in our study limits the use of some approaches (*e.g.*, assignment tests) commonly used to estimate dispersal. However, with the collection of additional samples from PCFG whales, a parentage-based approach, similar to that used by Peery *et al*. (2008), may be valuable in documenting internal recruitment into the group and thus in assessing the demographic independence of the PCFG.

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Supporting Information

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Table S1. Samples used in the study, including the SWFSC accession number, GeneticID, collection method (B = biopsy, H = harvest, S = stranding), date of collection, location of collection, strata, and whether the sample was retained in the final analysis. Samples were removed because they were considered duplicates (code 1), due to poor quality (code 2), or because they could not be assigned to a stratum (code 3, which includes whales that were sampled in the PCFG range but did not meet the criteria for being included in the PCFG stratum). GeneticID represents a unique identifier for individuals, such that samples that were considered to be from the same individual were assigned the same GeneticID. The strata specified include: North, CHK (Chukotka), PCFG, and South. Samples considered part of the CHK stratum were also included in the North stratum in the analyses. The South stratum includes samples collected from whales within the PCFG seasonal range but which did not meet the criteria for being classified as PCFG whales (see text for further explanation).

Table S2. Characteristics of the microsatellite loci used in the study, including the species for which primers were initially designed, the size of repeats, the annealing temperature used in the study (Ta), the reference listing primer sequences, the number of alleles per locus, the proportion of missing genotypes, the expected heterozygosity (He), the observed heterozygosity (Ho), and the results of the test for heterozygote deficiency (HWE; Rousset and Raymond 1995).

Table S3. The total number of samples in each stratum, the number of samples removed from the study due to poor quality (see criteria described in text), the number of duplicate samples removed, and the number of individuals remaining in each stratum for each analysis. Duplicate samples (*i.e.*, samples from the same individual) were identified based on genotyping of eight microsatellite loci. Samples collected on the southern feeding ground but not considered to represent the PCFG ($n = 36$) are not included in the table.

Genetic differences between western and eastern gray whales (*Eschrichtius robustus*)

R.G. LEDUC*, D.W. WELLER*#, J. HYDE*, A.M. BURDIN++, P.E. ROSEL**, R.L. BROWNELL, JR.*, B. WÜRSIG # AND A.E. DIZON *

Contact e-mail: Rick.LeDuc@noaa.gov

ABSTRACT

Molecular data were used to examine the differentiation between the western and eastern gray whale (*Eschrichtius robustus*) populations. Control region sequences were generated from samples collected in the western Pacific ($n = 45$) and eastern Pacific ($n = 120$). There were 36 unique haplotypes identified. Ten haplotypes were represented in the western samples, and 33 in the eastern samples. Seven of these haplotypes were shared between populations, leaving three haplotypes that were only seen in the western samples and 26 only in the eastern. Although there were no fixed (diagnostic) differences between the western and eastern groups, they were significantly different in their haplotype frequency distributions and should be considered as separate populations. None of the 33 haplotypes found in the eastern samples had a frequency of over 11%, yielding an estimated haplotypic diversity of 0.95. This finding indicates that the reduction in abundance due to whaling may not have had a great effect on the haplotypic diversity of the eastern population, although the loss of rare haplotypes may still have occurred and would be difficult to detect. In contrast, the western group was dominated by two haplotypes, which represented over 77% of all individuals sampled, resulting in a substantially lower haplotypic diversity of 0.70. The lack of fixed differences between the two populations and frequency of shared haplotypes renders these data inappropriate for forensic applications at the population level.

KEYWORDS: GRAY WHALE; GENETICS; POPULATIONS; CONSERVATION; NORTH PACIFIC

INTRODUCTION

Although the gray whale (*Eschrichtius robustus*) once occurred in both the North Atlantic and North Pacific, it became extinct in the Atlantic several hundred years ago (Mead and Mitchell, 1984), is severely depleted in the western Pacific (e.g. Weller *et al.*, 2002), and was greatly reduced in the eastern Pacific before its recovery (IWC, 1998). Currently, gray whales are considered as two separate management stocks living along the eastern and western boundaries of the North Pacific. While both were reduced by historical whaling, only the eastern gray whale has recovered to near pre-exploitation levels (IWC, 1998). The western gray whale was thought to be extinct as recently as the early 1970s (Bowen, 1974) but is known to survive today as a remnant population (see review in Weller *et al.*, 2002). Although studies of the behaviour and biology of both eastern and western gray whales have been conducted (see Swartz *et al.*, 2000 for review), questions about the level of genetic differentiation between eastern and western gray whales, or how their exploitation may have affected genetic diversity, have remained largely unaddressed. Contemporary gene flow between them is not likely in that the geographic distributions do not overlap, and the migratory routes are disjunct and lead to opposite sides of the North Pacific basin. However, the possibility of dispersal has yet to be tested with genetic data. If gene flow is negligible or non-existent and the stocks have differentiated genetically since becoming allopatric, an additional question is whether they have diverged enough to allow individual whales from unknown localities (e.g. market samples of meat) to be characterised as eastern or western. As part of an ongoing US-Russia research project studying western gray whales in the Okhotsk Sea, biopsy samples have been routinely taken from animals summering off Sakhalin Island, Russia (Weller *et al.*, 2002). In addition, many samples are available from the eastern gray whale population. Together, these datasets provide an opportunity to characterise the genetic makeup of eastern and western gray whales and to quantify their degree of differentiation.

MATERIALS AND METHODS

Samples from the western population were obtained as biopsies from free-ranging animals on their summer feeding grounds off the northeastern coast of Sakhalin Island, Russia, primarily during 1998 and 1999. Since the biopsied animals were photographed at the time of sampling, cross-matching with the photo-identification catalogue (Weller *et al.*, 1999) enabled the removal of duplicate samples prior to sequencing, giving a total of 42 samples. Three biopsy samples from the same study area were collected in 1995 (Brownell *et al.*, 1997). In the absence of identification photographs, these were only added to the western samples after microsatellite analysis (not described) confirmed they were not from individuals sampled in 1998-1999. This resulted in a total of 45 western samples. A total of 120 eastern samples were collected from many localities between southern California and the Chukotka Peninsula in Russia. These samples were taken primarily from strandings, as well as a few from directed subsistence takes, fishery bycatch and biopsies of living whales. A similar check of individual identity was not done for the eastern North Pacific samples due to the lack of a comprehensive photo-identification catalogue. However, given that over 90% of the eastern samples were collected from dead animals, and given an estimated population size of over 26,000 (Rugh *et al.*, 1999), the effect of any possible duplicate sampling is negligible.

* *Southwest Fisheries Science Center, National Marine Fisheries Service, 8604 La Jolla Shores Drive, La Jolla, CA 92037-0271, USA.*
# *Texas A&M University, Marine Mammal Research Program, 4700 Avenue U, Building 303, Galveston, TX 77551, USA.*
++ *Kamchatka Institute of Ecology and Nature Management, Russian Academy of Sciences, Kamchatka, 683000, Russia.*
** *National Marine Fisheries Service, 219 Fort Johnson Road, Charleston, SC 29412, USA.*

In addition to these samples, sequences of a 361 base pair (bp) segment of the mitochondrial control region from two gray whales that were sampled in Japan (M. Goto and L. Pastene, pers. comm.) are used here in our discussion of the gray whale market samples sequenced by Baker *et al.* (2002). One whale stranded on the eastern side of Hokkaido in 1995 (Anon., 1997), and the other was an animal harpooned in the Sea of Japan off western Hokkaido in 1996 (Brownell and Kasuya, 1999). These sequences were not used in the population genetic analyses.

Using standard protocols, DNA was extracted from each sample, and a 523 bp region of the 5' end of the mitochondrial control region was amplified and sequenced. The primers used for amplification and sequencing were 5'-TACCAAATGTATGAAACCTCAG-3' (Rosel *et al.*, 1995) and 5'-CCTCCCTAAGACTCAAGGAAG-3' (designed at SWFSC). Haplotypic diversity was calculated using the computer program Arlequin (Schneider *et al.*, 2000), which was also used to calculate the divergence between populations with F_{ST}, ϕ_{ST} (an F_{ST} analogue) and χ^2, as well as to create a minimum spanning tree based on the number of differences between haplotypes. Haplotypic diversity (h) is calculated by the formula $h = 1 - \Sigma p_I^2$, where p_I is the frequency of the Ith haplotype (Nei, 1987).

RESULTS

A total of 36 haplotypes defined by 37 variable sites were found among the 165 samples examined. Thirty-three of these haplotypes occurred in eastern samples and 10 in the western samples; seven haplotypes were shared between the two samples. Fig. 1 shows the minimum spanning network of the 36 haplotypes. Fig. 2 shows the frequencies of the different haplotypes in the eastern and western samples. Haplotypic diversity differed greatly with the eastern samples showing a diversity of 0.95 +/- 0.01 and the western samples having a value of 0.70 +/- 0.05. The average percent difference (i.e. nucleotide diversity) between individuals differed little, with the eastern samples averaging 1.6% sequence difference from each other and the western samples averaging 1.7%. The average percent difference for between-population pairwise comparisons was 1.9%. In genetic studies, one must be cautious that some results, such as the much lower level of diversity found in the western gray whale population, are not caused by inadequate or biased sampling. However, it is doubtful that this is the case here. The 120 eastern samples actually represent a much lower overall proportion of the eastern gray whale population than the 45 samples do from the western population, which may number less than 100 animals (e.g. see Weller *et al.*, 2002). Therefore, the probability of there being appreciable amounts of unsampled variation in the western population is relatively low, despite the smaller number of samples. Finally, examination of the degree of genetic sub-division between the eastern and western samples indicated that they are significantly different from each other ($\phi_{ST} = 0.117, p < 0.001$; $\chi^2 = 65.9, p < 0.001$; $F_{st} = 0.087, p < 0.001$).

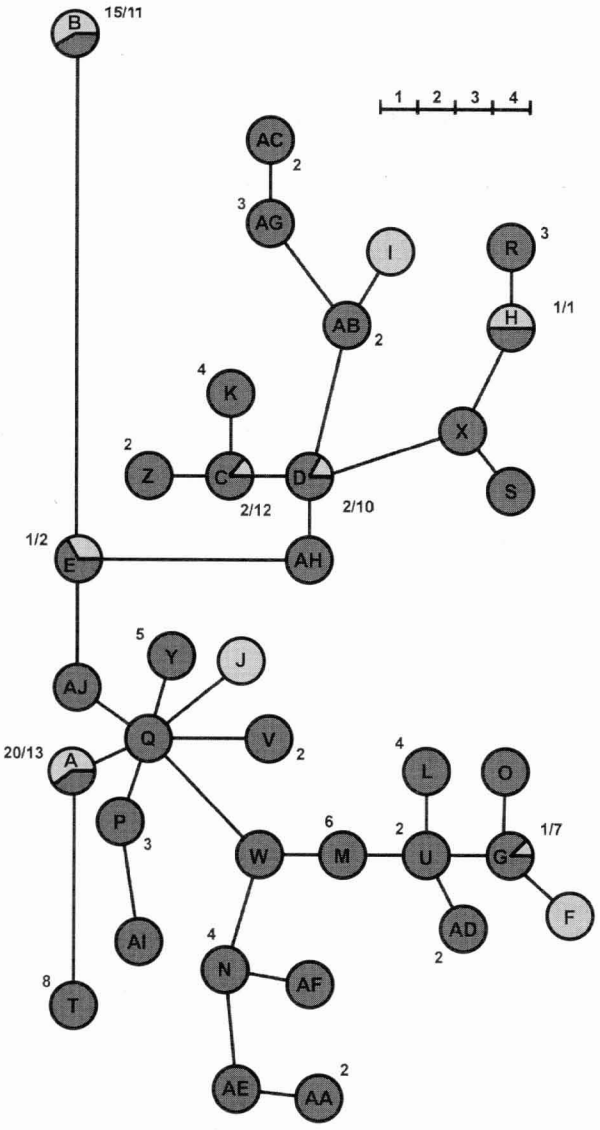

Fig. 1. Minimum spanning tree of the 36 haplotypes from this study. Numbers beside circles indicate the number of individuals having that haplotype in western (light gray) and eastern (dark gray) sample sets. Circles without numbers indicate haplotypes only represented by single individuals. The scale gives number of changes along connecting branches.

DISCUSSION

The results presented here show that the eastern and western gray whales are genetically differentiated at the population level. The significant difference found between the two populations and the negligible levels of gene flow that it implies, agrees well with their very different recovery histories; dispersal that is significant in any management sense should not be expected to occur. However, the statistical population differentiation arises primarily from differences in haplotypic frequencies (Fig. 2) and reflected in their respective haplotypic diversity indices. The populations have apparently not been isolated for a sufficiently long period of time for the shared haplotypes to be removed via genetic drift, and therefore no diagnostic character or characters within the 523 bp region can be reliably used to distinguish one population from another, or to determine the source of a gray whale of unknown affinity (e.g. a forensic analysis of market meat). The case could be made that if a test animal has a haplotype unique to the eastern samples, then it probably arose from there, since the absence of that haplotype in the western population is based on a fairly thorough sampling scheme (perhaps 50% of the population sampled so far). However, the converse (a test animal having a haplotype unique to the western sample set being from the Okhotsk Sea population) is more difficult to

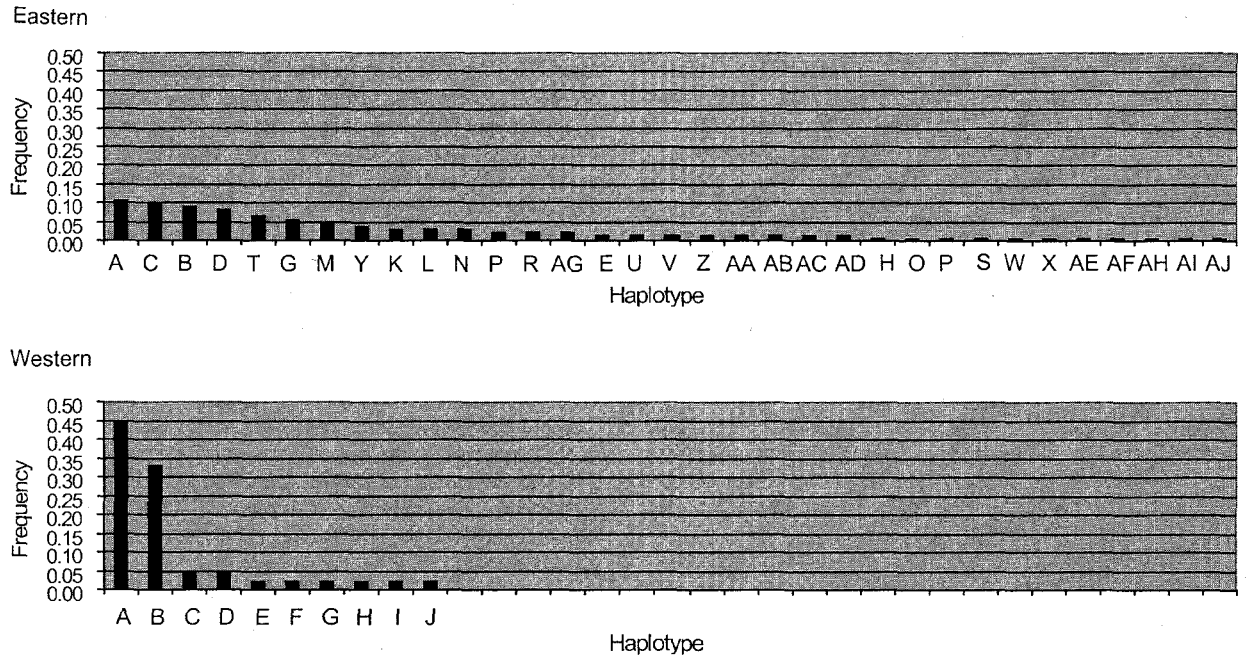

Fig. 2. Frequency distributions of haplotypes in each of the gray whale populations.

argue, since the very high diversity in the eastern population allows for the presence of many unsampled haplotypes. Although the genetic differences between the populations are modal rather than absolute, the differentiation is large, and demographically they should be treated as isolated population units, especially for management purposes as they have been and are by the International Whaling Commission (e.g. IWC, 1998).

The differences between the two populations in their haplotypic diversities may reflect differences in their past levels of abundance and effects of exploitation. Haplotypic diversity (h) is affected by both the numbers of haplotypes present in the population and their relative frequencies, with numerous haplotypes and equal frequencies both serving to increase the value of h. In the present dataset, the differing values of h arise primarily from the differences in haplotype frequency distributions, which differed dramatically between the two populations (Fig. 2). In the eastern samples, the most common haplotype was only represented in 10.8% of the individuals, and seven of the 33 haplotypes were represented in over 5% of the samples. The overall effect is one of a fairly even frequency distribution of haplotypes. In contrast, the two most common haplotypes in the 45 western samples were represented by 20 (44.4%) and 15 individuals (33.3%), with the remaining eight haplotypes appearing in single animals or in pairs. If the 10 western haplotypes were evenly distributed in the sample set, h_{west} would increase from 0.70-0.90, but an equivalent redistribution of the 33 eastern haplotypes would only increase h_{east} from 0.95-0.97. In other words, given the differences in sample sizes, the western and eastern sample sets contained comparable numbers of haplotypes, albeit with very different frequency distributions.

The haplotypic diversity value (0.95) calculated for the eastern samples in the present dataset is similar to the value (0.94) found by Steeves *et al.* (2001) in their study of 57 samples of eastern gray whales. These relatively high values for contemporary eastern gray whales seem to indicate that there was little loss of genetic variation in this population due to historical whaling. However, it is possible that some loss of diversity due to whaling may have occurred without a reduction in haplotypic diversity. In the calculation of haplotypic diversity, the frequencies of haplotypes are squared, so that the resulting value of h is not greatly affected by the occurrence or number of rare haplotypes, those contained in the population in very low frequencies. Therefore, although the eastern sample set contained 11 haplotypes only represented by single samples, the loss of other rare haplotypes cannot be ruled out.

In the western population, the lower haplotypic diversity value may be, but is not necessarily, a result of whaling. The lower value for the western animals may be related to their history of overexploitation, but it is also consistent with a smaller long-term effective population size (N_e). The amount of diversity that a population can maintain is directly determined by its N_e, which for the haplotypic and uniparentally-inherited mitochondrial genes, is approximately one-quarter of the N_e of nuclear genes. Although there are no reliable estimates for the pre-exploitation size of the western gray whale population, it was very likely to have been smaller than the eastern population (Weller *et al.*, 2002). Furthermore, the ten haplotypes found in the western sample set are not closely related to each other. Indeed, the two dominant western haplotypes (A and B) are very different from each other (Fig. 1). In a statistical sense, the occurrence of relatively few, but quite divergent, haplotypes explains why the western population exhibits an equal level of average sequence divergence when compared to the eastern population, despite its lower haplotypic diversity. Biologically, this pattern is consistent with either a loss of haplotypes due to long-term genetic drift or a whaling-induced bottleneck.

Although the haplotypic diversity is lower in the western population, the fact that 10 haplotypes still remain in a population this small is encouraging. It may indicate that a considerable amount of variation is still contained within the gene pool. In comparison, only five haplotypes have been observed in the western North Atlantic population of right whales, currently estimated at approximately 300 individuals (Malik *et al.*, 2000). However, the retention of 10

haplotypes in the western gray whale population has some relevance to another important issue, namely whether or not the western population is recovering. Weller *et al.* (2002) estimated that less than 50 of the western gray whales are mature, and that the current sex ratio of this population is approximately 60% male:40% female. This translates into an estimate of approximately 19 reproductive females; probably even less according to Weller *et al.* (2002). The recovering eastern population has been estimated to have had a maximum growth rate of 3.3% per year (for the interval 1967/68 to 1987/88), even higher if the aboriginal take of approximately 180/yr was taken into account (IWC, 1998). Applying a 3.3% recovery rate, and assuming that there are 19 reproductive females today in the western population, there would have been only about six reproductive females in the western population when whaling ended in 1966. That is an extremely unlikely scenario considering that there were still 10 extant western haplotypes in 1999, two of which are now in very high frequency. Even if there had been ten reproductive females extant in 1966, each with a different haplotype, reproductive success would have had to be extremely skewed towards two of those matrilines.

There are a number of possible explanations for this many haplotypes persisting in such a small population. First, the current abundance estimate could be low. However, photographic identification data (Weller *et al.*, 1999; 2002 do not support the existence of an appreciably greater abundance off Sakhalin Island, although a still undiscovered feeding area cannot be ruled out. A second possibility is that the population has grown much more slowly than 3.3% since 1966 (i.e. the bottleneck was not as severe as six, or even ten, reproductive females). Although this scenario would bode well for the level of genetic diversity still contained in the population, it would nonetheless have serious implications for their viability. If the population in 1966 contained much more than six adult females, it raises the possibility that the population has only been holding steady or even continuing to decline since then rather than recovering. In other words, a population the size of the western gray whales that has been growing since 1966 would not be expected to contain as many as 10 haplotypes. These sub-optimal population trajectories suggest the existence of some yet to be determined source of mortality (e.g. bycatch in fisheries, direct kills, vessel strikes, etc.) or other impediment to recovery (e.g. habitat degradation as reviewed in Weller *et al.*, 2002).

Another possibility is that there is some dispersal from the eastern stock. In general, the gene pool of a small population is strongly influenced by even trivial amounts of gene flow from a larger neighbour, and the significant differences found between these populations would seem to contradict this possibility. However, given the maternal inheritance of the mitochondrial data examined here, male dispersal could still occur but would have little or no long-term effect on haplotype distributions (and mitochondrial differentiation). Indeed, of the eight western haplotypes represented by only one or two individuals, only two (*E* and *H*) came from females, with the remaining six only represented by males. Future work using microsatellite data may be able to test hypotheses of male dispersal. Because of the higher diversity and number of haplotypes in the eastern population, animals dispersing into the western population are most likely to carry haplotypes considered rare in the west (i.e. ones other than 'A' or 'B'). Animals with these rare haplotypes could be the focus of microsatellite-based assignment tests (e.g. Paetkau *et al.*, 1995), to see if they show greater affinity to the eastern population than do the rest of the western animals. However, since it is the number of females that seems to have dropped to critical levels at present (Weller *et al.*, 2002), any influx of males that may occur would not be of immediate benefit to the western population, although it would mitigate any effects of inbreeding and loss of diversity in the nuclear genome. Overall, the present findings that the mitochondrial differentiation between eastern and western gray whales is large and female dispersal is negligible at best, coupled with the paucity of females in the western population (Weller *et al.*, 2002), underscores the critical status of the western gray whales (e.g. see IWC, 2002).

Based on molecular identification, Baker *et al.* (2002) determined that seven commercial market products purchased in Wakayama Prefecture, Japan in August and October 1999 were samples of gray whale meat. They noted that all seven products had the same haplotype as a GenBank gray whale sequence (Accession #L35611), from a whale sampled off the coast of Washington, USA. The GenBank sequence and the sequences from the Wakayama gray whale products are all identical to our haplotype 'A' (Figs 1 and 2), the most common haplotype in both the eastern and western sample sets (10.8% and 44.4%, respectively). The sequences are also identical to the sequence provided to us by M. Goto and L. Pastene (pers. comm.) for the whale harpooned off Hokkaido in 1996 (Brownell and Kasuya, 1999), the whale also referred to as the 'Suttsu' whale by Baker *et al.* (2002). This haplotype is shared between the two populations and it is not possible to definitively assign the Wakayama meat samples (or any given gray whale sample) to either population using mitochondrial sequence data. Nevertheless, given the match, and the apparent butchering of the carcass (Brownell and Kasuya, 1999), a reasonable explanation is that the meat from the Wakayama market originated from the whale harpooned off Hokkaido. This explanation can be tested by analysing both samples using microsatellite data, or any other molecular data that allow the genotyping of individual whales. Finally, the sequence sent to us by M. Goto and L. Pastene (pers. comm.) from the 1995 stranding in eastern Hokkaido matched both haplotype 'G' and 'O' of our dataset (the shorter sequence sent by Goto and Pastene did not include the variable sites that distinguish haplotype 'G' from haplotype 'O').

In summary, results presented here show that eastern and western gray whales can be genetically differentiated at the population level, and should be recognised as geographically isolated and demographically closed population units. However, because of shared haplotypes, it is not possible at this time to genetically identify an individual sample to either population. Furthermore, the presence of 10 western haplotypes in a population this small is inconsistent with a population that has undergone any appreciable growth.

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Author for correspondence:
Ladd M. Irvine
e-mail: ladd.irvine@oregonstate.edu

†Present address: National Oceanographic and Atmospheric Administration, Protected Species Division, Honolulu, HI 96818, USA.

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Marine biology

Critically endangered western gray whales migrate to the eastern North Pacific

Bruce R. Mate[1], Valentin Yu. Ilyashenko[2], Amanda L. Bradford[3,†], Vladimir V. Vertyankin[4], Grigory A. Tsidulko[2], Vyacheslav V. Rozhnov[2] and Ladd M. Irvine[1]

[1]Marine Mammal Institute, Department of Fisheries and Wildlife, Oregon State University, Hatfield Marine Science Center, Newport, OR 97365, USA
[2]Institute of Ecology and Evolution of the Russian Academy of Science, Moscow 119071, Russia
[3]School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington DC 98195-5020, USA
[4]Kronotsky State Nature Biosphere Reserve, Elizovo, Kamchatka 684010, Russia

LMI, 0000-0001-5135-3496

Western North Pacific gray whales (WGWs), once considered extinct, are critically endangered with unknown migratory routes and reproductive areas. We attached satellite-monitored tags to seven WGWs on their primary feeding ground off Sakhalin Island, Russia, three of which subsequently migrated to regions occupied by non-endangered eastern gray whales (EGWs). A female with the longest-lasting tag visited all three major EGW reproductive areas off Baja California, Mexico, before returning to Sakhalin Island the following spring. Her 22 511 km round-trip is the longest documented mammal migration and strongly suggests that some presumed WGWs are actually EGWs foraging in areas historically attributed to WGWs. The observed migration routes provide evidence of navigational skills across open water that break the near-shore north–south migratory paradigm of EGWs. Despite evidence of genetic differentiation, these tagging data indicate that the population identity of whales off Sakhalin Island needs further evaluation.

1. Introduction

Gray whales (*Eschrichtius robustus*) occur in both the eastern and western North Pacific Ocean [1]. Considered separate populations, both were severely depleted by commercial whaling. Eastern gray whales (EGWs) have recovered and are now thought to be near carrying capacity [2]. Western gray whales (WGWs), once thought to be extinct, currently number approximately 130 individuals and are listed as critically endangered by the International Union for Conservation of Nature [3]. Historically, widely ranging along the Asian coast, contemporary WGW aggregations are known primarily from summer feeding grounds off Sakhalin Island (SI), Russia [4]. WGWs were thought to winter off southern China [4], but current winter reproductive areas and migratory corridors are unknown. Here, we use satellite-monitored tracking data to conduct the first investigation of WGW migratory corridors and breeding areas to better evaluate threats to the population. The tag data reveal extensive migrations to traditional EGW breeding habitats, calling into question the identity of the WGW stock.

2. Material and methods

The International Whaling Commission's WGW Satellite Tagging Steering Committee established tagging protocols followed throughout two expeditions [5,6]: from 1 September to 7 October 2010 and 21 August to 22 September 2011. Only adult males in good body condition [7] were considered 2010 tagging candidates. Prior to a tagging approach, we visually identified whales from unique pigmentation patterns,

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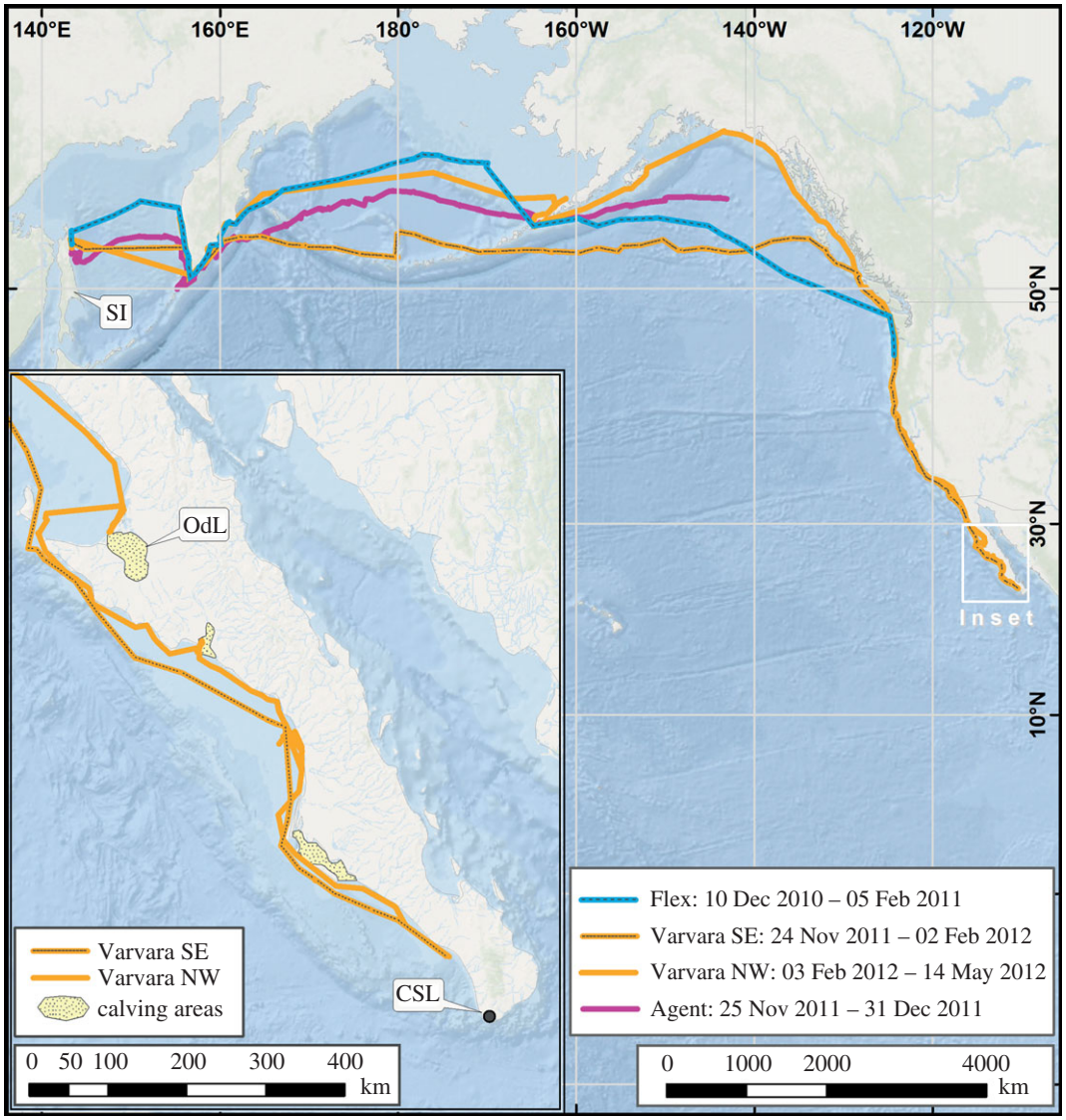

Figure 1. Routes of three western gray whales migrating from Sakhalin Island, Russia, to the eastern North Pacific. The legend depicts departure and arrival/end dates. Varvara visited all three major eastern gray whale reproductive areas off Baja California, Mexico (inset). (Online version in colour.)

using a WGW photo-identification catalogue. Sex is known for almost 80% of catalogued individuals from previous biopsy sampling, and many individuals were photographed as calves allowing age determination. Initially in 2011, only juveniles less than 6 years and females that had calves that year were not candidates. The latter criterion was later amended to allow tagging of females in good body condition that had weaned a calf.

We conducted tagging from a variety of small (less than or equal to 7 m) vessels powered by inboard diesel or four-stroke gas outboard engines, which were launched from the 50 m *Igor Maximov* support ship. We deployed tags from a distance of less than 4 m using a modified air-powered line-thrower [8]. Photos and videos were taken of tag deployments to document whale identity, tag penetration and location.

Tags consisted of a Wildlife Computers Spot-5 Argos transmitter and three Saft A-cell lithium batteries cast in an epoxy-filled stainless steel cylinder. The implantable tags were 28.2 cm long and 2.0 cm in diameter with attachments similar to those used for tagging other large whales [8]. To reduce the likelihood of infections, we partially coated tags with 2.5 g of Gentamycin sulfate, a broad-spectrum antibiotic, in a bio-soluble methacrylate for long-term release of the antibiotic into the tag site. Tags were sealed in gas-permeable bags for 12 h of ethylene-oxide sterilization.

Tags were programmed to transmit during four 1 h periods daily, coinciding with good satellite coverage over a broad range of possible North Pacific migration paths and destinations. Service Argos calculated locations with estimated accuracy based on the timing and number of transmissions received during individual satellite passes [9]. Three of seven location classifications have specific accuracies from less than 150 m (LC 3) to approximately 1 km (LC 1) [10]. We filtered unreasonable data by removing poor quality locations and limiting swim speeds to less than 10 km h^{-1} [8]. Distances travelled and swim speeds were calculated using ArcGIS 10.1 and are minimum estimates calculated from straight lines between consecutive locations.

3. Results

Three of seven tagged adult WGWs off SI during the two expeditions transmitted long enough to document migration away from SI after 68–89 days of near-shore movements: a male (13 year old 'Flex') in 2010 and two females (6 year old 'Agent' and 9 year old 'Varvara') in 2011. Each whale took different outbound routes across the Bering Sea, through the Aleutian Island chain, and across the Gulf of Alaska (figure 1), travelling an average of 6.2 km h^{-1} (table 1).

Tags attached to Flex and Varvara functioned long enough to document the whales entering the EGW southbound migration corridor. The last received location from Flex was 5 February 2011 off Lincoln City, OR, USA, after

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Table 1. Tracking summary information of three western gray whales instrumented with satellite-monitored radio tags off Sakhalin Island, Russia.

whale	tracking segment	start date	end date	distance km (nmi)	days	speed km h^{-1} (nmi h^{-1})
Flex	feeding	4 Oct 2010	10 Dec 2010	938 (506)	68.0	0.6 (0.31)
Agent		28 Aug 2011	24 Nov 2011	2600 (1403)	88.7	1.2 (0.66)
Varvara		31 Aug 2011	24 Nov 2011	1280 (691)	84.2	0.6 (0.34)
Flex	southeast migration	10 Dec 2010	5 Feb 2011	7661 (4137)	56.1	5.7 (3.1)
Agent		24 Nov 2011	31 Dec 2011	5464 (2950)	36.3	6.3 (3.4)
Varvara		24 Nov 2011	2 Feb 2012	10 880 (5875)	69.5	6.5 (3.5)
Varvara	reproductive areas (end of migration—Ojo de Liebre)	2 Feb 2012	26 Feb 2012	1147 (619)	24.0	2.0 (1.1)
Varvara	northwest migration	26 Feb 2012	14 May 2012	10 484 (5661)	78.8	5.5 (3.0)

travelling at least 7661 km. Flex was re-sighted in good body condition during the 2011 SI tagging expedition. Varvara departed SI on 24 November 2011, 17 days earlier than Flex, and passed Lincoln City on 8 January 2012, during the peak of the EGW southern migration. She travelled 10 880 km south to within 103 km of Cabo San Lucas, Baja California Sur, Mexico (CSL), on 2 February 2012, 69.5 days after departing SI (figure 1). Varvara spent 42 days off Baja California, Mexico including 32 days of generally northward movement, passing all three major EGW reproductive areas [11]. From CSL to the northernmost breeding area at Laguna Ojo de Liebre (OdL), Varvara travelled 1147 km, averaging 2.0 km h^{-1} (figure 1, inset). Her 10 484 km migration from OdL back to SI followed a different route from her eastward trip, crossing the eastern Bering Sea near the southerly face of the retreating ice edge and took 79 days, ending on 14 May 2012. Some slower movement segments were recorded along the north side of the Alaska Peninsula and while crossing the Bering Sea. The overall average speed for her spring migration was 5.5 km h^{-1}. The entire 22 511 km round-trip migration lasted 172 days.

4. Discussion

Varvara's 10 880 km autumn migration constitutes the longest recorded distance travelled during a mammal migration [12]. The linear travel segments over deep water made by tagged whales in this study indicate excellent navigation abilities [13] in sharp contrast with the slower-paced, near-shore and shallow-water migration of EGWs along North America [11]. Varvara's near-shore spring migration route until reaching the Bering Sea was typical of EGWs. However, her more northerly westward route across the Bering Sea indicates she was not obliged to return by the same specific route of her eastward migration, further reinforcing a strong ability to navigate. The occasional slow movement segments observed along the Alaska Peninsula and during the western crossing of the Bering Sea may indicate opportunistic feeding.

New-born gray whale calves follow their mothers during the spring migration to the mother's foraging area, where weaning occurs in late summer [11]. Juvenile and adult WGWs first identified as calves off SI have returned there to feed [4], indicating a very strong allegiance to their mother's migratory destination. Similar natal philopatry has been observed in humpback whale calves, in the North Pacific and elsewhere, returning to their mothers' migratory destinations [14]. Thus, the three migratory tracks documented by this study strongly suggest the tagged whales were born in EGW reproductive areas.

The utilization of feeding areas in the western North Pacific by whales that winter in the eastern North Pacific raises questions about the present status of WGWs. Since these tracking data became available, a preliminary comparison between WGW and EGW photo-ID catalogues discovered 10 WGWs have been photographed near British Columbia and in San Ignacio Lagoon, Baja California, Mexico [15]. Those sightings, combined with two genetic matches, further strengthen the linkage between these two presumed stocks and question whether the present WGWs came from the population previously thought to be extinct or from recovered EGWs with an expanded range [16].

Recent evidence that 'true' WGWs (i.e. whales breeding in Asian waters) are extant includes: four fishing net deaths off the Pacific coast of Japan between 2005 and 2007, including a yearling first observed as a calf off SI [17]; a gray whale stranded in November 2011 off the Fujian Province in southern China [15], adjacent to the region speculated to serve as a reproductive area for WGWs [17]; and a March 2012 live sighting in Mikawa Bay, Japan [15]. EGWs have been sighted well outside their established ranges [18], so it is possible that WGWs are extinct and these western North Pacific sightings represent a wider EGW foraging range, and more variable migratory timing than is presently thought. It is also possible that the SI region is a foraging area where EGWs and a smaller-than-estimated 'true' WGW population co-mingle, with the latter group making a southerly migration along the Asian coast to an as yet undiscovered breeding area or that spatial and temporal concentrations of whales from SI, during their occupancy in the regular winter range of EGWs, allow them to maintain genetic separation from other EGWs. Overall, the tagging and photo-ID data indicate that the population identity of whales off SI needs further evaluation.

Ethics statement. The procedures used in this study were reviewed and approved by the International Whaling Commission's Western Gray Whale Satellite Tagging Steering Committee and the Oregon State University Institutional Animal Care and Use Committee.

Data accessibility. Data for this study are archived at the International Whaling Commission (http://iwc.int/data-availability) and at the Oregon State University Marine Mammal Institute.

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Author contributions. B.M. participated in the conception, design and coordination of the study, participated in field work and drafted the manuscript. V.I. participated in the conception, design and coordination of the study and reviewed the manuscript. A.B. participated in the design of the study, participated in field work and reviewed the manuscript. V.V. led the field work. G.T. participated in the design of the study and participated in the field work. V.R. participated in the conception, design and coordination of the study and reviewed the manuscript. L.I. participated in the field work and reviewed the manuscript. All authors gave final approval of the version to be published.

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2

Atlantic Gray Whales

James G. Mead and Edward D. Mitchell

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Introduction

The gray whale (*Eschrichtius robustus*), common in the north Pacific at the present time, was first known to science on the basis of subfossil remains from Europe. There are historical references to gray whale in the North Atlantic, such as the "sandloegja" of Iceland (Fraser, 1970) and the "scrag whale" (Dudley, 1725) of early New England whalers. In the early literature pertaining to the North Atlantic, there are a few reports of whales that do not seem to correspond to Atlantic species. Some of these are, no doubt, erroneous and garbled accounts of species that are known from that ocean, but some may represent unrecognized accounts of the Atlantic gray whale. We will go through the historical accounts and add newly found subfossil specimens that demonstrate the existence of a population of gray whales in the western North Atlantic until relatively recent times.

To make sense of these reports, one must have criteria to differentiate accounts of gray whales from those of other whales. The main external characters that set gray whales apart from other large cetaceans are

1. Appearance of the dorsal region. Most species of whale have a well-formed dorsal fin. Gray whales have a series of low knob-like crenulations on the back starting where the dorsal fin would be. There are three species of whale that could be mistaken for a gray whale; the sperm (*Physeter catodon*), humpback (*Megaptera novaeangliae*), and right whale (*Balaena glacialis*). The sperm whale has a low dorsal fin or hump followed by a series of crenulations. On closer examination, it may be distinguished from a gray whale by the shape of its head and the presence of teeth. Some humpback whales have a low triangular dorsal fin that could be interpreted by persons not familiar with whales as not being a dorsal fin. In the North Atlantic Ocean, the humpback's

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extremely long white flippers are markedly different from gray whales' short gray flippers. Right whales have no dorsal fin at all. Their smooth black back sets them apart from gray whales, which have mottled gray backs.

2. Ectoparasites and pigmentation. Gray whales are heavily infested with barnacles (*Cryptolepas rhachianecti*) and whale lice (*Cyamus scammoni, C. ceti,* and *C. kessleri*). This, coupled with their coarsely mottled pigmentation, is one of the species' most distinctive traits. The only other whales with ectoparasite infestations sufficiently dense to cause them to be confused with grays are humpbacks and right whales. However, ectoparasites are generally confined to the head in right whales and to the flukes, flippers, chin, and genital slit in humpbacks, whereas the ectoparasites may be distributed over the entire body of gray whales. Other species of large whales are usually dark on the back and lighter below. Gray whales are coarsely mottled with varying shades of gray both above and below.

3. Color of the baleen. Gray whale baleen is "cream to pale yellow," similar in color to the baleen of finbacks (on part of their right sides) and most minke whales, but it is much thicker and coarser in grays.

Balaenopterids can be mistaken for gray whales. While working at a whaling station in Newfoundland in 1971, one of us (Mead) was approached by the skipper (Clarence George) of one of the small vessels used to take minke whales and asked what would happen if he took a gray whale. Several years before he had seen an animal with white markings over its body and no dorsal fin but rather a series of bumps in its place. He had looked it up in a book and come to the conclusion that it had to be a gray whale, and besides he had killed at least one of everything else in the temperate North Atlantic (including the right whale) and "knew" it was none of those. He knew that the gray whale was protected in the Pacific but wondered if that protection extended to the Atlantic. A few days later Mead happened to be on board the regular catcher vessel which worked out of that station (M. V. *West Whale 8*) and asked the skipper (Arne Borgen), who had whaled out of a station on Vancouver Island and was familiar with gray whales, if he had ever seen anything that looked like a gray. He at first said he had not and wondered why Mead asked. When Mead told him Clarence George's story, his face lit up and he said that he remembered that whale. He had seen it a few miles out of the station and had initially been surprised because it looked for all the world like a gray whale. He followed it and finally came to the conclusion that it was an injured balaenopterid. He harpooned it and when it was hauled up on the station slipway it turned out to be an emaciated finback that had lost the dorsal fin and was scarred over large portions of the body.

To clarify past accounts, we shall review the pertinent literature in chronological order.

Literature Accounts without Specimens

The earliest account of cetaceans in the North Atlantic containing information relevant to this problem of the existence of gray whales in the North Atlantic is the "Speculum Regale" (kongespiel; konungs-skuggsja; kings' mirror), an Icelandic manu-

script of the mid-thirteenth century. This work has been commented upon in some detail by Eschricht and Reinhardt (1866, pp. 23–34). The manuscript contains a list, with descriptions, of the cetaceans of Iceland which number some 20 species. It apparently also once contained illustrations that have since been lost. We have examined an English translation of the Speculum Regale (Larson, 1917) and found no descriptions that are obviously of gray whales. There are one or two that could potentially be gray whales but there is insufficient information given to allow verification.

Eschricht and Reinhardt (1866, p. 31) mention a list of the cetaceans of Iceland that was written in the seventeenth century and sent by an Icelandic cleric to Olaus Worm. This list appears to have formed the basis for the chapter on cetaceans in Worm's *Museum Wormianum*, published in 1655 (see Allen, 1882, p. 417 for comments). As abridged and amended by Worm the information presented consists merely of a list of 22 species, many of which have no description and none of which can be related to the gray whale.

In 1611, The Muscovy Company of England sent an expedition consisting of two ships under the command of Thomas Edge to Spitzbergen to investigate the possibility of whaling there. The instructions for this expedition included a list of the various whales that they might encounter and their relative commercial values (Lubbock, 1937, pp. 60–63; Allen, 1882, p. 412). Allen indicated that these instructions appeared in "Purchas His Pilgrimes" in 1625, bearing the date of issue of 31 March 1611. Lubbock quoted portions of this list which clearly describe the Greenland right whale (*Balaena mysticetus:* bearded whale), the right whale (sarda), the sperm whale (trumpa), one of the finner whales (*Balaenoptera* sp.: gibarta), another finner whale, possibly the blue whale (*Balaenoptera musculus:* sedeva), and what was apparently the humpback (sedeva negro). In addition to these six there was another sort of whale described, the otta sotta, which Lubbock was unable to identify. We repeat the account quoted by Lubbock (1937, p. 63) from the instructions given to Edge:

> The fourth sort of whale is called Otta Sotta, and is of the same colour as the Trumpa having finnes in his mouth all white but not above halfe a yard long, being thicker than the Trumpa but not so long. He yeeldes the best oyle but not above 30 hogs' heads.

The color and size of the baleen and oil yield are more consistent with an identification of a gray whale than with any other known species. The only other whale with all-white baleen is the minke whale, which is shorter, of a uniform darker color dorsally and white ventrally, and has a much lower oil yield. Of particular note is the statement about the quality of the oil, which indicates that it was not only taken commercially but that it was particularly sought after.

The commission from the Muscovy merchants to Thomas Edge bears further examination in the of the state of knowledge about Spitzbergen at that time. Eschricht and Reinhardt (1866, p. 26) stated that news of the abundance of whales in Spitzbergen was brought by Jonas Poole who visited there in 1610. Thus it seems unlikely that the commission of 1611 was based on information derived from activities at Spitzbergen. Edge took with him to Spitzbergen a number of Basques known for their skill in pursuit of whales, and it is likely that the information of the commission was obtained from Basque sources.

Also of interest is an engraving (Fig. 1), unfortunately of somewhat dubious origin, which has appeared in a variety of publications (e.g., Walton Advertising and Printing Company, 1915, p. 15; Dow, 1925, Plate 44). It appears to have come from Churchill's Voyages, a collection of narratives of travel and exploration published in various editions from 1704 onward. In the edition that we have examined, this engraving is associated with an account of the voyage of John Monck (Jens Munk) to Hudson Bay in 1619 and 1620 (Churchill and Churchill, 1704, pp. 541–569). Appended to the narrative of the voyage is an account of uncertain origin of whaling at Spitzbergen. The title page bears the comment "translated from the High-Dutch original, printed at Frankfort upon the Maine, 1650." The compilers of this edition have associated it with Monck, but neither the authorship nor the source of the engraving is clear. The engraving shows a whale on the beach surrounded by what appear to be whalers and merchants. The whale pictured clearly represents none of the balaenopterids or the black right whale. This leaves only the Greenland right whale and the scrag whale. If we assume for the moment that the scrag whale is the gray whale and use this species as the basis for comparison with the engraving, some interesting features become apparent. In the engraving the head is relatively less bowed than in the Greenland right whale and in general is more similar to the gray whale, particularly in the relative depths of the lower jaw and rostrum. The pigmentation pattern, generally light along the whole ventral surface, is also more similar to the gray whale than to the Greenland right whale, in which the underside of the tip of the lower jaw and sometimes the ventral surface of the tailstock are usually

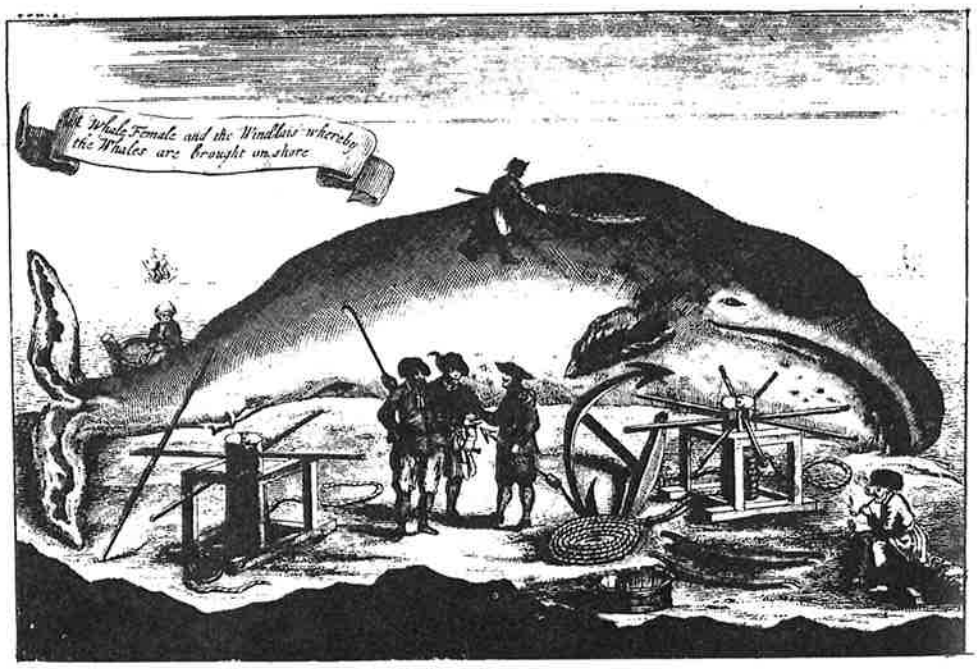

Fig. 1. *Dutch engraving.*

much lighter than the rest of the ventral surface, which is usually black. The shape of the flipper is more similar to that of the gray whale than to the broad flippers of the Greenland right whale. The pigmentation shown on the flippers and flukes resembles the mottling seen on the appendages of the gray whale.

Unfortunately the engraving turns out to be a copy of a portion of a painting of a Danish whaling station at Spitzbergen done in 1634 (Dalgård, 1962; Plate 4). There are numerous resemblances between the original painting and the engraving in Churchill, from the arrangement of the people and their dress to the equipment shown scattered about. The one thing that has changed is the whale. In the original painting it is much more like a Greenland right whale than a gray whale. The resemblance of the image in the copy to a gray whale was apparently solely the result of the engravers' inability to copy accurately the whale in the painting.

Fraser (1970, p. 17) gave the translation of Gudmundsson's seventeenth century (about 1640) description of a whale that the Icelanders referred to as the "sandloegja":

> Sandloegja (fig. 5). Good eating. It has white baleen plates, which project from the upper jaw instead of teeth, as in all other baleen whales, which will be discussed later. It is very tenacious of life and can come on land to lie as seal like to rest the whole day. But in sand it never breaks up.

It is sufficient to say that we agree with Fraser's conclusion that the sandloegja of Gudmundsson represents the gray whale, indicating that this animal was known to the Icelanders at this time by the palatibility of its flesh, its habits, and its physical characteristics. We initially thought this information might have derived from earlier Icelandic works, specifically the "Speculum Regale," but as stated earlier we could find no accounts in that work from which this information could have come.

De Vries (1853) gave an account of whaling in Delaware Bay (a large embayment formed at the mouth of the Delaware River and bounded by the states of New Jersey and Delaware) in the early part of the seventeenth century. Whales were apparently very numerous there, but as de Vries points out in several places, yielded very little oil. At one point he mentions the capture of seven whales which yielded only 32 "cartels" (65 barrels) of oil. De Vries paid considerable attention to documenting economical aspects of whaling in Delaware Bay, with much comment on the low oil yield of the whales. From the fact that baleen, which was extremely valuable at that time, was not mentioned, we can conclude that the whales taken may not have been right whales.

Van der Donck (1841) presented considerable information on whaling in "New Netherlands" (New York state) in the mid-seventeenth century. He spoke of a good whale fishery in Delaware Bay and described the whales there in the following terms: "Whales are numerous in the winter on the coast; and in the bay where they frequently ground on the shoals and bars; but they are not as fat as the Greenland whales." Van der Donck also mentioned an instance in March of 1647 in which two whales "of common size" swam 43 miles up the Hudson River. One of these stranded there; the other returned to within 12 miles of the sea before it also stranded ("near which place four others also stranded the same year"). As from de Vries' account (1853), one gathers from van der Donck that whaling took place only in the winter. It is notable that there is no mention of baleen as a product of this industry, although considerable stress is

placed on the economics of the venture. This leads to the conclusion that they also may not have been right whales.

Dudley (1725), in his famous letter relating to the whales of the coasts of New England, provided the first mention of an enigmatic whale known as the scrag whale. Dudley gives accounts of recognizable right, sperm, finback, and humpback whales. In addition he describes another kind of whale in these words (1725, p. 258):

> The Scrag whale is near a-kin to the Fin-back, but instead of a Fin on his Back, the Ridge of the After-part of his Back is scragged with a half Dozen Knobs or Knuckles; he is nearest the right Whale in Figure and for Quantity of Oil; his Bone is white, but won't split.

There has been much written about the identity of the "scrag whale of Dudley." Authors fall into two groups, those who thought the scrag whale was the gray whale and those who did not believe one could determine its identity. We intend to demonstrate that there is enough evidence that gray whales existed along the American coast to ascertain that what Dudley meant by scrag whale is in fact the gray whale.

Douglass (1760, p. 58), in a discussion of the British territories in North America, gave an account of the whales and the whaling industry in which he mentions the "bunch" of the humpback and merely states "the scrag whale has several of these bumps."

St. John (1782, p. 169) presented a list of the whales known at Nantucket that included right, humpback, finback, sulphur-bottom, and sperm whales, but nothing which could pertain to the gray whale. As True (1904, p. 43) noted, St. John seems to have had first-hand knowledge of whaling in this area, which may indicate that the gray whale was no longer present in any numbers at this time.

In his history of the colony of Nantucket, Macy (1835, p. 28) mentioned that in the early days of the colony (prior to 1672) a whale of the kind called "scragg" entered the harbor and was pursued and killed by the settlers. He remarks that this instance provided the start of the Nantucket whaling enterprise. It is unclear, in the reference of Macy (1835, p. 28) to scrag whales at Nantucket, Massachusetts prior to 1672, whether the term was in use in 1672 or was simply supplied by Macy at the time of his writing.

Cuvier (1836, p. 309) dismissed Dudley's scrag whale as probably an erroneous account of a balaenopterid. Cuvier had interpreted Dudley's remark about the protruberances on the back of the scrag whale to mean they were bony, leading him to discredit the rest of Dudley's account as improbable.

Gray (1850) commented on the validity of *Balaena gibbosa* (the scientific name based on Dudley's account of the scrag whale), which he felt was "a *Balaena*, probably well known formerly." To support his case he cited Beale (1839) as saying that the scrag whale was known to contemporary whalers. We have read Beale (1835, 1839) and were unable to locate this information. Gray himself seems to have had no original information on this subject.

Eschricht and Reinhardt (1866, p. 42) commented upon the usage of the term "scrag whale" by whalers in the Pacific and concluded that most of these could be simply references to young right whales. They stated (1866, p. 43) that

Scrag and Scrag-whale have been common appellations during at least 150 years, and, like the name of the right-whale itself, have at different times and in different places been applied to cetaceans quite different from one another.

It seems from their account that some of the whales termed "scrag" may have been gray whales. Brown (1868, p. 547), in a discussion of the whales of Davis Strait and Baffin Bay, said that he could not imagine what Dudley's scrag whale was, as the whalers did not know of such an animal.

The comparisons which Cope (1868c) (see p. 44) made between the *Agaphelus gibbosus* specimens and the Pacific gray whale material to which he had access are sufficient to indicate that *A. gibbosus* was quite different. In our opinion the shape of the base of the baleen plates, the nature of the coronoid process, the shape of scapula, and the pattern of pigmentation of Cope's *A. gibbosus* are definitely balaenopterid. The supposed lack of dorsal fin and ventral grooves is most certainly due to errors arising from the description which Cope received of the badly decomposed and mutilated carcass of the Long Beach specimen.

It is not entirely clear, however, which species of balaenopterid was represented by the Long Beach stranding. Based on the white color of the baleen there are two possibilities; the finback and the minke whale. Cope's size estimate of 43 feet (13 m), plus the information that the vertebral epiphyses were unfused, strongly suggests that the specimen was a young finback. The size of the auditory bulla, the pigmentation pattern, and the size of the baleen, however, indicate that it was a minke. If it were the latter, it would have been an extremely large animal (adults of this species rarely excede 10 m in length); this is contrary to the other evidence that this was a very young animal.

All evidence argues that the Long Beach stranding was probably a minke, the details of which were perhaps confused with defective information or remains of an independent stranding of a finback. This conclusion agrees with Cope's initial (1867) and final (1884) diagnoses, with the detailed account of True (1904, p. 105), and the discussion of Hershkovitz (1961).

Captain Atwood of Provincetown, Massachusetts wrote (in Allen, 1869, p. 203) of a scrag whale sometimes taken near that locality. He said that some of the whalers were of the opinion that it was a right whale. However, he stated that its most prominent feature was a small number of projections on the dorsal ridge near the tail, "having some resemblance to the teeth of a saw." Allen had sent the account of Atwood to Cope, who attached the name *Agaphelus gibbosus* to this animal.

Allen (1869, p. 203) placed *Eschrichtius robustus* on the list of mammals of Massachusetts on the basis of the jaw which Cope mentioned from the New Jersey coast (not the "*Agaphelus*" stranding at Long Beach). In 1869 Cope published further descriptions of fossil material which he assigned to *Eschrichtius*, still not recognizing its relationship to *Agaphelus* (Cope, 1869a; see Chapter 1, this volume).

Gray (1870) stated that the scrag whale (*A. gibbosus*) was abundant in America and was still caught now and then by whalers. This was probably derived from the account of Atwood in Allen (1869). Gray (1871) included *Eschrichtius robustus* as a part of the recent Atlantic cetacean fauna based on Cope (1868b).

Flower (1872) described subfossil material of *Eschrichtius* from Cornwall and cited the jaw from the New Jersey coast (Cope, 1868b) as evidence of the occurrence of this species on the western coasts of the Atlantic. He did not, however, make the connection between the species and the Pacific gray whale.

Ten years later Cope (1869b), having examined more material of the Pacific gray whale, recognized its distinctness from the specimen which he had assigned to *Agaphelus gibbosus* and formed the new genus *Rhachianectes* for it. In so doing he lost the one fortuitous correlation he had made, that of the scrag whale and the Pacific gray whale.

Van Beneden and Gervais (1880, p. 236) considered *Agaphelus gibbosus* to be a young right whale. This conclusion is certainly based on the earlier idea of "scrag" whales as young or emaciated right whales rather than on any evaluation of the basis of Cope's taxon. They cited (1880, p. 236) the jaw from New Jersey which Cope (1868b) referred to *Eschrichtius robustus*. References to this specimen have probably been confused with the variety of fossil cetaceans from the Miocene which Cope assigned to *Eschrichtius* (see Barnes and McLeod, this volume). Fischer (1881, p. 35) noticed the account of *Agaphelus* from Cope's works and included it in his list of cetaceans from the southwest of France, without adding anything new to the account.

Finally, in 1884, Cope recognized the errors in the account of the Long Beach stranding and referred the specimen to *Balaenoptera rostrata* (minke), as he had originally done in 1867. He noted that "the species may, however, be the *Balaena gibbosa* of the old authors," indicating that the scrag whale question remained unsettled in his mind.

True (1884, p. 628) provided a good indication of the state of knowledge of the problem in a tabular presentation of the cetaceans of North America and their distribution. In this table he listed *Rhachianectes glaucus* (Pacific gray whale) as occurring only in the Pacific, *Agaphelus gibbosus* (the scrag whale of Dudley and Cope) only in the western Atlantic, and *Balaenoptera robusta* (the subfossil *Eschrichtius* material) as occurring on both sides of the Atlantic but not in the Pacific. Clearly he had noted all of the specimens in the literature but, like his predecessors, had made none of the connections.

Lydekker (1894, p. 1185) was apparently the first to make the connection between *Eschrichtius robustus* and the Pacific gray whale. He said, of the geographic distribution of gray whale:

> from the evidence of certain bones found in the superficial deposits of the British Islands, and described under the name of *Eschrichtius*, it is, however, not improbable that it formerly frequented the Atlantic.

True (1904) commented extensively on both the scrag whale and *Agaphelus gibbosus*. He was of the opinion that the scrag whale was an aberrant right whale. He presented a detailed analysis (1904, p. 105) of the history of *Agaphelus gibbosus*, concluding that it was a mutilated specimen of a minke. On p. 48 of this work he presented a list of the whales that Gray (1871) considered to inhabit American waters, a list which contained *Eschrichtius robustus*. True commented that the inclusion of this species must rest on the statement of Cope that there was a jaw of this form in the

Rutgers museum. Although True presented measurements of some of the material at Rutgers, he apparently never examined the collection himself as he made no further mention of this jaw and did not include *E. robustus* in his account of the Atlantic fauna. In addition, True's monograph contains numerous useful references to early whaling along the Atlantic coast of North America, many of which have information in them on the scrag whale question.

Allen (1916) was of the opinion that "scrag whale" referred to small or emaciated individuals of the right whale, and went so far as to illustrate (Plate 9) a "scrag whale" (an immature female of a right whale). He also made note of the confused state of *Balaena gibbosa* Erxleben (1777), which included some accounts of what were probably the humpback. He included Gray's (1865) specimen of *Eschrichtius robustus* in his synonomy of *Megaptera nodosa*, but gave no reasons for this decision. He also assigned *Balaenoptera robusta* Lilljeborg (the holotype of *Eschrichtius robustus*) to *Balaenoptera physalus*, again with no discussion of the obvious differences between the two.

The question of the relationship of the subfossil occurrence of *Eschrichtius robustus* to the Pacific gray whale was finally examined by van Deinse and Junge (Junge, 1936; van Deinse and Junge, 1937). They reviewed all of the known occurrences of *E. robustus* in the eastern Atlantic and concluded that this material could not be differentiated from the Pacific gray whale. In conclusion they state:

> Provided with these facts we can state, therefore, that *Eschrichtius gibbosus* [= *robustus*] must have occured still along the European coasts in the first centuries A.D. Along the American coast of the Atlantic this species still must have been present in the beginning of the 18th century, for at that time it was still caught by the whalers. And we think it not at all improbable that along the Atlantic coasts of North America in future *skeleton fragments of this species will be found.* (emphasis ours)

Cederlund (1938) made a detailed comparison of the *Eschrichtius robustus* remains described by Lilljeborg with Andrews' (1914) description of the gray whale and with two European skeletons of the gray whale. He concluded that the material of the holotype, although lacking any skull remains, was remarkably similar to comparable elements of gray whale. He also discussed the question of the scrag whale and concluded that this term had been applied to both the Atlantic gray whale and to aberrant individuals of the right whale.

Hubbs (1959), in a review of the natural history of gray whale, stated that gray whales were present in the Atlantic until early whaling and might still be there, but he did not document his conclusions. In his account of the description of the sandloegja, Fraser (1970) equated it with both the scrag whale and gray whale. He suggests, on the basis of the account of the sandloegja, that the North Atlantic gray whale may have been exterminated at an early date by human predation.

Eastern Atlantic Specimens

The first scientific mention of gray whale came in 1861 (Table I), when Lilljeborg described remains found on the coast of the Gulf of Bothnia at Gräsö, Roslagen,

Table I
Subfossil Specimens of Atlantic Gray Whales

Year found	Locality	Material	Age (years BP)	Authority
European material				
1829	Pentuan, England	Partial skeleton		Flower (1872)
1859	Gräsö, Sweden	Partial skeleton	4000–6000	Lilljeborg (1861)
1861	Babbacombe Bay, England	Vertebra		Gray (1864)
1865	Babbacombe Bay, England	Vertebra		Gray (1866)
1879	Ijmuiden, Netherlands	Partial skull		Deinse and Junge (1937)
1916	Ijmuiden, Netherlands	Partial skull	1400	Deinse and Junge (1937)
1935	Wieringermeer-Polder, Netherlands	Partial skeleton	4000–6000	Deinse and Junge (1937)
North American material[a]				
1850s	Toms River, New Jersey	Jaw	455 ± 90	This chapter
1959	Myrtle Beach, South Carolina	Partial skeleton	865 ± 165	This chapter
1969	Chesapeake Bay, Virginia	Partial skull	10140 ± 125	This chapter
1970s	Nags Head, North Carolina	Jaw	865 ± 50	This chapter
1976	Corolla, North Carolina	Squamosal	2415 ± 90	This chapter
1977	Southampton, New York	Jaw	275 ± 35	This chapter
1977	Corolla, North Carolina	Partial skull		This chapter
1978	Rehobeth, Delaware	Squamosal		This chapter
1979	Cape Lookout, North Carolina	Partial skull	1190 ± 245	This chapter

[a]Carbon 14 dates on the North American specimens determined by the Radiocarbon Laboratory, Smithsonian Institution. Samples were run on collagen fraction remaining in the bone.

Sweden (Fig. 2) under the name *Balaenoptera robusta*, in the belief that it was a new species of finner whale (Lilljeborg, 1861). The remains included the mandibles and most of a postcranial skeleton but no skull fragments. All seem to have belonged to a single physically mature individual, inasmuch as all vertebral epiphyses remained attached to the centra. The description was subsequently translated into English (Lilljeborg, 1866) with some additional figures added. A complete description of all the elements was prepared and published in English (Lilljeborg, 1867).

Lilljeborg's material was found in a field, 10–15 ft (3–5 m) above sea level and 840 ft (260 m) from the current shoreline. The remains were in a stratum of sand and clay 2–4 ft (60–120 cm) beneath the surface, associated with shells of *Mytilus edulis* and *Macoma balthica*. Lilljeborg considered this deposit to be postglacial and estimated its age at 4000–6000 years. Van Deinse and Junge (1937) reconsidered the age of this find and agreed that Lilljeborg's estimate was essentially correct.

Although it was not described until 1872, the first specimen of gray whale to be found along the northeast coast of the Atlantic was a partial skeleton excavated in 1829 from the Happy Union Tin Stream Works at Pentuan, Cornwall, England. The specimen consisted of the right lower jaw, a lumbar vertebra, a humerus, radius, and two metacar-

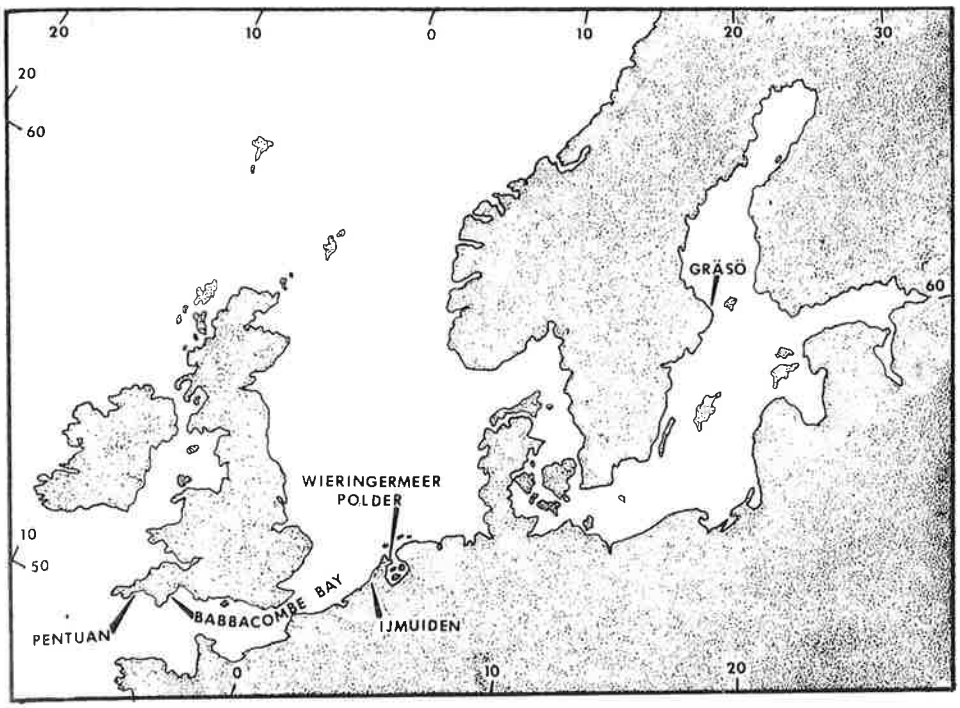

Fig. 2. *Location of eastern Atlantic specimens.*

pals, all probably from the same individual. According to Flower (1872), who described this material, it was slightly smaller than Lilljeborg's specimen from Gräsö and was a somewhat younger individual, as the vertebral epiphyses were not fused to the centra. These remains came from a depth of about 7 m in a stratum of marine sands, about 850 m from the present shoreline (Colenso, 1832, p. 36). The overlying sediments consisted of river sands and gravels, and the immediately underlying sediments were sands containing the remains of a number of terrestrial mammals, including man.

The third specimen to be described of this species from the northeast Atlantic was a cervical vertebra washed ashore at Babbacombe Bay, England and found by a Mr. Pengelly on November 24th, 1861. This vertebra was sent to Gray who immediately associated it with Lilljeborg's material on the basis of the extremely wide neural canal. Gray (1864, p. 350) initially thought that it was from a species of humpback whale and accordingly designated it "*Megaptera? robusta.*" He felt it was sufficiently different to warrant a subgeneric distinction and accordingly proposed the subgenus *Eschrichtius*, which he subsequently (1865, p. 41) elevated to full generic rank. In June of 1865, Mr. Pengelly recovered from the same locality another cervical vertebra which Gray (1866, p. 373) also identified as *Eschrichtius*. No estimates have been made of the age of this specimen.

No further remains of Atlantic gray whales came to light until 1937, when van Deinse and Junge published on a series of finds from the Netherlands. Stimulated by a

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recently found specimen, they searched museum collections and uncovered some earlier material. The first was a partial skull of a juvenile, found in 1879 at Ijmuiden on the North Sea coast of the Netherlands, just west of Amsterdam. Unfortunately there was no information on the circumstances under which this specimen was found on which to base an estimate of its age. The second was also from Ijmuiden and was a partial skull of an adult found in 1916 at a depth of about 1 m during excavation for a new harbor. Van Deinse and Junge (1937, p. 184) suggested an age of about 500 AD, based upon the amount of accumulated silt overlying it. The final specimen was a partial skeleton, consisting of a broken skull, mandible, hyoid, miscellaneous vertebrae, ribs, and limb elements, found by a farmer in 1935 while plowing a field in the Wieringermeer-Polder, a portion of the Zuiderzee about 40 miles (60 km) north of Amsterdam which had been drained in 1930. Van Deinse and Junge estimated the length of this animal at 8 m. Based on a pollen analysis of associated sediment, they estimated an age of 4000–6000 years (van Deinse and Junge, 1937, p. 184).

Fredén (1975) examined a number of subfossil remains of seals and whales from the west coast of Sweden. Although he did not present information on any specimens identified as gray whales and specifically excluded any material found along the current coastline, he did list a number of finds of unidentified whales, some of which might prove to be this species.

Western Atlantic Specimens

Edward Drinker Cope (1867) assigned a series of Miocene fossil cetaceans to the subgenus *Eschrichtius*, which Gray had formed for subfossil remains from Europe. These have been determined to be unrelated to the gray whale (see Chapter 1, this volume). Gray and Cope were deliberating on the strength of certain resemblances of these remains to the humpback. Thus when Cope first encountered recent material of *Eschrichtius* in the form of the Pacific gray whale, he did not make the connection between the two. It is in this same paper (Cope, 1867, p. 147) that Cope first mentioned a whale stranded at Long Beach, New Jersey. He referred this specimen to the minke whale.

In the next year Cope (1868a) made an informal announcement of a new genus *Agaphelus*, based upon the Long Beach stranding, the scrag whale of Dudley, and the Pacific gray whale. Subsequently another short notice appeared (Cope, 1868b) mentioning *Agaphelus* and giving a brief reference to a whale jaw, which Cope assigned to *Eschrichtius robustus* (Lilljeborg). In a third paper of the same year, Cope (1868c) formally defined *Agaphelus* and described the two species, *A. gibbosus* (based upon the Long Beach stranding and the scrag whale of Dudley) and *A. glaucus* (based upon the Pacific gray whale). It must be borne in mind that much of Cope's concept of *Agaphelus* was based upon the scrag whale of Dudley, and although he was familiar with remains of *Eschrichtius* described by Lilljeborg, he never made the connection between it and *Agaphelus*.

The specimen of *Eschrichtius robustus* that Cope (1868b) mentioned was a jaw sent

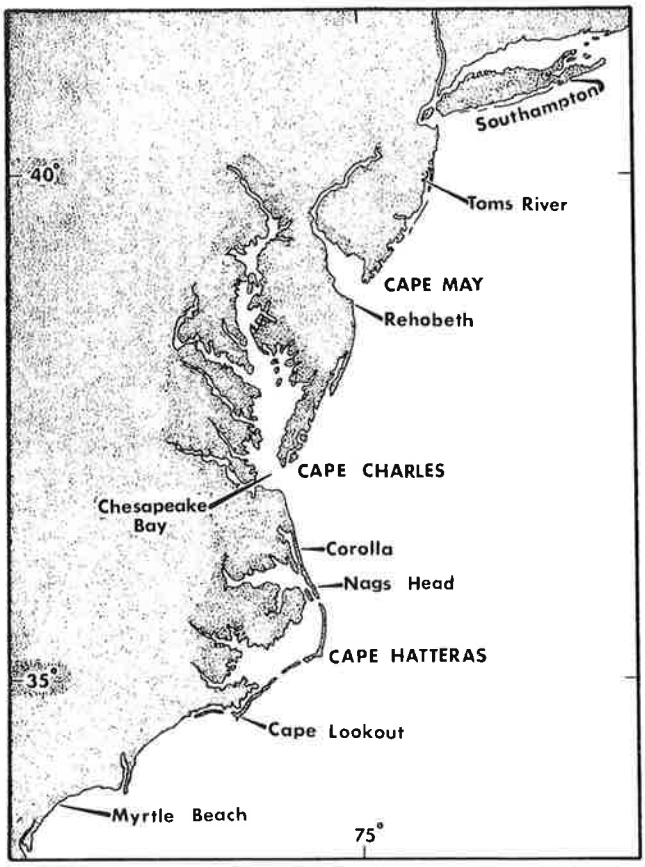

Fig. 3. *Location of western Atlantic specimens.*

to the Rutgers College museum by a Mrs. Dunham sometime about 1855. The data associated with this specimen are limited to those found on the paper label glued to the specimen and include only the name of the donor and the locality, Toms River, New Jersey (Fig. 3). There are a number of other bones in the museum collection which were contributed by the same donor, all apparently from Toms River. The jaw was examined by Cope (1868b, p. 194) who commented on it in a list of the recent mysticetes of the Atlantic coast of the United States:

> The *Eschrichtius robustus* is admitted on the evidence of a ramus of the under jaw in the Museum Rutger's College, which is of peculiar form, and closely resembles the figure given by Lilljeborg of that portion of this rare species.

Although this reference was cited in numerous subsequent works (Gray, 1871, p. 52; Flower, 1872, p. 442; van Beneden and Gervais, 1880, p. 236; True, 1904, p. 48) the jaw was apparently never reexamined and the connection between it and the Pacific gray whale was never made.

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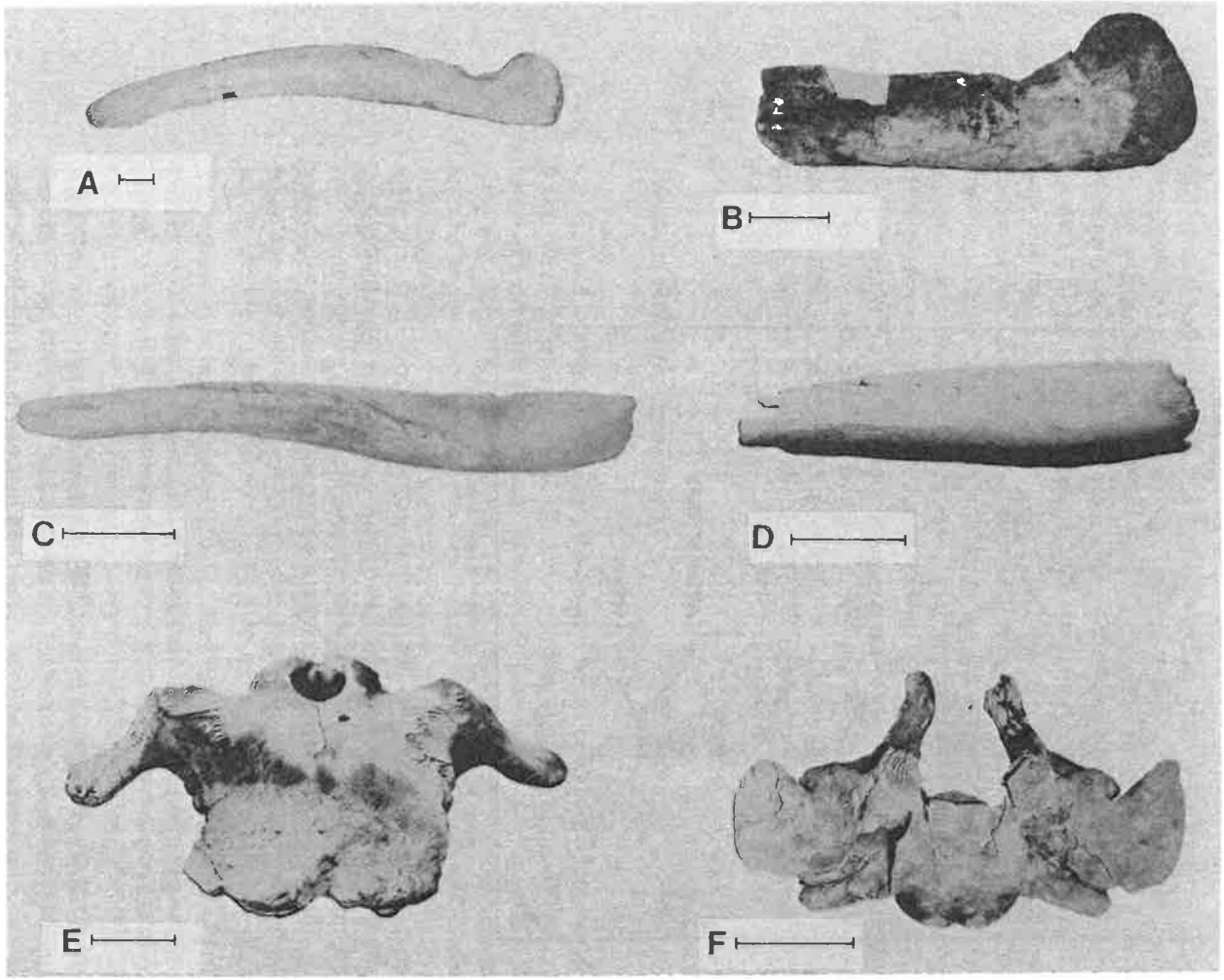

Fig. 4. *Photographs of North American specimens of the Atlantic gray whale. Scale bars = 20 cm. (A)–(D) are lateral views of left mandibles. (A) USNM 187448, Toms River, New Jersey; (B) USNM 23260, Myrtle Beach, South Carolina; (C) USNM 244465, Nags Head, North Carolina; (D) USNM 244307, Southampton, New York; (E) posterodorsal view of partial skull of USNM 299838, Corolla, North Carolina; (F) ventral view of partial skull of USNM 187449, Chesapeake Bay, Virginia.*

The specimen is a left mandible (Fig. 4A), 272 cm long and in excellent condition. Comparing its length with the mandible of the Korean specimen described by Andrews (1914, p. 264), a 1250-cm male with a mandibular length of 243 cm, the total length of the Rutgers specimen is estimated as 1400 cm. This specimen has been transferred to the United States National Museum (USNM 187448)[1] (Table I).

The second specimen of a gray whale from the western north Atlantic was found September 7, 1959 by amateur divers at Myrtle Beach, South Carolina. This specimen, apparently including most of a skeleton, was discovered about 50 ft (15 m) offshore in about 5 ft (1.5 m) of water. The divers recovered the posterior portion of the mandible (Fig. 4B) and brought it to the Smithsonian Institution where Charles Handley identified it as from a gray whale. As encouraged by Handley, the divers returned to attempt to recover more of the specimen but discovered that a storm had disrupted the locality; they were unable to locate any further remains. This specimen (USNM 23260) is from a large adult, comparable in size to the Rutgers specimen.

In 1969 Captain Floyd Durette recovered a partial skull of a juvenile gray whale which he sent to the United States National Museum (USNM). Exact locality data are unavailable, but it is presumably from near the mouth of Chesapeake Bay, Virginia, as this was the general area of Captain Durette's work at the time. The specimen (USNM 187449; Fig. 4F) consists of the posterolateral portion of a cranium with most of the dorsal and ventral elements missing (i.e., it consists of squamosals, exoccipitals, parietals, and the basioccipital). This is the oldest specimen of the Atlantic gray whale that we have radiocarbon dated. The age of the specimen is 10,140 ± 125 years BP.

A fragment of a right squamosal of a young gray whale was found on the beach at Corolla, North Carolina on 26 March 1976 by Avean Meekins. He took it to the North Carolina Marine Resource Center in Manteo, North Carolina, where one of us (Mead) examined it. We borrowed the specimen and compared it to juvenile gray whale material in the USNM, ascertaining that it was from an animal about 25 feet long. A cast was made of the specimen (USNM 244308), and a sample was taken for radiocarbon dating. The original was returned to the North Carolina Marine Resource Center in Manteo, North Carolina.

A midportion of a badly weathered left mandible (Fig. 4D) of a juvenile was found by Mae St. Germaine on the beach at Southampton, Long Island, New York, on May 31, 1977. A cast was prepared (USNM 244307), a sample taken for radiocarbon dating, and the original specimen returned to Mrs. St. Germaine. The height at the coronoid process was 18.2 cm (plus approximately 2–3 mm for abrasion).

A complete left mandible (USNM 244465; Fig. 4C) of a juvenile was donated to the USNM by Betty Clark of Nags Head, North Carolina, who said it had been found by a friend in the vicinity of Nags Head in the 1970s. The length of the mandible was 120 ± 5 cm.

A cranium of an adult (Fig. 4E) was found on the beach at Corolla, North Carolina in the fall of 1977 by Virgil Lanning. The width across the zygomatic processes was about

[1]USNM numbers refer to specimens that are in the collection of the Division of Paleobiology, United States National Museum, Washington, D.C.

Fig. 4. *Photographs of North American specimens of the Atlantic gray whale. Scale bars = 10 cm. (A) USNM 244307, Southampton, New York; (B) USNM 23260, Myrtle Beach, South Carolina; (C) USNM 244465, Nags Head, North Carolina; (D) USNM 244307, Southampton, New York; (E) posterodorsal view of partial skull of USNM 299838, Corolla, North Carolina; (F) ventral view of partial skull of USNM 187449, Chesapeake Bay, Virginia.*

141 cm (131 cm measured, plus about 10 cm estimated to have been lost by abrasion). The width across the articular condyles was 31 cm. This specimen was donated to the USNM (299838). We tried to radiocarbon date this specimen but it had been contaminated by current atmospheric radioactive carbon to such an extent that dates were useless.

A fragment of the squamosal of an adult was found on the beach at Rehobeth, Delaware in August of 1978. This was donated to the USNM (256749) by Gloria Waggener.

The cranium of a juvenile was discovered in April 1979 on the beach at Cape Lookout, North Carolina. The width across the zygomatic processes was 80 cm. This specimen is currently housed at the Hampton Mariners Museum in Beaufort, North Carolina.

We have just learned of an additional find of an Atlantic gray whale. It was found on Jupiter Island, Florida (approximate geographic coordinates 27° 3′ north, 80° 6′ west). Dr. Daniel Odell (University of Miami) sent some photographs of the specimen and the data to us in January 1983. The specimen consists of most of the cranium of what looks like an adult which was found on the beach after a storm. This extends the known distribution of the Atlantic population nearly 500 miles to the south. The specimen is currently in the possession of the Hobe Sound National Wildlife Refuge.

The radiocarbon ages for the samples from the western North Atlantic are shown in Table I. The most recent date (1675 AD) is from a period when colonists had settled in America and the next youngest is potentially so (1405–1585 AD). The oldest specimen that we radiocarbon dated was USNM 187449, which gave an estimated age of 10,140 ± 125 years. No sample was run on USNM 256749 because it was felt that the removal of so much bone would essentially destroy the specimen. The importance of these radiocarbon ages is not to define exactly the period of existence of gray whales in the north Atlantic but merely to give an idea of how recently they became extinct.

Taxonomy of the Atlantic Gray Whale

Eschrichtius

Eschrichtius Gray 1864, p. 350. [Subgenus of *Megaptera*. In the following year he elevated it to full generic rank (Gray, 1865)]. Type species *Balaenoptera robusta* Lilljeborg 1861, p. 602.
Agaphelus Cope 1868a, p. 159. Type species *Balaena gibbosa* Erxleben 1777, p. 610.
Rhachianectes Cope 1869a, p. 15. Type species *Agaphelus glaucus* Cope 1868a, p. 160.

Eschrichtius robustus

Balaenoptera robusta Lilljeborg 1861, p. 602. Type specimen the Gräsö whale preserved in the University Museum of Upsalla, Sweden.
Megaptera? robusta Gray 1864, p. 350.
Eschrichtius robustus Gray 1865, p. 42.

Agaphelus glaucus Cope 1868a, p. 160. Lectotype a side of baleen in the museum of the Essex Institute, Salem, Massachusetts (True, 1904, p. 81), which has subsequently been lost.
Rhachianectes glaucus Cope 1869a, p. 15.
Eschrichtius glaucus Maher 1961, p. 257.

One of the taxonomic problems concerning the Atlantic gray whale has been the disposition of the name *Balaena gibbosa* Erxleben (1777, p. 610). This has usually been associated with the scrag whale, which formed the basis for the species name *gibbosus* being applied to the gray whale. Allen (1882, p. 467) stated that Erxleben had included the scrag whale in the *species obscurae* part of his compilation and that *Balaena gibbosa* Erxleben was a *nomen nudum*. However, as True (1904, p. 42) pointed out, this was an error on the part of Allen, and indeed Erxleben included the scrag whale within the synonomy of *Balaena gibbosa*, although it is the last of nine items in the synonomy. Although Erxleben's compilation does not refer specifically to Dudley's work, he does give white baleen plates in his diagnosis of *Balaena gibbosa* which is one of the more striking characters in Dudley's (1725) description of the scrag whale. While there is good reason to believe the Dudley's scrag whale formed part of the basis of *Balaena gibbosa* Erxleben, the humpback whale also formed part of the basis of *B. gibbosa*. The confusion that has centered around the name *B. gibbosa* renders it highly undesirable. Should its validity arise again as a possibility, an appeal should be made to the International Commission on Zoological Nomenclature to suppress it in favor of *Eschrichtius robustus*, which has a type specimen and a long history of unambiguous usage.

We agree with Cederlund (1938, p. 282) that the holotype of *Eschrichtius robustus* is sufficient evidence to demonstrate the conspecificity of the extinct Atlantic and extant Pacific populations of the gray whale. This is contrary to the opinion expressed by Schevill (1952). In that paper he quotes van Deinse and Junge (1937, p. 181) as follows:

> We must emphasize that the bones we have now at hand we cannot give any argument that the Pacific and Atlantic representative of *Eschrichtius* should be specifically different.

Schevill (1952, p. 1) goes on to say that "But by the same token these bones cannot prove that these whales are specifically identical." We agree that proof of specific identity is not conclusive when only the bones of an extinct animal are at hand, but is commonly the usage in paleontology to judge animals specifically identical if differences judged by competent taxonomists to be specifically distinctive cannot be found between the bones of the animals. Geographic separation, in the case of sharks, large fish, marine birds, and whales, cannot in itself form the basis for a judgement of specific identity. Rice and Wolman, who did the last major work on the gray whale (1971), recognized the Pacific population as *Eschrichtius robustus*. Any further questions along this line can only be resolved by a critical comparison of all of the Atlantic gray whale material with a broad suite of specimens of the Pacific gray whale in order to take such variables as age and sex into account.

In the event that the Atlantic and Pacific populations of gray whales are demonstrated to warrant specific or subspecific distinction, the specific name *Eschrichtius*

glaucus (Cope) will be available for the Pacific form. The lectotype of the species, as designated by True (1904, p. 81), is a set of baleen in the museum of the Essex Institute, Salem, Massachusetts. It is probable that a neotype will have to be designated because the lectotype material cannot be found (W. Schevill, personal communication).

Conclusion

There are three accounts in the literature that we interpret to be reliable records of gray whales in the North Atlantic. One of these was an Icelandic record of the sixteenth century (Fraser, 1970), another was the account of Dudley in 1725, the third was a commission from the Muscovy Merchants to Thomas Edge in 1611 which dealt with a whale called the "otta sotta," which fits the description of a gray whale. There are several other reports which, although they do not give enough information to allow positive identification of the whales concerned, appear to describe gray whales.

The species was first known to science on the basis of subfossil specimens from Europe. It is now known in the Atlantic from a total of seven European specimens and nine American specimens. Six of the American specimens were found in the last 10 years, despite the fact that there has been no special effort to find them. Based upon these finds we conclude that the gray whale was, at some time, common in American waters and was sometimes known to whalers as the scrag whale. Radiocarbon dates show the most recent specimen to have existed in colonial times, around 1675 AD.

Summary

Eschrichtius robustus was first known to science on the basis of a subfossil skeleton from Gräsö, Sweden described by Lilljeborg in 1861. In subsequent years six more subfossil specimens were described from the coasts of England and the Netherlands. Van Deinse and Junge (1937) compared these remains to the Pacific gray whale and concluded that they could not be separated on a specific basis.

Dudley (1725), in a short paper enumerating the whales then known off New England, described a whale known as the "scrag" whale. This species was discussed at length by biologists, most of whom came to the conclusion that it represented young or emaciated individuals of the right whale. This was to a large part based upon the supposed lack of evidence of a western Atlantic population of *Eschrichtius*, but in fact Cope (1868a) had published on a jaw of this species that had been found on the New Jersey coast. Since that time there have been eight more discoveries of remains of *Eschrichtius* on the Atlantic coast of North America, upon which we report in this paper. Radiocarbon dates reveal that the youngest specimen died during colonial times (1675 AD).

Fraser (1970) published on a sixteenth century Icelandic account which he interpreted as evidence of the persistence of a gray whale (sandloegja) population in the North Atlantic at that time. Lubbock (1937) published a seventeenth century account of a

whale called the "otta sotta," whose description fits the gray whale. Several other more anecdotal accounts also fit the gray whale.

The conclusion is that a population of *Eschrichtius robustus* existed on both sides of the Atlantic and was present on the coasts of North America up to the seventeenth century AD.

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This investigation was prompted by Clarence George's inquiry in 1971 about Atlantic gray whales. Since that time it has involved help from the following people: Doug Oliver, a student at Rutger's, who took photographs of the whale remains in the attic of their museum in response to our telephone requests; Dr. R. C. Murray of that same institution, who suggested that the remains be transferred to the United States National Museum; Dr. Robert Brownell, who kindly transported it to Washington; Dr. Charles Handley, who recognized the second specimen as a gray whale, asked the collectors, Mr. Maklion and Mr. Aleksandrov to try to obtain more of the specimen, and kindly made the specimen available to us; Dr. Lawrence Barnes, who brought an unidentified specimen in the United States National Museum to our attention; Charles Potter, who deserves special thanks for recognizing two of the specimens as being gray whales. We thank Floyd Durette, Betty Clark, Avean Meekins, Steve Daniels, Mae St. Germaine, Virgil Lanning, Gloria Waggener, and Karen Davis, who were involved in the collecting of specimens.

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ZOOLOGY

Occurrence and Distribution of Mitochondrial Lineages of Gray Whales (*Eschrichtius robustus*) in Russian Far Eastern Seas

I. G. Meschersky[a], M. A. Kuleshova[b], D. I. Litovka[c], V. N. Burkanov[d, e], R. D. Andrews[f, g], G. A. Tsidulko[a], V. V. Rozhnov[a], and V. Yu. Ilyashenko[a]

[a]*Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Leninskii pr. 33, Moscow, 119071 Russia*
[b]*Moscow State Pedagogical University, Department of Zoology and Ecology, ul. Kibal'chicha 6, Moscow, 129164 Russia*
[c]*Pacific Reseach Fisheries Center, Chukotka Branch, ul. Otke 56, Anadyr, 689000 Russia*
[d]*Pacific Geographical Institute, Kamchatka Branch, Far East Branch, Russian Academy of Sciences, ul. Partizanskaya 6, Petropavlovsk-Kamchatsky, 683000 Russia*
[e]*National Marine Mammal Laboratory, AFSC, NMFS, NOAA, Seattle, USA 7600 Sand Point Way, NE, Building 4, Seattle, WA, 98115, USA*
[f]*University of Alaska, Fairbanks, 905 N. Koyukuk Drive, 245 O'Neill Building, Fairbanks, Alaska, 99775-7220, USA*
[g]*Alaska SeaLife Center, P.O. Box 1329, Seward, AK 99664, USA*
e-mail: molecoldna@gmail.com

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Abstract—This article presents data on frequencies of mitotypes (control region and cytochrome b and ND2 genes) in groups of Gray Whales found off the Chukotka Peninsula, Koryak coast, eastern Kamchatka and Sakhalin Island. From north to south the number of mitotypes decreased dramatically, but mitotypes which were predominant in the south were the same as ones also abundant in northern samples. For the control region sequences only, our data and data presented in the literature suggest that breeding areas in Baja California may include diversity of both distant groups of mitochondrial lineages known for the species. On the other hand, the same control region sequences may be found in different mitochondrial genomes, and so conclusions based on this mtDNA fragment only may be incorrect.

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INTRODUCTION

The gray whale (*Eschrichtius robustus*, Lillijeborg, 1861) is a representative of the Eschrichtiidae family of the suborder of baleen whales (Mysticeti). This species feeds on benthic animals, so during the feeding period, the whales keep close to shallow coastal areas. Also, gray whales perform the most distant migrations within the marine mammals from the feeding area to the reproduction area. Recently, the gray whale has inhabited the northern Pacific Ocean, where two stocks appeared after the last glacial period (Swartz et al., 2006) because of the separation of the feeding grounds. They are the eastern (or California-Chukchi) group, and the western (or Korean-Okhotsk) group. The population of the eastern group was primarily about 15000–20000 whales, according to the estimated data accepted by the International Whaling Committee (IWC). It had decreased as low as 2800 by 1900 because of whaling, but was restored after the total prohibition of commercial harvesting, and was about 27000 whales in the 1980s.

The pre-harvest population of the western group, mostly reproducing along the Chinese and Korean coasts, and the southern coast of Honshu Island, and feeding in the Sea of Okhotsk, was about several thousands of individuals. The last western gray whale harvested was in the coastal zone of Korea in 1966. Since then, this group was considered to be extinct. However, single whales, pairs, and groups of three individuals were observed from time to time along the Japanese coast and in the Sea of Okhotsk up to the 1980s; later, larger groups of 4–34 whales were recorded (Maminov and Blokhin, 2004; Nambu et al., 2010). In the early 2000s this group was included in the Red List of the International Union for Conservation of Nature (IUCN) as a subpopulation in the critically endangered category (Reilly et al., 2013). Currently, the population of this group is estimated as 150–180 individuals.

The idea of the reproductive isolation of both the western and eastern groups has been criticized repeatedly (Nishiwaki and Kasuya, 1970; Omura, 1974). The registering of gray whales in the Laptev Sea (Shpak et al., 2013), along Franz Josef Land, in the Mediterranean Sea, and along the Namibian coast has allowed hypothesizing the beginning of the restoration of the historical geographical range of this species, particularly, by reinhabiting of the areas that belonged to the range of

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the extinct western group by representatives of the California-Chukchi population (Ilyashenko, 2012).

Analysis of the genetic diversity of the gray whales of the eastern group observed both at their wintering grounds along the Baja California coast and northwards has been performed by several research groups (Steeves et al., 2001; Goerlitz et al., 2003; Alter and Palumbi, 2009; Alter et al., 2009, 2012). Meantime, data on the gray whales migrating along the Russian coasts are scarce (LeDuc et al., 2002), although there was a large amount of research performed in recent years, the results remain unpublished.

The aim of the present study was to analyze the data on the mitochondrial lineages of the gray whales inhabiting the Far Eastern seas of Russia.

MATERIALS AND METHODS

The tissues of gray whales harvested in the course of subsistence whaling by Chukotka indigenous hunters (Lorino, Sireniki, Novo-Chaplino, Yanrakynnot, and Lavrentia settlements, here and further, Chukotka) in 2001 (14 specimens), 2003 (13), 2004 (18), 2005 (17), 2007 (10), 2008 (6), and 2010 (34 specimens) were analyzed.

Also, the skin tissues sampled by the remote biopsy method in accordance with permission of the Russian Federal Supervisory Natural Resources Management Service (Rosprirodnadzor) in the following areas:

—along the Koryak Coast from Olyutorsky Cape to Khatyrka River estuary (Igla Cape, Dezhnev Bay, Khatyrka River estuary (here and further, Koryak Coast)) in June–August 2010 (21 samples);

—along the eastern coast of Kamchatka (Kamenistaya Bay, Olga Bay, Asacha Bay, and Avachinsky Gulf (here and further, Kamchatka)) in summer of 2004 (3 samples), 2010 (20 samples), and 2011 (one sample);

—along the coast of Sakhalin Island, Pil'tun Bay (here and further, Sakhalin) in summer of 2010 (9 samples) and 2011 (13 samples).

The tissues were stored in ethanol or in 20% solution of dimethyl sulfoxide (DMSO) in saturated solution of NaCl. The total DNA was extracted using the InviMag Tissue DNA Mini Kit/KF96 (STRATEC Molecular, Germany) on a KingFisher Flex/96 magnetic particle processor (Thermo Fisher Scientific, Finland).

Several loci of the mitochondrial DNA (mtDNA) were amplified for the following sequencing:

—the control region, using the primers MT4 (5'-cctccctaagactaaaggaag-3') and H00034 (5'-taccaaatgtatgaaacctcag-3') according to (LeDuc et al., 2002) at the primer annealing temperature of 54°C;

—the cytochrome b gene, using the primers cet_cbF (5'-aatgacatgaaaaatcatcgtt-3') and cet_cbR (5'-ctccttttccggtttacaa-3') at an annealing temperature of 52°C;

—the subunit 2 of the NADH dehydrogenase gene (ND2), using the primers cet_nd2_F (5'-catacccgaaaatgttggt-3') and cet_nd2_R (5'-tagggctttgaaggctcttg-3') at an annealing temperature of 52°C.

The same primers were used for the sequencing reaction, and internal primers cet_cb_intF (5'-gaaacattggggtaatcctactat-3') and cet_cb_intR (5'-gtttgctggggtgtagttatc-3') were additionally applied for the sequencing of cytochrome b gene.

The design of the original primers was performed using the software Primer3 (Rozen, Skaletsky, 2000). All PCR (polymerase chain reaction) were performed using standard mixtures MagMIX 2025 (Dialat Ltd., Russia), and the primers were synthesized by JSC Syntol (Russia). The sequencing reactions were performed using BigDye Terminator v. 3.1 kit (Applied Biosystems, United States), and the sequencing was done on Genetic Analyzer 3130 and Genetic Analyzer 3500 (Applied Biosystems, United States). Quality control of the automatic decoding of chromatograms, the merging of forward and reverse individual sequences, and their alignment and storage was done using BioEdit software (Hall, 1999).

The sex of the specimens was determined by simultaneous amplification of the X and Y chromosome fragments (Jayasankar et al., 2008) using the primers labeled with a fluorescent dye. The PCR results were visualized on the sequenator in the presence of the size standard to compare the lengths of the obtained fragments to those expected.

To avoid analyzing duplicate samples from the same whale, samples that were obtained by the remote biopsy method within one season in one locality and that shared the same sex and haplotype of the mtDNA control region were subjected to genotyping of five microsatellite loci (DlrFCB5, DlrFCB17, Ev94Mn, 417/418, and 464/465) using the method described earlier (Meschersky et al., 2013). When all five genotypes were the same, the sample was treated as originating from the same specimen. The possibility that duplicate samples of one whale were collected in different localities was not checked following the principle that each local sample represents the lineages that may be found in the area, disregarding the individual affiliation of the specimens.

The data were processed using the software Arlequin v. 3.1 (Excoffier et al., 2005), Network 4.6.0.0 (Bandelt et al., 1999), and MEGA v. 5.2.2 (Tamura et al., 2011).

RESULTS

Ten haplotypes of cytochrome b gene (1137 base pairs (bp), that is a complete gene sequence, excluding the stop-codon), nine haplotypes of ND2 gene (1044 bp, complete gene sequence) and 37 haplotypes of control region (the fragment including 65 bp of tRNA-Pro gene and 555–556 bp of the control region itself) were found for mtDNA of the studied specimens. The

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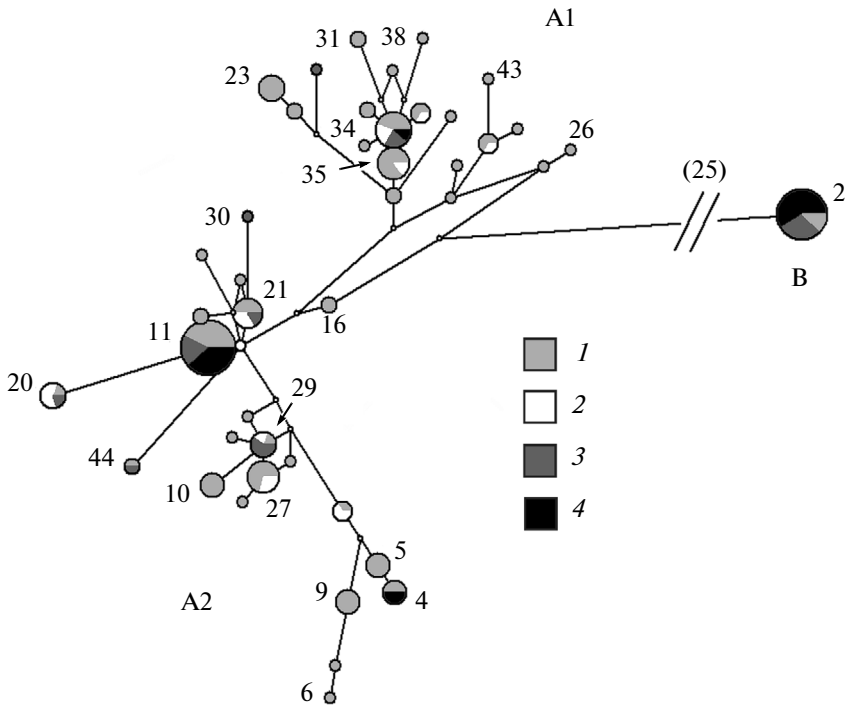

Fig. 1. Median joining network of mitotypes of the gray whales (2802 bp). The circle diameter refers to the frequency of the mitotype in the total sample population, the sector sizes—to the regional samples. Different color tones indicate the haplotypes registered at Chukotka (*1*), Koryak Coast (*2*), Kamchatka (*3*), and Sakhalin (*4*). The number in the brackets indicates the number of the mutated positions differs between mitotypes 2 and 16; in the other cases, the minimal distance between the circles refers to one mutated position. A1, A2, and B are the mitotype groups.

sequences were deposited in GenBank under the accession numbers KJ865243–KJ865298. These sequences were combined in 44 mitotypes within the individual mitochondrial genomes (Table 1).

The overall characteristic of the specimens studied in different regions and included in the analyses is presented in Table 2. The sequences of all three studied loci of mtDNA were obtained for all the whales from the Koryak Coast, Kamchatka, and Sakhalin, but several samples collected in these areas were excluded as belonging to the same individuals. Although there were 112 samples from Chukotka, only 85 specimens provided sequences for all three mtDNA loci, so only these samples were used in further analyses. For the 27 Chukotka whales that were excluded, the sequences of only one or two loci were obtained. For these whales 18 sequences of the cytochrome b gene and 12 sequences of ND2 gene (all were haplotypes found already), and 17 sequences of the control region, including the haplotypes W2x (KJ865271, two specimens) and NW8 (KJ865289, one specimen) were determined.

The median joining network of the defined mitotypes (Fig. 1, the mitotype numbers are given selectively) suggests two distinct groups; the group B is presented by only one mitotype referred to as 2, which differs from the closest mitotype 16 by the 25 altered positions (24 nucleotide substitutions and one indel). The other group (A) may be divided into two subgroups, A1 (mitotypes 4–11, 17, 19–21, 24–25, 27–30, 32, 39, 40, 44) and A2 (mitotypes 1, 3, 12–15, 18, 22–23, 26, 31, 33–38, and 41–43), while the position of mitotype 16 remains uncertain. However, the unity of both groups, A1 and A2, is low, i.e., the value of bootstrapping is less than 50 when applying the Neighbor Joining, Maximum Parsimony, and Maximum Likelihood methods (the results are not presented). The weighted average distances between the mitotype groups B and A1/A2 are 28.8 ± 5.3 and 27.6 ± 5.0 nucleotide substitutions, respectively, and between A1 and A2, there are 6.1 ± 2.3 substitutions. Along with that, the average intergroup distances for A1 and A2 are 6.6 ± 1.5 and 6.1 ± 1.3 substitutions, respectively. The mitotypes of all the mitotype groups are present, in one or another frequency of each one, in both northern (Chukotka and Koryak Coast) and southern (Kamchatka and Sakhalin) areas.

The comparison of haplotype frequencies (Fst) was applied for comparative analysis of the samples. The average pairwise difference (Φst) between the mitotypes was not applied, because the sampling sites were not the areas of the genetic diversity origin, i.e., ranges of long-term isolated populations.

Both sexes were found nearly equally in all the sample groups, when males comprised 47.6–57.9% of the studied specimens. There were no significant differences in haplotype frequency between the male/female sam-

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Table 1. Mitotype composition of the studied gray whales

Mitotype	Haplotype of cytochrome b gene	Haplotype of ND2 gene	Haplotype of control region
1	CB-01 (KJ865243)	ND2-06 (KJ865295)	Cx (KJ865255)
2	CB-02 (KJ865244)	ND2-02 (KJ865291)	Bx (KJ865254)
3	CB-03 (KJ865245)	ND2-01 (KJ865290)	Dx (KJ865256)
4	CB-03	ND2-01	NW4 (KJ865285)
5	CB-03	ND2-01	Wx (KJ865260)
6	CB-04 (KJ865246)	ND2-01	AAx (KJ865275)
7	CB-04	ND2-01	AEx (KJ865279
8	CB-04	ND2-01	Mx (KJ865263)
9	CB-04	ND2-01	Nx (KJ865264)
10	CB-05 (KJ865247)	ND2-03 (KJ865292)	Lx (KJ865262)
11	CB-05	ND2-06	Ax (KJ865253)
12	CB-05	ND2-06	ABx (KJ865276)
13	CB-05	ND2-06	AGx (KJ865280)
14	CB-05	ND2-06	APx (KJ865283)
15	CB-05	ND2-06	Dx
16	CB-05	ND2-06	Ex (KJ865257)
17	CB-05	ND2-06	Gx (KJ865258)
18	CB-05	ND2-06	NW7 (KJ865288)
19	CB-05	ND2-06	Qx (KJ865265)
20	CB-05	ND2-06	Tx (KJ865267)
21	CB-05	ND2-06	Yx (KJ865273)
22	CB-05	ND2-07 (KJ865296)	Hx (KJ865259)
23	CB-05	ND2-07	Rx (KJ865266)
24	CB-05	ND2-08 (KJ865297)	ADx (KJ865278)
25	CB-05	ND2-08	AOx (KJ865282)
26	CB-05	ND2-08	APx
27	CB-05	ND2-08	Gx
28	CB-05	ND2-08	NW5 (KJ865286)
29	CB-05	ND2-08	Ux (KJ865268)
30	CB-05	ND2-09 (KJ865298)	AIx (KJ865281)
31	CB-07 (KJ865248)	ND2-05 (KJ865294)	Zx (KJ865274)
32	CB-07	ND2-06	Ax
33	CB-07	ND2-06	AGx
34	CB-07	ND2-06	Cx
35	CB-07	ND2-06	Dx
36	CB-07	ND2-06	Kx (KJ865261)
37	CB-07	ND2-06	NW3 (KJ865284)
38	CB-07	ND2-06	NW6 (KJ865287)
39	CB-07	ND2-06	Vx (KJ865269)
40	CB-07	ND2-06	Yx
41	CB-08 (KJ865249)	ND2-06	Cx
42	CB-09 (KJ865250)	ND2-07	Xx (KJ865272)
43	CB-10 (KJ865251)	ND2-06	ACx (KJ865277)
44	CB-11 (KJ865252)	ND2-04 (KJ865293)	Jx (KJ865260)

The numbers in the brackets refer to the accession numbers of the sequences in GenBank.

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Table 2. Number of the sampled specimen (numbers in brackets) and the frequency of the mitotypes in the analyzed samples

Mitotype	Chukotka		Koryak Coast		Kamchatka		Sakhalin	
	males (47)	females (38)	males (9)	females (8)	males (11)	females (8)	males (10)	females (11)
1	2	–	–	1	–	–	–	–
2	1	1	–	–	4	1	3	7
3	–	1	–	–	–	–	–	–
4	1	1	–	–	–	–	1	1
5	2	1	1	–	–	–	–	–
6	–	1	–	–	–	–	–	–
7	–	1	–	–	–	–	–	–
8	–	1	1	1	–	–	–	–
9	3	1	–	–	–	–	–	–
10	3	1	–	–	–	–	–	–
11	3	6	–	–	2	2	5	3
12	1	–	–	–	–	–	–	–
13	1	1	1	–	–	–	–	–
14	–	1	–	–	–	–	–	–
15	1	1	–	–	–	–	–	–
16	–	2	–	–	–	–	–	–
17	1	–	–	–	–	–	–	–
18	1	–	–	–	–	–	–	–
19	–	–	–	1	–	–	–	–
20	–	1	1	2	–	–	–	–
21	1	2	–	2	–	1	–	–
22	2	–	–	–	1	–	–	–
23	3	2	–	–	–	–	–	–
24	–	1	–	–	–	–	–	–
25	1	–	–	–	–	–	–	–
26	–	1	–	–	–	–	–	–
27	2	3	2	–	2	–	–	–
28	1	–	–	–	–	–	–	–
29	–	1	1	–	1	2	–	–
30	–	–	–	–	1	–	–	–
31	–	2	–	–	–	–	–	–
32	2	–	–	–	–	–	–	–
33	1	–	–	–	–	–	–	–
34	3	1	1	1	1	1	1	–
35	6	–	1	–	–	–	–	–
36	1	–	–	–	–	–	–	–
37	1	–	–	–	–	–	–	–
38	–	1	–	–	–	–	–	–
39	1	–	–	–	–	–	–	–
40	1	–	–	–	–	–	–	–
41	–	2	–	–	–	–	–	–
42	–	–	–	–	1	–	–	–
43	1	–	–	–	–	–	–	–
44	–	1	–	–	–	1	–	–

"–", mitotype was not registered.

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ples in all regions (P(Fst) = 0.52–0.15). This allowed us to combine the data disregarding the whale gender in the total sample for each studied area.

We also combined the data for the samples obtained in Chukotka for different years. In most of the cases, there were no significant differences between these samples (P(Fst) = 0.06–0.89), although some mitotypes were registered here only in a single year. The only exception was the year 2007 (8 specimens), which differed significantly from 2001 (6 specimens, P(Fst) = 0.04) and from 2004 (16 specimens, P(Fst) = 0.009). The interannual and seasonal differences in genetic lineage occurrence in different areas are of great interest; however, our data do not allow us to apply such analysis due to the small amount of data.

The genetic diversity of the studied samples supports the highest diversity of mitotypes for the whales of Chukotka and Koryak Coast (Table 3). For the Koryak Coast, the absolute number of mitotypes was significantly lower, but their relative rate was even higher taking into account the difference in the sample size, and the decrease in the index of haplotype diversity in comparison to the Chukotka population was insignificant. The Kamchatka and Sakhalin populations showed the middle and the lowest diversity, respectively, of mitotypes. The high rate of nucleotide diversity in these areas reflected a high frequency of mitotype 2, which is significantly distinct from the other known sequences.

The pairwise comparison of the mitotype frequencies showed the significant differences between all the pairs of the areas except Chukotka/Koryak Coast (Table 4).

Table 3. Diversity indexes of the mitochondrial lineages of the studied regional samples of the gray whale

Sampling area	n	h	n/h	H	π, %
Chukotka	85	41	2.07	0.971	0.345
Koryak Coast	17	11	1.55	0.945	0.288
Kamchatka	19	9	2.11	0.895	0.600
Sakhalin	21	4	5.25	0.648	0.604

n—number of specimens; h—number of mitotypes; n/h—number of specimens with same mitotype; H—index of haplotype diversity; π—index of nucleotide diversity.

Table 4. Fst values (above the diagonal) and significance level (P(Fst), under the diagonal) obtained when comparing the regional samples.

	Chukotka	Koryak Coast	Kamchatka	Sakhalin
Chukotka		0.01040	0.03940*	0.12436*
Koryak Coast	0.10645		0.04918*	0.20222*
Kamchatka	0.0000*	0.01465*		0.16505*
Sakhalin	0.0000*	0.0000*	0.0000*	

The asterisk (*) indicates significant differences.

DISCUSSION

A decrease in the absolute number and diversity of the mitotypes of gray whales was observed when moving from the northern areas (Chukotka and Koryak Coast) southwards (eastern Kamchatka coast) and then westwards (Sakhalin) (Fig. 2). Along with that, the composition of the mitochondrial lineages presented in the different areas remained similar. Once one of the lineages was not present, the other ones, which were also present in the previous sample, but with low frequency, began to dominate. Only two exceptions were found, mitotypes 30 and 42; they were present in the sample obtained along the eastern coast of Kamchatka, but were totally absent in the samples from Chukotka and/or Koryak Coast. Each of these two mitotypes was found only once, and we cannot exclude the possibility that if another sampling will be performed in the northern areas, these mitotypes may be found. It is also known that the control region haplotypes A1 and X present in these mitotypes were found for the gray whales of California-Chukchi population (LeDuc et al., 2002).

No significant differences were found when comparing the composition and frequency of the mitotypes of whales observed in Chukotka and the Koryak Coast. A decrease in the absolute number of the mitotypes noted for the whales of the Koryak Coast was not found for such parameters as "the number of specimens with the same mitotypes" and "the index of haplotype diversity," and it is linked, probably, with the small sample size. Regard must be paid to the absence of statistical differences between the California-Chukchi population analyzed previously (LeDuc et al., 2002), when 120 specimens were included in the analysis (523 bp fragment, GenBank AF326789–AF326824), and our Chukotka (Fst = –0.001, P(Fst) = 0.619) and Koryak Coast (Fst = –0.002, P(Fst) = 0.359) samples when comparing the frequency of the haplotypes of the control region.

The gray whales feeding along the eastern coast of Kamchatka and Sakhalin differed significantly not only from the groups inhabiting Chukotka and the Koryak Coast, but also between each other. This was caused by the significant decrease of the number of mitochondrial lineages and their diversity parameters. Such a pattern and ambiguity of its interpretation have been noted since the beginning of the genetic studies of the Sakhalin population of gray whales (LeDuc et al., 2002).

The uncertainty is that both explanations, the presence of whales of the original, previously presumed extinct, Korean-Okhotsk population and the arrival of California-Chukchi whales that chose this area as a new feeding ground, may be true. In the first case, we are faced with the bottleneck effect, when the initial

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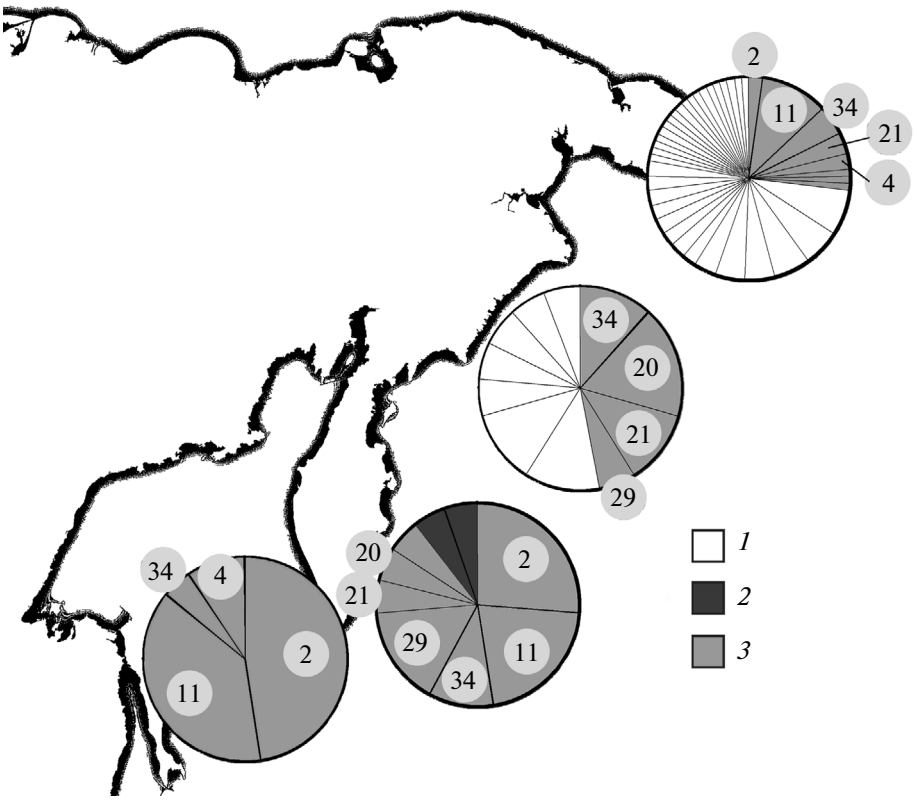

Fig. 2. Ratio of the mitotype frequencies in the regional samples of the gray whales. (*1*) Mitotypes found exclusively on Chukotka or Koryak Coast; (*2*) only at Kamchatka; (*3*) both at Chukotka/Koryak Coast and at Kamchatka/Sakhalin. The numbers on the diagrams indicate the dominant mitotypes.

diversity was eliminated, and the current diversity is based on the single mitotypes of a small number of surviving whales. In the second case the same result may be explained by the initially low number of the newcomers. If the latter hypothesis is true, and the migration route will become a pathway for young individuals that come here with their mothers, the number of migrating whales will increase, but number of mitotypes will remain limited, and there will be no reason to suspect phylogenetic affinity between these mitotypes.

When analyzing the mitochondrial lineages as markers of distinct populations, regard must be paid to mitotype 2, which is the most distinct from all the other mitotypes known by now. This mitotype is registered frequently for the whales inhabiting the historical range of the Korean-Okhotsk population. However, analyzing the published data on the sequence of the control region of mtDNA in the gray whales studied in the reproduction area along the Baja California coast, we cannot make conclusions on the population or regional specificity of the haplotypes reported. For example, the haplotype of control region Hap1, the sequence of which coincides by 100% with the sequence of the homological fragment of haplotype B/Bx in our mitotype 2 (Fig. 3a), was found in the Californian population of the gray whales (118 specimens, GenBank EU807842–EU807866, 441 bp, (Alter et al., 2009). Haplotype Hap1 was one of the dominating haplotypes (7.6% by frequency) within those samples, but no related variants were found (Alter et al., 2009). In another sample of the same area (83 specimens, GenBank AY514457–AY514484, 305 bp), there was no sequence that referred directly to the haplotype B/Bx (Goerlitz et al., 2003). However, five other haplotypes that differed from B/Bx by 2–3 nucleotide substitutions and that formed the well supported (bootstrapping value of 99, Neighbor Joining method) clade with it (Fig. 3b) were found. The summarized rate of these five haplotypes in the sample was 12% (Goerlitz et al., 2003); i.e., it was also quite high.

Therefore, we assume that in the California-Chukchi population the mitochondrial lineages relative to mitotype 2 may be present in both a significant amount and of perceptible diversity. The last assumption is quite important, because this mitotype is present in whales inhabiting Chukotka, Kamchatka, and Sakhalin by a unique sequence that has no similar variants. Meantime, taking into account the significant genetic distance and, therefore, the evolutionary time of the mitotype existence, such variants evidently should exist in the modern gene pool of the studied species.

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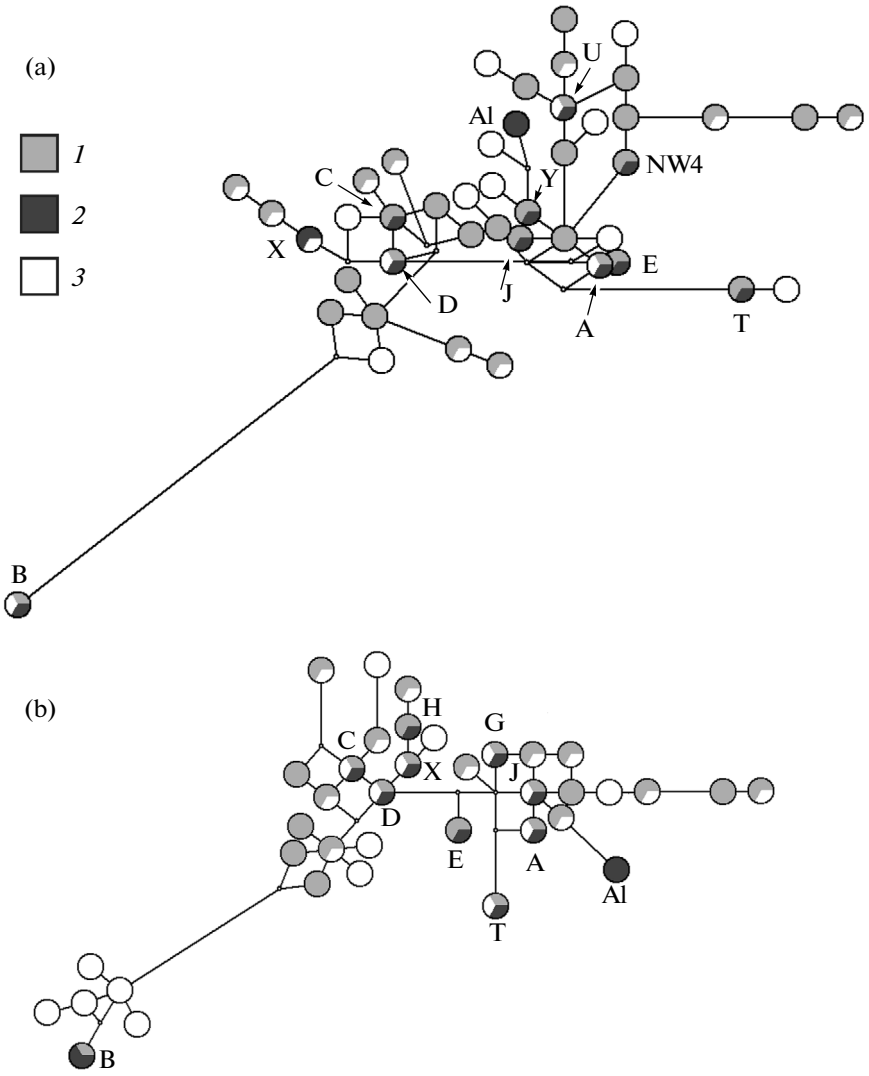

Fig. 3. Median joining networks of the mtDNA control region haplotypes known for gray whales in coastal waters of Chukotka and the Koryak Coast (*1*) and Sakhalin and Kamchatka (*2*) according to LeDuc et al., 2002 and the present study; and in the reproductive area of the gray whales in Baja California (*3*) accordingly to Alter et al., 2009 (a) and to Goerlitz et al., 2003 (b).

The hypothesis of the presence of such mitotypes in the California-Chukchi population of gray whales cannot be currently tested because of the absence of data on the longer sequences of the mtDNA of this population. Based on our data, an important conclusion may be made: the restriction of a genetic analysis to the sequences of the mtDNA control region only (as was done up until the present time) is insufficient to clarify the pattern of regional distribution of gray whale mitochondrial lineages. The same haplotypes of the mtDNA control region found in the historical range of the Korean-Okhotsk population and in Chukotka and the Koryak Coast, such as the haplotypes A, C, and D may be associated with different cytochrome b haplotypes in the different mitochondrial genomes (Table 1).

Unfortunately, the sequences of the ND2 gene of the gray whale are absent in GenBank, and the cytochrome b gene is represented by only 10 sequences, despite the fact that this locus is used traditionally to study the population structure of mammals. These sequences of cytochrome b reflect six haplotypes, five of which coincide with our data, except for one unusual substitution, which is common for sequences of EF165336–EF165341 and may appear as a result of a system error during sequencing in one of two labs. One of these five haplotypes, haplotype 2 (EF165337), matches the haplotype CB-02 presented in mitotype 2 (Table 1). This haplotype was found primarily in a sample of California-Chukchi whales, analyzed earlier (LeDuc et al., 2002) but unfortunately the authors of the later study (Alter and Palumbi, 2009) did not provide data on either the frequency of the haplotype

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in the sample or of its coexistence with the haplotype of the control region in individual mitochondrial genomes.

The existence of two distinct mitotype groups in the Pacific populations of gray whales is an interesting fact that appears to be worth of further study. However, it is obvious that the initial divergence of these mitotype groups reflects much more distant times than development of the recent gray whale population structure in the Pacific Ocean, which is linked to the second part of the Holocene (Swartz et al., 2006). Probably, here we are faced with the result of bidirectional migrations of the gray whales of the Atlantic and Pacific populations during the interglacial periods. But recently the distance between haplotypes does not correlate with the different parts of this species' modern (pre-whaling) range. The data on the occurrence and frequency of the mitochondrial lineages of the gray whales inhabiting the Pacific Ocean may be used to compare their local diversity, but not to describe the current population structure of this species.

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Translated by D. Martynova

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NOAA Technical Memorandum NMFS

AUGUST 2018

UPDATED ESTIMATES OF THE PROBABILITY OF STRIKING A WESTERN NORTH PACIFIC GRAY WHALE DURING THE PROPOSED MAKAH HUNT

Jeffrey E. Moore and David W. Weller

Marine Mammal and Turtle Division, Southwest Fisheries Science Center
National Marine Fisheries Service, National Oceanic and Atmospheric Administration
8901 La Jolla Shores Drive, La Jolla, CA 92037 USA

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EXECUTIVE SUMMARY

Observations of gray whales (*Eschrichtius robustus*) from the western North Pacific (WNP) migrating to areas off the coast of North America (Alaska to Mexico) raised concerns that this small population could be encountered during a hunt of eastern North Pacific (ENP) gray whales proposed by the Makah Indian Tribe in northern Washington, USA. In 2013, an analysis was conducted to estimate the probability of striking (i.e. killing or seriously injuring) a WNP whale under the Makah Tribe's hunt proposal (Moore and Weller 2013). NOAA Fisheries is considering a draft proposal that would govern ENP gray whale hunts by the Makah for up to 10 years. Under the draft proposal, hunting seasons would alternate between winter-spring hunts in even-numbered years and summer hunts during odd-numbered years. It is presumed that only in even-numbered years (thus, for 5 of the 10 years) would WNP whales potentially be encountered during the hunt. In each of these years, the draft proposal would allow for up to 3 gray whales to be struck. Based on this alternative hunting scheme and the availability of updated gray whale data, this report re-estimates the probability of striking a WNP whale reported earlier (Moore and Weller 2013). One of the models from the 2013 analysis (Model 2A) was used to generate new estimates. We estimate that for an individual strike on a gray whale, the expected probability of it being a WNP whale is 0.004 (95% CRI: 0.002 – 0.007). For a single year's hunt (3 strikes), the expected probability of striking ≥1 WNP whale would be 0.012 (0.006 – 0.019). Across the 10-year hunt period (15 strikes), the probability of striking ≥1 WNP whale would be 0.058 (0.030 – 0.093).

INTRODUCTION

Two gray whale (*Eschrichtius robustus*) populations are recognized in the North Pacific Ocean. Significant mitochondrial and nuclear genetic differences have been found between whales in the western North Pacific (WNP) and those in the eastern North Pacific (ENP) (LeDuc *et al*., 2002, Lang *et al*. 2010, Lang *et al*., 2011). The ENP population ranges from wintering areas in Baja California, Mexico, to feeding areas in the Bering, Beaufort, and Chukchi Seas (Fig. 1). An exception to this generality is the relatively small number (100s) of whales that summer and feed along the Pacific coast between Kodiak Island, Alaska, and northern California (Weller *et al*., 2013). These whales are collectively called the Pacific Coast Feeding Group (PCFG). The International Whaling Commission (IWC) has defined PCFG whales as individuals observed between 1 June and 30 November from 41°N to 52°N in two or more years (IWC, 2012), and NOAA Fisheries has adopted this definition in recent assessments (Weller *et al.*, 2013). The usual and accustomed (U&A) fishing grounds of the Makah Indian Tribe are off the coast of northern Washington, USA, and overlap with a portion of the PCFG summering area (Fig. 1).

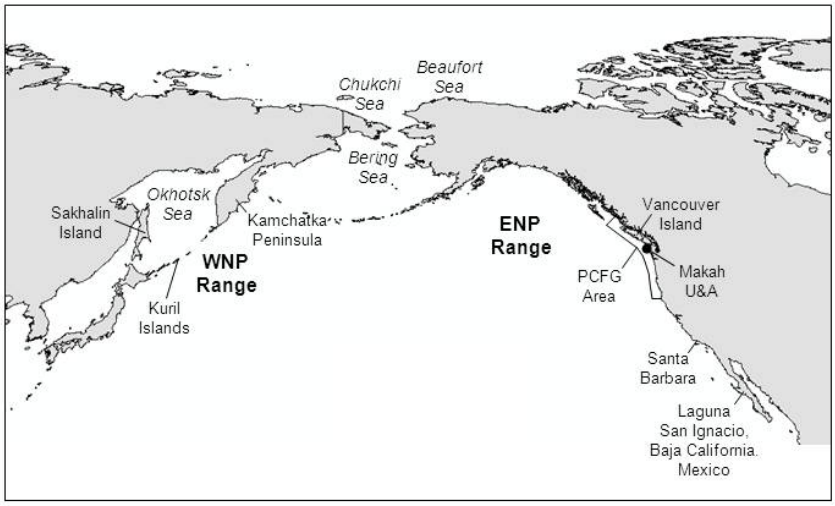

Figure 1. Areas in the western and eastern North Pacific mentioned in the report.

The WNP population feeds in the Okhotsk Sea off Sakhalin Island, Russia (Weller *et al*., 1999; Weller *et al*. 2012), and in nearshore waters of the southwestern Bering Sea off the southeastern Kamchatka Peninsula (Tyurneva *et al*., 2010). The historical distribution of gray whales in the Okhotsk Sea greatly exceeded what is found today (Reeves *et al*., 2008). Whales associated with the Sakhalin feeding area can be absent for all or part of a given feeding season (Bradford *et al*., 2008), indicating they use other areas during the summer and fall feeding period. Some of the whales identified feeding in the coastal waters off Sakhalin, including reproductive females and calves, have been documented off the southern and eastern coast of Kamchatka (Tyurneva *et al*., 2010). A small number of whales observed off Sakhalin have also been sighted off the northern Kuril Islands in the eastern Okhotsk Sea and Bering Island in the western Bering Sea (Weller *et al*., 2003).

Mixing of whales identified in the WNP and ENP has been observed (Weller *et al*., 2012). Lang (2010) reported that two adult individuals from the WNP, sampled off Sakhalin in 1998 and 2004, matched the microsatellite genotypes, mtDNA haplotypes, and sexes (one male, one female) of two whales sampled off Santa Barbara, California in March 1995. Between 2010 and 2012 three whales outfitted with satellite transmitters were tracked moving from Sakhalin in the WNP to the ENP (Mate *et al*., 2015). Finally, photographic matches between the WNP and ENP, including matches between Sakhalin, Vancouver Island and Laguna San Ignacio (Fig. 1), have further confirmed use of areas in the ENP by whales identified in the WNP (Weller *et al*., 2012, Urbán *et al*., 2012). Despite this level of mixing, significant mtDNA and nuclear genetic differences between whales in the WNP and ENP have been found (LeDuc *et al*. 2002, Lang *et al*., 2011).

In 1995, following the 1994 delisting of ENP gray whales under the U.S. Endangered Species Act, the Makah Indian Tribe notified NOAA Fisheries of its interest in re-establishing limited ceremonial and subsistence whale hunting. The decision-making history on this issue is complex and not described here except to note that in 2005, the Makah Tribe submitted a detailed proposal for hunting ENP gray whales in the coastal portion of its U&A off northern Washington, USA, as part of a request for a waiver of the U.S. Marine Mammal Protection Act's (MMPA) take moratorium (16 USC 1371(a)(3)(A)). Subsequently, observations of WNP gray whales migrating through areas off the coast of North America (Alaska to Mexico) emphasized the need to evaluate the probability of a WNP gray whale being encountered in aboriginal hunts for ENP gray whales (IWC, 2012). Following recommendations of the Scientific Committee of the International Whaling Commission (IWC), analyses were conducted to estimate such probability in the context of the Makah Tribe's hunt proposal (Moore and Weller, 2013). These analyses informed a draft Environmental Impact Statement (DEIS), completed in 2015 (NMFS, 2015), pertaining to the Makah Tribe's MMPA waiver request.

NOAA Fisheries is presently considering a MMPA waiver and associated draft proposal that would govern a modified version of the Tribe's hunt proposal. The objective of the analysis reported here was to provide updated estimates of the probability that one or more WNP whales might be subjected to strikes[1], unsuccessful strike attempts (i.e., harpoon throws that do not penetrate), and vessel approaches during hunts and hunt training exercises considered in the draft proposal. This report is based on the methods used by Moore and Weller (2013) and incorporates updated information about the population sizes of ENP and WNP gray whales and their occurrence within the proposed hunt area.

METHODS

Hunt proposal

NOAA Fisheries' draft proposal would govern a Makah Tribe hunt of ENP gray whales in the coastal portion of the U&A (i.e., the "hunt area") over a 10-year hunt period. In odd-numbered years, the hunt would take place from 1 July through 31 October, a period when no sightings of WNP whales have been recorded in the ENP, and when gray whales generally (apart from PCFG

[1] As described in NOAA Fisheries' DEIS (NMFS, 2015), the term "strike" is interpreted to be consistent with the IWC Schedule definition as meaning "to penetrate with a weapon used for whaling."

animals) are in northern feeding areas. Thus, hunted animals in these odd-numbered years would presumably belong to the PCFG and it is assumed that WNP whales would not be at risk from proposed hunt operations. In even-numbered years, the hunt would take place from 1 December through 31 May. This period coincides with both the southward (December to mid-February) and northward (mid-February to late May) migration of ENP whales and overlaps with the time when WNP gray whales have been sighted in the ENP. Thus, in even-numbered years there is a potential risk to WNP whales from proposed hunt operations. In each of the even-numbered years, a maximum of 3 gray whales per year could be struck (including "struck and lost" animals). Over the 10-year period of the proposed hunt, a maximum of 15 whales could be struck (in even-numbered years) that would have some probability of being WNP whales. We therefore evaluate the probability of striking at least one WNP whale per even-numbered year (out of 3 strikes) and for the 10-year period (out of 15 strikes). We also evaluate associated rates of WNP whales being subjected to aforementioned "unsuccessful strike attempts" (i.e., harpoon throws that do not penetrate) and "approaches" (i.e., whales approached by vessels during hunts and hunt training exercises).

Data

Abundance estimates - The most recent ENP abundance estimate (for 2015/2016) is 26,960 (CV = 0.05) (Durban *et al.*, 2017). The most recent WNP abundance estimate (for 2015) is 200 (CV = 0.03) for the 1+ population (i.e., excluding calves) (Cooke 2018). We then multiplied the WNP estimate by 1.099 to account for calves. This multiplier is based on the ratio of the population size with and without calves in 2012 (IUCN, 2012).

Mixing proportions based on sightings in the Makah Hunt Area - During spring surveys (March to May) in 1996-2012 there were 181 observed whale-days in the Makah hunt area (Calambokidis *et al*., 2014). To clarify the term "whale-day" – all sightings of an individual on a particular day collectively count as 1 whale-day (e.g., multiple sightings of the same individual on the same day count as just 1 whale-day, but the same individual seen the next day would count as a second whale-day). None of the 181 whale-days observed included WNP whales[2]; 73 (40.3%) were considered PCFG whales; and the rest (108, or 59.7%) were assumed to be migrating ENP whales.

However, rather than use 40.3% as the expected PCFG proportion in the hunt area during an even-year hunt, we use 28% for this mixing proportion (i.e. 72% of animals encountered during an even-year hunt are likely to be non-PCFG animals). This value is based on analyses summarized in a 2018 IWC workshop (IWC, 2018).

Proportion of WNP whales migrating with ENP whales - The proportion of the WNP population that migrates along the North American coast is unknown but estimated to be at least 0.37 based on analysis by Cooke (2015) and reported to a 2015 IWC workshop on gray whale population structure (IWC, 2016).

[2] Although not in the Makah hunt area, Weller *et al*. (2012) report observing three WNP whales on 2 May 2004 and three more on 25 April 2008 near Barkley Sound off the west coast of southern Vancouver Island, British Columbia, Canada.

Model

Moore and Weller (2013) considered four models in their analysis but they based final inferences on what they termed Model 2B. Here, we use Model 2A instead. Models 2A and 2B are similar. The difference is that for Model 2A, the conditional probability of a non-PCFG whale being a WNP (rather than ENP) whale is simply based on the ratio of WNP:ENP population size. This is an intuitive estimator, though it does rely on the assumption that WNP and ENP animals migrating together are using the same migration corridors and behaving similarly. For Model 2B, this assumption is relaxed and we allow for broader uncertainty by stating that the conditional probability varies uniformly from zero (if the WNP whales do not migrate through the Makah area at all) to some maximum value that is based on (but not equivalent to) the ratio of WNP:ENP population size. However, it is difficult to define that maximum value, and allowing a lower probability of zero is not precautionary and arguably should not be considered without supporting evidence.

Model 2 (A and B) makes use of the mixing proportion/sightings data for the Makah hunt area, as well as WNP and ENP abundance estimates. WNP whales are assumed to be moving with the ENP migrants, so that the marginal probability of a WNP whale being struck is the probability that the struck whale is a migrant, P_{mig} (i.e., probability of not being a PCFG whale), multiplied by the conditional probability of being a WNP whale given that it is a migrant ($P_{WNP|mig}$). Thus, $P_{WNP} = P_{mig}P_{WNP|mig}$.

P_{mig} is defined as $1 - P_{PCFG}$, where P_{PCFG} is given by an informative prior: $P_{PCFG} \sim$ Beta (5.3648, 13.7952) which has a mean of 0.28 and SD of 0.1 (IWC 2018).

We assume that the per-capita likelihood of a migrating (non-PCFG) whale in the hunt area being a WNP whale (i.e., $P_{WNP|mig}$) is simply given by the proportion of the migrating population made up of WNP whales. This proportion depends on what fraction of the WNP population migrates along the U.S. West Coast, which we call *m*, and the relative size of the WNP to the ENP population. Thus, $P_{WNP|mig} = mN_{WNP}/(mN_{WNP} + N_{ENP})$. Let $m \sim$ Uniform (0.37, 1), based on Cooke *et al.* (2015). N_{WNP} and N_{ENP} are treated as lognormally distributed variables with means and CVs as given above.

Estimation

Earlier analyses (Moore and Weller, 2013) used Bayesian estimation. In the current exercise, analysis was conducted using OpenBUGS software, but estimation is not strictly Bayesian because there are no new data updating the informative prior inputs. Rather, the present analysis is essentially a Monte Carlo procedure, with distributions for the parameters of interest (e.g., probability of striking a WNP whale) being derived from random draws from informed prior distributions for the input parameters. Derived parameter distributions are summarized from two MCMC chains, each 25,000 samples in length (50,000 samples total).

Derived parameters

The key parameter of interest is the per-strike probability of striking a WNP whale. Derived from this parameter are the probabilities of striking at least one WNP out of 3 gray whale strikes (i.e., the annual probability of striking a WNP whale, for the even-numbered years) or out of 15 gray

whale strikes (i.e., probability for the whole 10-year period). These are calculated as $P(x > 0) = 1 - (1 - P_{WNP})^X$, where X is 3 or 15. Additionally, we can derive the expected number of WNP strikes as $E(x) = P_{WNP}X$. Using data collected during previous hunts (NMFS, 2015), the following two assumptions were used to calculate analogous estimates for vessel approaches and unsuccessful strike attempts: (1) there will be 353 vessel approaches per year (3530 across all 10 years)[3], and (2) there will be 6 unsuccessful strike attempts for every strike in an even-year hunt[4].

RESULTS

Parameter estimates

Estimated parameters from all model sets are in Table 1. Figure 2 shows the distribution for P_{WNP}. It is straightforward to integrate across the uncertainty in P_{WNP} to obtain a single probability estimate. We did this for the probability of striking ≥ 1 WNP whale over the entire 10-year hunt period (i.e., out of 15 strikes). This probability was 0.058.

Table 1. Distribution summaries for key model parameters. "Prob(WNP)" is the probability of at least 1 WNP animal being struck or subjected to unsuccessful strike attempts or vessel approaches given the specified number of events.

Parameter	Posterior mean	2.5% CRI	Posterior median	97.5% CRI
Prob(WNP) for a single interaction, i.e., P_{WNP}	0.004	0.002	0.004	0.007
Prob(WNP|3 strikes in 1 yr)	0.012	0.006	0.012	0.019
Prob(WNP|15 strikes in 10 yrs)	0.058	0.030	0.057	0.093
Prob(WNP|18 unsuccessful strike attempts in 1 yr)	0.070	0.036	0.069	0.110
Prob(WNP|90 unsuccessful strike attempts in 10 yrs)	0.299	0.167	0.298	0.442
Prob(WNP|353 approaches in 1 yr)	0.735	0.511	0.751	0.899
Prob(WNP|3530 approaches in 10 yrs)	~ 1.0	0.999	~ 1.0	~ 1.0
Expected WNP|3 strikes in 1 yr	0.012	0.006	0.012	0.019
Expected WNP|15 strikes in 10 yrs	0.060	0.030	0.059	0.097
Expected WNP|18 unsuccessful strike attempts in 1 yr	0.072	0.036	0.071	0.116
Expected WNP|90 unsuccessful strike attempts in 10 yrs	0.361	0.182	0.353	0.582
Expected WNP|353 approaches in 1 yr	1.416	0.714	1.386	2.283
Expected WNP|3530 approaches in 10 yrs	14.160	7.141	13.860	22.830

[3] This number is conservative because it assumes that all approaches (hunting and training) in both even and odd years occur during the winter/spring period when WNP whales may be present. Realistically we would expect a substantial number of approaches to occur outside this period, i.e., during the summer when ocean conditions are more favorable and, in odd years, when hunting approaches are restricted to July - October.

[4] We expect zero in odd years because the draft proposal limits training strikes (which count as unsuccessful strike attempts) to the summer-fall hunting season, when WNP whales are not expected to be present.

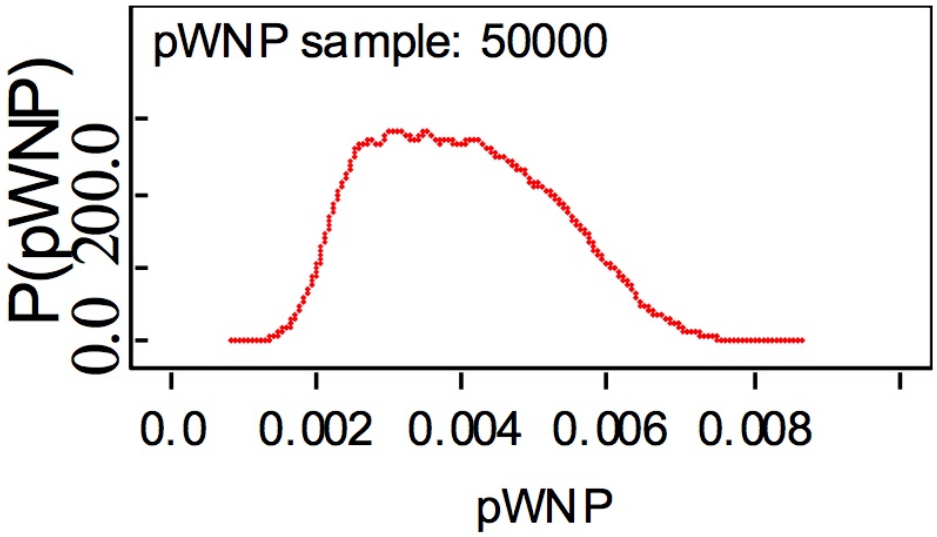

Figure 2. Posterior distribution for probability that any given strike is a WNP whale.

DISCUSSION

Estimates from our analysis may be precautionary since they assume that the Makah hunt will achieve proposed maximum strike limits, and because the assumption of Model 2A is that WNP whales are homogenously mixed with ENP whales. The likelihood of striking a WNP whale is overestimated if fewer total animals are struck or if in reality the WNP animals use a different migration corridor and are less likely to travel through the Makah hunt area. Given uncertainties associated with the model and scenario assumptions, these results serve as a rough approximation of the potential for WNP gray whales to be subjected to strikes, unsuccessful strike attempts and vessel approaches during a Makah hunt operating under a draft proposal currently being considered by NOAA Fisheries.

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email: *maureen.hinman@trade.gov.*) This meeting is physically accessible to people with disabilities. Requests for sign language interpretation or other auxiliary aids should be directed to OEEI at (202) 482–5225 no less than one week prior to the meeting.

SUPPLEMENTARY INFORMATION: The meeting will take place from 8:30 a.m. to 3:30 p.m. EDT. The general meeting is open to the public and time will be permitted for public comment from 3:00–3:30 p.m. EDT. Those interested in attending must provide notification by Tuesday, March 15, 2016 at 5:00 p.m. EDT, via the contact information provided above. Written comments concerning ETTAC affairs are welcome any time before or after the meeting. Minutes will be available within 30 days of this meeting.

Topics to be considered: The agenda for this meeting will include discussion of priorities and objectives for the committee, trade promotion programs within the International Trade Administration, and subcommittee working meetings.

Background: The ETTAC is mandated by Public Law 103–392. It was created to advise the U.S. government on environmental trade policies and programs, and to help it to focus its resources on increasing the exports of the U.S. environmental industry. ETTAC operates as an advisory committee to the Secretary of Commerce and the Trade Promotion Coordinating Committee (TPCC). ETTAC was originally chartered in May of 1994. It was most recently re-chartered until August 2016.

Dated: February 25, 2016.

Man Cho,

Acting Office Director, Office of Energy and Environmental Industries.

[FR Doc. 2016–04607 Filed 3–1–16; 8:45 am]

BILLING CODE 3510–DR–P

DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

RIN 0648–XA937

Guidelines for Assessing Marine Mammal Stocks

AGENCY: National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), Commerce.

ACTION: Notice of availability; response to comments.

SUMMARY: NMFS has incorporated public comments into revisions of the guidelines for preparing stock assessment reports (SARs) pursuant to section 117 of the Marine Mammal Protection Act (MMPA). The revised guidelines are now complete and available to the public.

ADDRESSES: Electronic copies of the guidelines are available on the Internet at the following address: *http://www.nmfs.noaa.gov/pr/sars/guidelines.htm.*

FOR FURTHER INFORMATION CONTACT: Shannon Bettridge, Office of Protected Resources, 301–427–8402, *Shannon.Bettridge@noaa.gov.*

SUPPLEMENTARY INFORMATION:

Background

Section 117 of the Marine Mammal Protection Act (MMPA) (16 U.S.C. 1361 *et seq.*) requires NMFS and the U.S. Fish and Wildlife Service (FWS) to prepare stock assessments for each stock of marine mammals occurring in waters under the jurisdiction of the United States. These reports must contain information regarding the distribution and abundance of the stock, population growth rates and trends, estimates of annual human-caused mortality and serious injury from all sources, descriptions of the fisheries with which the stock interacts, and the status of the stock. Initial stock assessment reports (SARs, or Reports) were first completed in 1995.

NMFS convened a workshop in June 1994, including representatives from NMFS, FWS, and the Marine Mammal Commission (Commission), to develop draft guidelines for preparing SARs. The report of this workshop (Barlow et al., 1995) included the guidelines for preparing SARs and a summary of the discussions upon which the guidelines were based. The draft guidelines were made available, along with the initial draft SARs, for public review and comment (59 FR 40527, August 9, 1994), and were finalized August 25, 1995 (60 FR 44308).

In 1996, NMFS convened a second workshop (referred to as the Guidelines for Assessing Marine Mammal Stocks, or "GAMMS," workshop) to review the guidelines and to recommend changes to them, if appropriate. Workshop participants included representatives from NMFS, FWS, the Commission, and the three regional scientific review groups (SRGs). The report of that workshop (Wade and Angliss, 1997) summarized the discussion at the workshop and contained revised guidelines. The revised guidelines represented minor changes from the initial version. The revised guidelines were made available for public review and comment along with revised stock assessment reports on January 21, 1997 (62 FR 3005) and later finalized.

In September 2003, NMFS again convened a workshop (referred to as GAMMS II) to review the guidelines and again recommend minor changes to them. Participants at the workshop included representatives of NMFS, FWS, the Commission, and the regional SRGs. Changes to the guidelines resulting from the 2003 workshop were directed primarily toward identifying population stocks and estimating Potential Biological Removal (PBR) for declining stocks of marine mammals. The revised guidelines were made available for public review and comment on November 18, 2004 (69 FR 67541) and finalized on June 20, 2005 (70 FR 35397, NMFS 2005).

In February 2011, NMFS convened another workshop (referred to as GAMMS III) to review the guidelines and again recommend changes to them. Participants at the workshop included representatives from NMFS, FWS, the Commission, and the three regional SRGs. The objectives of the GAMMS III workshop were to (1) consider methods for assessing stock status (*i.e.,* how to apply the PBR framework) when abundance data are outdated, nonexistent, or only partially available; (2) develop policies on stock identification and application of the PBR framework to small stocks, transboundary stocks, and situations where stocks mix; and (3) develop consistent national approaches to a variety of other issues, including reporting mortality and serious injury information in assessments. Nine specific topics were discussed at the workshop. The deliberations of these nine topics resulted in a series of recommended modifications to the current guidelines (NMFS, 2005). The main body of the GAMMS III workshop report includes summaries of the presentations and discussions for each of the nine agenda topics, as well as recommended revisions to individual sections of the guidelines (Moore and Merrick, 2011). Appendices to the workshop report provide a variety of supporting documents, including the full proposed revision of the guidelines (Appendix IV). On January 24, 2012 (77 FR 3450), NMFS made the GAMMS III workshop report available for public review, and requested comment on the proposed revisions in Appendix IV. The report is available at *http://www.nmfs.noaa.gov/pr/pdfs/sars/gamms3_nmfsopr47.pdf.*

Revisions to the Guidelines for Preparing Stock Assessment Reports

The paragraphs below describe the proposed guideline revisions that were recommended by the GAMMS III workshop participants, as well as a summary of how NMFS has or has not incorporated those proposed revisions into the final revised guidelines. They are organized by topic, as outlined in Appendix IV of the GAMMS III workshop report.

Topic 1: PBR calculations with outdated abundance estimates. For an increasing number of marine mammal stocks, the most recent abundance estimates are more than 8 years old. Under existing guidelines (NMFS, 2005), these are considered to be outdated and thus not used to calculate PBR. The current practice is to consider the PBR for a stock to be "undetermined" after supporting survey information is more than eight years old, unless there is compelling evidence that the stock has not declined during that time.

The workshop participants recommended and the proposed guidelines included the following revisions to calculate PBRs for stocks with old abundance information: (1) During years 1–8 after the most recent abundance survey, "uncertainty projections" would be used, based on uniform distribution assumptions, to serially reduce the minimum abundance estimate (N_{min}) by a small increment each year; (2) after eight years, and assuming no new abundance estimate has become available, a worst-case scenario would be assumed (*i.e.,* a plausible 10-percent decline per year since the most recent survey), and so a retroactive 10-percent decline per year would be applied; and (3) if data to estimate a population trend model are available, such a model could have been used to influence the uncertainty projections during the first eight years.

NMFS received a number of comments expressing strenuous objection to/concern with the proposed framework for stocks with outdated abundance estimates, which has led us to reevaluate the topic. As such, NMFS is not finalizing these recommended changes related to Topic 1 at this time. Rather, we will be further analyzing this issue, and should we contemplate changes to the guidelines regarding this topic, NMFS will propose them and solicit public comment in a separate action.

Topic 2: Improving stock identification. For most marine mammal species, few stock definition changes have been made since the initial SARs were written. The proposed guidelines directed that each Report state in the "Stock Definition and Geographic Range" section whether it is plausible the stock contains multiple demographically independent populations that should be separate stocks, along with a brief rationale. If additional structure is plausible and human-caused mortality or serious injury is concentrated within a portion of the range of the stock, the Reports should identify the portion of the range in which the mortality or serious injury occurs. These revisions to the guidelines have been made.

The GAMMS III workshop also addressed the terms "demographic isolation" and "reproductive isolation." Workshop participants agreed that the intended meaning of these terms when originally included in the guidelines was not of complete isolation, which implies that there should be no interchange between stocks. Therefore, they recommended and the proposed guidelines included clarification of terminology by replacing references to "demographic isolation" and "reproductive isolation" with "demographic independence" and "reproductive independence," respectively. These revisions to the guidelines have been made.

Related to this topic, the workshop participants also recommended that NMFS convene a national workshop to systematically review the status of stock identification efforts and to identify and prioritize the information needed to improve stock identification. NMFS convened such a workshop in August 2014 (Martien *et al.,* 2015). See response to Comment 10.

Topic 3a: Assessment of very small stocks. The PBR estimate for some stocks may be very small (just a few animals or even less than one). In such cases, low levels of observer coverage may introduce substantial small-sample bias in bycatch estimates. The proposed guideline revisions included a table in the Technical Details section that provides guidance on the amount of sampling effort (observer coverage and/or number of years of data pooling) required to limit small-sample bias, given a certain PBR level. If suggested sampling goals (per the table) cannot be met, the proposed guidelines instructed that mortality should be estimated and reported, but the estimates should be qualified in the SARs by stating they could be biased. NMFS has incorporated this language into the revised guidelines.

The proposed guidelines suggested removing the following sentence from the Status of Stocks section: "In the complete absence of any information on sources of mortality, and without guidance from the Scientific Review Groups, the precautionary principle should be followed and the default stock status should be strategic until information is available to demonstrate otherwise." NMFS has incorporated this revision into the guidelines, as NMFS does not consider the original text to be consistent with the MMPA's definition of "strategic."

Topic 3b: Assessment of small endangered stocks. Some endangered species, like Hawaiian monk seals, are declining with little to no direct human-caused mortality, and the stock's dynamics therefore do not conform to the underlying model for calculating PBR. Thus, PBR estimates for some endangered species stocks have not been included or have been considered "undetermined" in SARs. The proposed guidelines instructed that in such cases, if feasible, PBR should still be calculated and included in the SARs to comply with the MMPA. In situations where a stock's dynamics do not conform to the underlying model for calculating PBR, a qualifying statement should accompany the PBR estimate in the SAR. NMFS has incorporated this language into the revised guidelines.

Topic 4: Apportioning PBR across feeding aggregations, allocating mortality for mixed stocks, and estimating PBR for transboundary stocks.

Feeding aggregations: Given the definition that a population stock consists of individuals in common spatial arrangements that interbreed when mature, population stocks of species that have discrete feeding and breeding grounds (*e.g.,* humpback whales) have generally been defined based on breeding ground stocks. However, given the strong maternal fidelity to feeding grounds, migratory species such as humpback whales can have feeding aggregations that are demographically independent with limited movement of individuals between feeding aggregations. Such feeding aggregations can consist of a portion of one breeding population, or of portions of multiple breeding populations, and can represent a single demographically-independent unit, or a mix of two or more demographically-independent units. Although this approach of identifying stocks based on feeding aggregations seemed feasible, workshop participants felt this approach added significant complexity without providing substantial management advantages. The workshop participants did not recommend any such changes to the guidelines at this point. None were

included in the proposed guidelines nor have any been made in the final revisions.

Allocating mortality for mixed stocks: In some cases, mortality and serious injury occur in areas where more than one stock of marine mammals occurs. The proposed guidelines specify that when biological information is sufficient to identify the stock from which a dead or seriously injured animal came, the mortality or serious injury should be associated only with that stock. When one or more deaths or serious injuries cannot be assigned directly to a stock, then those deaths or serious injuries may be partitioned among stocks within the appropriate geographic area, provided there is sufficient information to support such partitioning. In those cases, Reports should discuss the potential for over- or under-estimating stock-specific mortality and serious injury. In cases where mortalities and serious injuries cannot be assigned directly to a stock and available information is not sufficient to support partitioning those deaths and serious injuries among stocks, the proposed guidelines instruct that the total unassigned mortality and serious injuries should be assigned to each stock within the appropriate geographic area. When deaths and serious injuries are assigned to each overlapping stock in this manner, the Reports should discuss the potential for over-estimating stock-specific mortality and serious injury. NMFS has incorporated this language into the revised guidelines.

Transboundary stocks: The proposed guidelines strengthen the language regarding transboundary stocks, cautioning against extrapolating abundance estimates from one surveyed area to another unsurveyed area to estimate range-wide PBR. They state that informed interpolation (*e.g.,* based on habitat associations) may be used, as appropriate and supported by existing data, to fill gaps in survey coverage and estimate abundance and PBR over broader areas. If estimates of mortality or abundance from outside the U.S. EEZ cannot be determined, PBR calculations should be based on abundance in the EEZ and compared to mortality within the EEZ. NMFS has incorporated this language into the revised guidelines and has provided a footnote defining informed interpolation.

Topic 5: Clarifying reporting of mortality and serious injury incidental to commercial fishing. Currently, SARs do not consistently summarize mortality and serious injury incidental to commercial fishing. The proposed guidelines specified that SARs should include a summary of all human-caused mortality and serious injury including information on all sources of mortality and serious injury. Additionally, a summary of mortality and serious injury incidental to U.S. commercial fisheries should be presented in a table, while mortality and serious injury from other sources (*e.g.,* recreational fisheries, other sources of human-caused mortality and serious injury within the U.S. EEZ, foreign fisheries on the high seas) should be clearly distinguished from U.S. commercial fishery-related mortality. Finally, the proposed guidelines contained the addition of a subsection summarizing the most prevalent potential human-caused mortality and serious injury threats that are unquantified in the SARs, and the SARs should also indicate if there are no known major sources of unquantifiable human-caused mortality and serious injury. NMFS has incorporated this language into the revised guidelines.

Topic 6: When stock declines are sufficient for a strategic designation. The proposed guidelines included the following: "Stocks that have evidence suggesting at least a 50 percent decline, either based on previous abundance estimates or historical abundance estimated by back-calculation, should be noted in the Status of Stocks section as likely to be below OSP. The choice of 50 percent does not mean that OSP is at 50 percent of historical numbers, but rather that a population below this level would be below OSP with high probability. Similarly, a stock that has increased back to levels pre-dating the known decline may be within OSP; however, additional analyses may determine a population is within OSP prior to reaching historical levels." NMFS has incorporated this language into the revised guidelines.

Additionally, the workshop participants recommended and the proposed guidelines included the following interpretation of the definition of a strategic stock: "A stock shall be designated as strategic if it is declining and has a greater than 50 percent probability of a continuing decline of at least five percent per year. Such a decline, if not stopped, would result in a 50 percent decline in 15 years and would likely lead to the stock being listed as threatened. The estimate of trend should be based on data spanning at least eight years. Alternative thresholds for decline rates and duration, as well as alternative data criteria, may also be used if sufficient rationale is provided to indicate that the decline is likely to result in the stock being listed as threatened within the foreseeable future. Stocks that have been designated as strategic due to a population decline may be designated as non-strategic if the decline is stopped and the stock is not otherwise strategic." NMFS received comments expressing concern with the proposed interpretation of "likely to be listed as a threatened species under the ESA within the foreseeable future" (sec. 3(19)(B) of the MMPA). NMFS is not finalizing the proposed changes related to this topic at this time. Rather, we will further analyze this issue. Should we contemplate changes to the guidelines regarding this topic, NMFS will propose them and solicit public comment in a separate action.

The proposed guidelines included the following direction regarding recovery factors for declining stocks: "A stock that is strategic because, based on the best available scientific information, it is declining and is likely to be listed as a threatened species under the ESA within the foreseeable future (sec. 3(19)(B) of the MMPA) should use a recovery factor between 0.1 and 0.5." As we are not finalizing the recommended changes regarding strategic stock designation (sec. 3(19)(B) of the MMPA), above, we have decided not to revise the guidelines regarding recovery factors under such situations at this time. Should changes to the guidelines regarding the above be contemplated, NMFS will include the recommended recovery factors when we solicit public comment on that action. Therefore, NMFS is not finalizing the recommended change related to this paragraph at this time.

Topic 7: Assessing stocks without abundance estimates or PBR. For many stocks, data are so sparse that it is not possible to produce an N_{min} and not possible to estimate PBR. When mortality and/or population abundance estimates are unavailable, the PBR approach cannot be used to assess populations, in spite of a statutory mandate to do so. The proposed guidelines included the following addition to the Status of Stocks section: "Likewise, trend monitoring can help inform the process of determining strategic status." NMFS has incorporated this language into the revised guidelines.

Topic 8: Characterizing uncertainty in key SAR elements. It is difficult to infer the overall uncertainty for key parameters as they are currently reported in the SARs. The proposed guidelines direct that the Stock Definition and Geographic Range, Elements of the PBR Formula, Population Trend, Annual Human-Caused Mortality and Serious Injury,

and Status of the Stock sections include a description of key uncertainties associated with parameters in these sections and an evaluation of the effects of these uncertainties associated with parameters in these sections. NMFS has incorporated this language into the revised guidelines with some minor revisions.

Topic 9: Including non-serious injuries and disturbance in SARs. Currently, many Reports include information on human-related mortality and serious injury from all known sources (not just from commercial fisheries) but do not include information on human-related non-serious injury or disturbance. The workshop participants concluded that the guidelines, with respect to the scope of content considered by the SARs, could be retained as they currently stand. However, they encouraged authors to routinely consider including information in the Reports about what "other factors" may cause a decline or impede recovery of a particular stock. A final recommended revision to the guidelines was the addition of the following italicized text: "The MMPA requires for strategic stocks a consideration of other factors that may be causing a decline or impeding recovery of the stock, including effects on marine mammal habitat and prey, *or other lethal or non-lethal factors.*" However, this italicized text is not contained in the MMPA, and therefore, as proposed could be misconstrued as being required by the MMPA. Therefore, the revision to the guidelines has been reworded for clarity.

Comments and Responses

NMFS solicited public comments on the proposed revisions to the guidelines (January 24, 2012, 77 FR 3450), contained in Appendix IV of the GAMMS III workshop report. NMFS received comments from the Commission, the three regional SRGs, two non-governmental environmental organizations (Humane Society of the United States and Center for Biological Diversity), representatives from the fishing industry (Western Pacific Regional Fishery Management Council, Garden State Seafood Association, Maine Lobstermen's Association, Hawaii Longline Association, Cape Cod Hook Fishermen's Association, and two individuals), the American Veterinary Medical Association, the States of Maine and Massachusetts, the Makah Indian Tribe, the Center for Regulatory Effectiveness, representatives from the oil and gas industry (American Petroleum Institute, International Association of Geophysical Contractors, and Alaska Oil and Gas Association), and one individual.

NMFS received a number of comments supporting its efforts to improve stock identification (topic 2). Many commenters urged NMFS to prioritize conducting regular surveys for those species with the greatest human-caused mortality or oldest survey data. Many commenters disagreed with NMFS' proposals to use a precautionary approach with aging abundance estimates (topic 1) and apportion PBR and serious injuries and mortalities (topic 4). Comments on actions not related to the GAMMS (*e.g.,* convening a Take Reduction Team or listing a marine mammal species under the Endangered Species Act (ESA)), or on items not related to portions of the guidelines finalized in this action, are not included below. Comments and responses are organized below according to the relevant workshop topics outlined in Appendix IV of the report.

Comments on General Issues

Comment 1: The Commission recommended that NMFS continue to encourage more exchange between regional SRGs to ensure consistency where needed and to promote useful and informative exchange among them.

Response: NMFS acknowledges this comment and will continue to encourage exchange between SRGs and strive to ensure consistency among the groups and among the SARs. To that end, we are convening a joint meeting of the three SRGs in February 2016, in addition to individual SRG meetings.

Comment 2: The Commission recommended that NMFS consider requiring a brief summary paragraph or table on the historical trend of each stock in the SARs, where appropriate, to combat the tendency to exclude important stock dynamics or allow for the shifting baselines phenomenon.

Response: It is unclear from the comment what historical trend information, specifically, the Commission is referencing that is not already provided in the SARs. Where able, we provide historical abundance data and estimate trends in abundance (see for example, the California sea lion SAR, which provides abundance data for the prior four decades). With respect to bycatch, we do not think it is feasible or appropriate to provide trends in bycatch rates over decades, as fisheries and monitoring programs change too frequently. The status of each stock is informed by current parameters, such as ESA listing status and relationship to OSP and PBR. Additionally, the statute specifies that the SARs provide current population trend information. We will continue to endeavor to provide as much historical abundance, trend, and human-related removal information (for example, historical whaling data as it relates to stock recovery and OSP, see Eastern North Pacific blue whale report) as possible, but at this time will not require a summary table or paragraph in each SAR.

Comment 3: NMFS should secure adequate support and funding to conduct marine mammal abundance surveys in the region at least every five years. Alternative cost-effective approaches to determining N_{min}, such as trend data from index sites, should be developed and specified as acceptable methods in the guidelines.

Response: NMFS agrees that such a schedule would be ideal, but we do not currently have the resources to accomplish this. We continue to develop and implement strategies to support more efficient use of ship time through multi-species ecosystem studies, better survey designs and sampling technologies, and leveraging inter- and intra-agency resources. NMFS is also exploring alternative approaches for assessing stock status (*e.g.,* through use of unmanned systems and acoustic technologies) apart from reliance on abundance survey data, in regions where regular surveys are cost-prohibitive. As noted in the workshop report, such approaches could include trend monitoring at index sites. Developing guidelines for alternative assessment methods was not a focus of the GAMMS III workshop, and so this does not appear in the revisions finalized here. However, NMFS will make efforts to consider how alternative sets of information could be used to aid its marine mammal stock assessments.

Comment 4: The effective management of marine mammals requires timely and accurate stock status information that is currently lacking. The proposed assumption that the existing measures protecting marine mammal species are failing to achieve management objectives and the continued use of old data to assess the status of stocks are unacceptable and fail to acknowledge collective efforts to reconcile marine mammal protection with varied ocean uses. NMFS should more frequently assess the status of marine mammal stocks and incorporate this new information into management actions.

Response: NMFS agrees that management of marine mammal stocks depends on timely and accurate stock information, and in many cases up-to-date stock assessments are not available, nor are the resources necessary to

conduct the assessment. NMFS acknowledges that the reliability of abundance estimates for calculating PBR is reduced over time. The proposed approach to calculating PBR with outdated abundance information assumed the worst-case scenario, but we are not finalizing that approach at this time. Accordingly, NMFS is analyzing methods to calculate PBRs for stocks with outdated abundance information as well as developing methods to collect data more efficiently and cost effectively. See response to Comment 3.

Comment 5: The Alaska SRG expressed concern that very different approaches are taken for PBR and mortality components of SARs. A great deal of modeling effort and simulations has gone into making the PBR calculations conservative, but there is no similar concern for the mortality and serious injury data. In some of the Alaska SARs, 20+ year-old observer data are the only mortality data for a particular fishery. The nature of Alaska fisheries can change quite quickly, so Alaska SRG members strongly object to using such old data. The reliability of removals data is just as important as population data when assessing stock status. This issue merits serious attention, and as a first step, the quality of removals data should be thoroughly and explicitly evaluated when uncertainty in SARs is evaluated.

Response: NMFS acknowledges that many of the data related to Alaska marine mammal stocks are dated. NMFS continues to rely upon and incorporate the best available data in the SARs, but in some cases these data are many years old. The revised guidelines instruct SAR authors to describe uncertainties in key factors, including human-caused mortality and serious injury, and to evaluate the effects of those uncertainties.

Comment 6: The proposed changes do not reflect an agency commitment to generating best available science upon which to base its decisions. In fact, this rule contains no statements as to what the agency intends to do with respect to old or non-existent assessments other than to reduce PBR. We request the agency comment for the record specifically how NOAA intends to address the GAMMS III stated need for accurate and timely census data.

Response: The MMPA requires that NMFS and FWS use the best available scientific information in its assessment and management of marine mammal stocks. NMFS strives to collect the data necessary for timely stock assessments in a cost-efficient manner, but agency resources are limited, and there are instances where data are either too old or non-existent. We are currently analyzing how to calculate PBR when data are outdated.

Comment 7: We appreciate NMFS' efforts to improve stock identification, small stock biases, non-serious injuries, and institute other SAR enhancements, and encourage NMFS to incorporate veterinary expertise relative to marine mammal population, health, and ecosystem conservation status.

Response: NMFS acknowledges this comment. NMFS continues to incorporate and rely upon veterinary expertise in activities related to stock assessment; for example, the development of the serious injury determination policy and procedures, and response to stranded animals and UMEs.

Comment 8: Several of the GAMMS III recommendations require more explanations and verbiage to be added to the SARs (*e.g.,* Topics 2, 5, 8, and 9).

Response: NMFS recognizes that the recommendations require additional text to be added to the SARs. We strive to maintain the conciseness of the SARs while providing best available science and meeting the directive of MMPA section 117(a).

Comment 9: NMFS should produce a record showing that the guidelines and GAMMS Report comply with the Information Quality Act (IQA) Pre-dissemination review requirements as follows: (1) All models that the guidelines or GAMMS Report use should be peer reviewed in order to determine their compliance with Council for Regulatory Environmental Modeling Guidance; (2) the method used by the guidelines and GAMMS Report to estimate population uncertainty violates the IQA accuracy and reliability requirement; and (3) the guidelines and GAMMS Report violate the IQA accuracy and reliability requirements by telling staff to make up abundance data and PBR when measured data do not exist ("informed interpolation"). In addition, NMFS should revise the guidelines and GAMMS Report to delete any suggestion that marine mammal SARs should discuss oil and gas seismic effects, as oil and gas seismic operations do not cause mortality or serious injury to marine mammals and do not cause a decline or impede recovery of any strategic stock.

Response: The GAMMS report referenced by the commenter is a summary of the proceedings of a workshop and was reviewed for accuracy prior to dissemination. We did not solicit comments nor are we responding to comments on the workshop report itself. The guidelines also underwent IQA pre-dissemination review prior to being finalized and released to the public. There is no requirement under the NOAA or OMB Information Quality Guidance to explain within the guidelines themselves how they have met IQA requirements.

The marine mammal SARs are based on the best available science. NMFS strives to use peer-reviewed data as the basis for reports. However, in some cases, the best available science may not have been published or subjected to a juried professional journal review, as this process can take months or years to complete. In other cases, data pertinent to assessments of stocks are routinely collected and analyzed but are not suitable for a stand-alone external peer-reviewed publication. Therefore, NMFS often relies on science that has been through a NMFS Science Center's internal expert review process and/or has been subjected to other internal or external expert review to ensure that information is not only high quality but is available for management decisions in a timely fashion. In these cases, all NOAA-authored literature should meet, at the least, the standards for Fundamental Research Communications established by the NOAA Research Council and by NMFS. NMFS may rely on the SRGs to provide independent expert reviews of particular components of new science to be incorporated into the SARs to ensure that these components constitute the best available scientific information. Likewise, upon SRG review of these components and the draft SARs themselves, NMFS considers the SRG review of the draft SARs to constitute peer review and to meet the requirements of the OMB Peer Review Bulletin and the Information Quality Act.

The proposed method for projecting uncertainty in abundance estimates (topic 1) is not being finalized at this time (see below). Any models that are employed in the SARs have been peer reviewed, as is their specific application to the SARs, and therefore meet the requirements of the IQA. Regarding the use of informed interpolation to estimate abundance within a study area based on habitat modeling or similar approaches (*i.e.,* model-based abundance estimation), this approach is commonly applied in ecology. The International Whaling Commission Scientific Committee recently acknowledged the strength and utility of model-based abundance estimation methods and is planning a workshop to formulate revisions to its guidelines for conducting surveys and analyzing data to include guidance on the use of these methods in management (IWC, 2015).

Model-based estimation of density is based on survey data and habitat or other covariates, which is entirely science based. To suggest we are directing staff to "make up abundance data and PBR" is a mischaracterization of what is contained in the revised guidelines. We have added a footnote to the guidelines to clarify the definition of "informed interpolation."

Regarding oil and gas activities, nowhere in the proposed guidelines are oil and gas or seismic activities specifically discussed. The guidelines do not direct the inclusion of oil and gas activities in the SARs; however, if oil and gas activities are found to be having a detrimental effect on a stock or its habitat, we would include it in the report, as we would with any other activity. The final revised guidelines (very slightly revised from the proposed guidelines) state: "The MMPA requires for strategic stocks a consideration of other factors that may be causing a decline or impeding recovery of the stock, including effects on marine mammal habitat and prey. In practice, interpretation of "other factors" may include lethal or non-lethal factors other than effects on habitat and prey. Therefore, such issues should be summarized in the Status of the Stock section for all strategic stocks. If substantial issues regarding the habitat of the stock are important, a separate section titled "Habitat Issues" should be used. If data exist that indicate a problem, they should be summarized and included in the Report. If there are no known habitat issues or other factors causing a decline or impeding recovery, this should be stated in the Status of the Stock section."

Comments on Topic 1: Assessing Stocks With Outdated Abundance Estimates

NMFS received a number of comments expressing strenuous objection to/concern with the proposed framework for stocks with outdated abundance estimates. As such, NMFS is not finalizing the proposed revisions related to Topic 1 at this time. Rather, we will further analyze this issue. Should we contemplate changes to the guidelines regarding this topic, NMFS will propose them and solicit public comment in a separate action.

Comments on Topic 2: Improving Stock Identification

Comment 10: The Commission recommended that NMFS convene a national workshop to systematically review the status of stock identification efforts and to identify and prioritize the information needed to improve stock identification.

Response: In August 2014, NMFS convened a workshop on the use of multiple lines of evidence to delineate demographically independent populations (Martien et al., 2015). The meeting participants agreed that the best way to provide guidance on the use of multiple lines of evidence when delineating demographically independent populations for marine mammals was to produce a Stock Delineation Handbook that can serve as a guide for future demographically-independent population delineation efforts. Development of the handbook is currently underway. Subsequent to the 2014 workshop, NMFS began developing an internal procedure for identifying and prioritizing stocks in need of examination for potential revisions that would complement and be integrated into the stock delineation workshop outputs and the existing SAR process.

Comment 11: The GAMMS III workshop report makes several very good recommendations for improving stock identification, and the Alaska SRG and the Humane Society of the United States agree with all of them.

Response: NMFS acknowledges this comment.

Comment 12: The Pacific SRG recommends that NMFS focus on the role of genetics in determining marine mammal stock structure and in defining the terms "stock" and "population."

Response: Although the guidelines are clear that genetic evidence is not the sole evidence that could be used to define stocks, changes in stock definition have relied on genetic data as the primary line of evidence, and species for which genetic evidence are not available have not had new stocks defined. The MMPA uses the term "population stock." The guidelines have a lengthy section on "Definition of stock" that has been discussed in each of the GAMMS workshops and in a special workshop devoted to stock definition (see response to Comment (10). The language that interprets "population stock" has remained largely unchanged since the first set of guidelines despite much discussion.

Comment 13: The Pacific SRG would like to have the following questions addressed: How do we integrate the MMPA's goal of maintaining a population as a functioning part of the ecosystem with the statute's definition of a stock (that emphasizes breeding interchange)? In a continuum of levels of genetic exchange, where does one draw the line between what is a stock and what is not? How will the proposed use of eco-regions be practically implemented in stock determination and how will migratory stocks that feed in one region and breed in another be treated under this proposal? How do we balance the conservation concerns resulting from stocks being defined very broadly versus the costs and management concerns resulting from stocks being defined very finely?

Response: The definition of "population stock" as "a group of marine mammals of the same species or smaller taxa in a common spatial arrangement, that interbreed when mature" is vague from a biological perspective. To some degree, all "groups" within a species interbreed when mature or else they would be considered different species according to the biological species concept. Clearly, population stock was intended to mean interbreeding at some greater level but that level is not specified. Interpretation becomes more difficult when considering known cases of migratory species with strong fidelity to both feeding and breeding grounds. Consider, for example, humpback whales that feed in Southeast Alaska and breed in Hawaii. These individuals can interbreed when mature but can (and do) interbreed with individuals that feed in other areas. If a threat occurred within Southeast Alaska that resulted in unsustainable deaths in that area, then if the "Southeast Alaska whales" were a stock, that stock's PBR could be used as an indicator that management efforts to mitigate that threat were warranted. In contrast, if "interbreed when mature" considered all the whales in Hawaii, then the human-caused mortality in Southeast Alaska may never exceed the PBR based on Hawaii, and eventually the ecosystem in Southeast Alaska would cease to have humpback whales as a functioning part. Such cases result in an apparent conflict between the words "interbreed when mature" and the goal to maintain population stocks as functioning elements of their ecosystem.

Often, changes to stock delineations in the SARs have relied on interpretation of genetic data. The Pacific SRG asks where one draws the line on what level of genetic exchange suffices to qualify as a stock. Interpretation has been based on the guidelines:

"Demographic independence means that the population dynamics of the affected group is more a consequence of births and deaths within the group (internal dynamics) rather than immigration or emigration (external dynamics). Thus, the exchange of individuals between population stocks is not great enough to prevent the depletion of one of the populations as

a result of increased mortality or lower birth rates."

To date, accepted "new" stocks have been strongly differentiated, indicating such low levels of exchange that immigration is relatively trivial. There will be, however, borderline cases. Such is the nature of imposing discrete categories on continuous processes.

The recommendations from the GAMMS III workshop do not propose basing stocks on eco-regions. Eco-regions were discussed during the workshop in two contexts: (1) In a working paper that demonstrated that most stocks are currently defined at a very large scale often encompassing several eco-regions, and (2) that eco-regions may highlight stocks that may deserve consideration in a stock definition meeting because that stock may be at too large a scale and could encompass multiple demographically independent populations.

Comment 14: In the SARs, a concise statement concerning uncertainty in stock structure could be included in the section on uncertainty discussed under Topic 8. Details should be provided only when publications are not yet available. The Pacific SRG questions the usefulness of repeating in nearly every SAR the sentence "It is plausible that there are multiple demographically-independent populations within this stock."

Response: The Pacific SRG requested that the reader of a SAR be able to readily assess the level of confidence that can be ascribed to the PBR calculation. A critical part of that calculation is abundance, which can be severely biased if stock definition is incorrect. We recognize that many SARs will include the same statement about the plausibility of multiple demographically independent populations within the stock, but we consider it necessary to better inform the reader's understanding of areas of uncertainty.

Comment 15: NMFS received a number of comments related to stock definition and stock delineation based on feeding aggregations. Such as: The revised guidelines should address whether, and under what circumstances, a feeding aggregation can be identified as a stock consistently with the MMPA's statutory definition of a stock. One commenter stated that it is not clear whether or how the definition of a stock in the proposed guidelines relates to the definition of a stock in the MMPA. One commenter suggested that the revised guidelines should clarify the meaning of "internal dynamics" and explain how it relates to the statutory interbreeding requirement. Another suggestion was that the revised guidelines should address the workshop participants' suggestion "that human-caused mortality on the feeding grounds be monitored and evaluated against a PBR calculation made for the feeding aggregation and that the feeding-ground PBR, mortality, and evaluation results be reported in the SARs, as is currently done for Pacific humpback stocks."

Response: The workshop participants discussed the possibility of basing stocks on feeding aggregations. Although workshop participants considered this approach to be feasible, they believed it added significant complexity without providing substantial management advantages, and did not recommend revisions to the guidelines at this time. Therefore, this revision of the guidelines does not specifically discuss identification of stocks based on feeding aggregations. We recognize and acknowledge these comments related to feeding aggregations and stock definition, but as they do not relate to the current revisions to the guidelines, we are not addressing them in this action. If the issue is further considered by the agency in a separate action, we will address those comments in the development of that action.

Comment 16: In the proposed guidelines, NMFS suggests that it may delineate marine mammal stocks based upon human factors such as incidental take as a result of human-caused mortality. However, the MMPA does not permit the determination of stock status based on human-related factors. Accordingly, when delineating stocks, NMFS can only consider the demographic and biological characteristics of the species at issue. Carving out stocks in areas where human-caused mortality is high, as NMFS proposes, would violate the MMPA.

Response: The guidelines state: "For example, it is common to have human-caused mortality restricted to a portion of a species' range. Such concentrated mortality (if of a large magnitude) could lead to population fragmentation, a reduction in range, or even the loss of undetected populations, and would only be mitigated by high immigration rates from adjacent areas." They caution that serious consideration should be given to areas with concentrated high human-caused mortality, but that actual stock definition should be based on biological considerations. In other words, high-localized human-caused mortality should highlight the need for stock identification scrutiny but not the lines of evidence used.

Comment 17: If it cannot be demonstrated with normal genetic analysis, then it is unwarranted to establish populations or subpopulations based on behavior or distribution. To split existing populations into smaller units only invites the development of fragmented PBRs with an aggregate value that will likely be lower than that of the whole population.

Response: Genetic data are certainly useful when attainable, but in many cases genetic samples (of sufficient quantity to draw sound inferences) cannot be obtained. There are many other lines of evidence that can be informative to determining stock structure, including behavior and distribution and also movement data from photographic identification or tagging. Genetic data are sometimes sufficient but are not exclusively needed to make sound inferences concerning stock structure. In 2014, NMFS convened a workshop to review the use of other lines of evidence, as consistency and accuracy in delineating stocks for species with limited data would be improved if guidelines were available on both the strengths of different lines of evidence and how to evaluate multiple lines together (Martien *et al.,* 2015). As a result of this workshop, NMFS is developing a handbook for identification of demographically independent populations, which includes genetic information as well as other lines of evidence.

Comment 18: The revised guidelines should acknowledge that factors other than demographic independence, such as a localized disease or a localized change in prey availability, might cause different population responses between geographic regions. In light of such factors, the revised guidelines should discuss under what circumstances it is appropriate to designate stocks solely on the basis of different population responses between geographic regions.

Response: Demographic independence is defined in terms of birth and death rates within the population and immigrations from outside the population. Presumably, the response of a population to 'localized disease or localized change in prey availability' would be changes in the birth and/or death rates. Thus, it would seem that the concern above is already accounted for in the guidelines.

Comment 19: If the revised guidelines continue to define a stock as a demographically-independent biological population, they should explain more clearly the circumstances under which a group of marine mammals can be designated as a stock even in the

absence of evidence that the group comprises a demographically independent biological population. Are such circumstances limited to those in which "mortality is greater than a PBR calculated from the abundance just within the oceanographic region where the human-caused mortality occurs," as suggested in the GAMMS III Report? Or can stocks be designated in other circumstances in the absence of evidence of demographic independence? If so, what other circumstances are contemplated?

Response: The section on definition of stocks in the guidelines seeks to clarify the practical process of definition given biological complexity and different types and qualities of available data. This section was contained in GAMMS II (NMFS 2005) and was not revised in this current revision of the guidelines. The guidelines note that particular attention should be given to areas where mortality is greater than PBR but do not limit stock definition to those circumstances. The stock definition workshop (see above) was suggested as a forum to improve stock definition in data-poor cases.

Comments on Topic 3: Assessment of Small and Endangered Stocks

Comment 20: The Commission recommends that NMFS adopt the workshop recommendation to include, when appropriate, a statement in each assessment explaining that bycatch data are not sufficient to estimate the bycatch rate with acceptable precision. The Commission and another commenter recommended NMFS treat each such stock as strategic unless and until the data are sufficient to demonstrate that it is not.

Response: NMFS agrees with the importance of including a statement in each stock assessment to indicate when bycatch estimates are prone to small-sample bias, though it should be noted that bias and precision are different issues. The guidelines recommend pooling years of information as necessary to achieve precision levels of CV less than 0.3.

At this point, NMFS does not make the default assumption that a stock is strategic until demonstrated otherwise. The MMPA requires a determination of a stock's status as being either strategic or non-strategic and does not include a category of unknown. The revised guidelines state, for non-ESA listed and/or non-depleted stocks, "if abundance or human-related mortality levels are truly unknown (or if the fishery-related mortality level is only available from self-reported data), some judgment will be required to make this determination. If the human-caused mortality is believed to be small relative to the stock size based on the best scientific judgment, the stock could be considered as non-strategic. If human-caused mortality is likely to be significant relative to stock size (*e.g.,* greater than the annual production increment) the stock could be considered as strategic."

Comment 21: When calculating PBR, NMFS should err on the side of caution rather than allowing loosely defined flexibility that may be used to the detriment of the stock. With stocks such as the Cook Inlet belugas or Hawaiian monk seals, the documented decline in abundance would seem to challenge the assumption that net productivity occurs. Therefore, a PBR of zero is appropriate and would promote regional consistency.

Response: NMFS recognizes that in some cases the dynamics of a stock do not comport with the underlying assumptions of the PBR framework. Given that Section 117 directs the agency to calculate PBR, the revised guidelines direct authors to calculate PBR but in such instances to qualify the calculation in the PBR section of the Report.

Comment 22: We support the calculation of PBR even for small stocks with little human-caused mortality to comply with the MMPA. However, we do not support the exception to depart from the PBR requirement.

Response: NMFS recognizes that, pursuant to Sec. 117 of the MMPA, each stock assessment report should include an estimate of the PBR for the stock. However, PBR is not always estimable. Most obviously, we lack abundance estimates for some stocks. Less obviously, the equation for estimating PBR makes assumptions about the underlying population growth model for marine mammals, and for stocks whose population dynamics do not appear to conform to these assumptions, the calculated PBR is considered unreliable as an estimate of the true potential biological removal. The revisions to the guidelines encourage reporting PBR for all stocks possible and qualifying in the SAR when the reported value is not considered reliable. Departure from this suggestion must be discussed fully within any affected report.

Comment 23: The Commission recommends that NMFS require stock assessment authors to set PBR to zero in those cases that are not in accord with the commonly assumed PBR framework and involve stocks with no tolerance for additional human-related removals.

Response: The revisions to the guidelines encourage reporting PBR for all stocks possible and qualifying in the stock assessment report when the reported value is not considered reliable or in cases where a stock's dynamics do not conform to the underlying model for calculating PBR. At this point, the guidelines are not instructing authors to set PBR to zero.

Comment 24: The Pacific SRG continues to support a decision not to report a PBR in the monk seal SAR.

Response: By ecological theory, *i.e.,* when the assumption of simple logistic population growth is reasonable and when a stock's status can be attributed to direct anthropogenic impacts, a non-zero estimate of PBR is not unreasonable. In the case of Hawaiian monk seal, however, it is not apparent that these model assumptions hold. See response to Comment 22.

Comment 25: The Alaska SRG preference would be to have an undetermined PBR when assessing endangered stocks. If numerical estimates of PBR are to be given in SARs, we recommend that language be included clarifying whether negligible impact determinations have been made, what they are, and if not, stating that no human-caused takes are authorized. We do not agree that this topic is beyond the scope of SARs and rather believe that inclusion of such information would help readers understand the actual meaning of PBR in this case.

Response: NMFS disagrees with including negligible impact determinations (NIDs) under section 101(a)(5)(E) of the MMPA in the SARs. The five criteria (64 FR 28800, May 27, 1999) that NMFS may use for making a final determination and issuing 3-year incidental take authorizations to Category I and II fisheries are complex and may be difficult to relate to the data contained in the SARs, which often change on an annual basis. Furthermore, while some NIDs may use fisheries bycatch data from the past five years in making an assessment, other NID analyses may contain bycatch data from more than five years, depending on changes in fisheries, particularly regulatory changes such as time/area closures or mandatory bycatch reduction methods. In addition, NMFS may use the more recent observer data or stranding data, which may not yet be included in the most recent SARs, which may also confuse readers. Further, NMFS does not authorize (or prohibit) incidental mortalities through the SAR process.

Comments on Topic 4: Apportioning PBR, Allocating Mortality, and Estimating PBR for Transboundary Stocks

Comment 26: The Commission recommends that NMFS include in their stock assessments comparisons of PBR for feeding aggregations, and estimate or apportion mortality and serious injury levels for each aggregation.

Response: The workshop participants discussed how feeding ground PBRs should be calculated for stocks where there was a desire to monitor potential risks to feeding aggregations; however, this was not reflected in the recommended revised text for the guidelines nor were comments solicited on this issue. NMFS is not including text regarding apportioning PBR among feeding aggregations in this revision of the guidelines.

Comment 27: The Commission recommends that NMFS apply the total unassigned mortality and serious injury to each affected stock in both data-rich and data-poor cases involving taking of mixed stocks that cannot be or are not identified in the field. Doing so is the only way to be precautionary and also provides the appropriate incentive to develop better information about the affected stocks.

Response: NMFS disagrees and believes that the guidelines are sufficiently conservative at this time.

Comment 28: The Commission recommends that NMFS discourage the use of informed interpolation, require strong justification where it is used, and require that it be accompanied by reasonable measures of uncertainty associated with the interpolation.

Response: The revised guidelines allow for the use of informed interpolation (*i.e.,* model-based abundance estimation) as appropriate and supported by existing data. NMFS has added text to the guidelines specifying that when informed interpolation is employed, the Report should provide justification for its use and associated measure of uncertainty. As a point of clarification, informed interpolation is not a person making an informed judgement; it is a model that is informed by the covariation between habitat or other variables and density that is making the "judgement."

Comment 29: We support the recommendation of assigning the total unassigned mortalities and serious injuries to each stock within the appropriate geographic area.

Response: NMFS acknowledges this comment.

Comment 30: NMFS should not assign the "unassigned mortality and serious injury" to each stock within the affected geographic area as it would effectively double count these human interactions and affect the PBR of multiple stocks. Instead, NMFS should develop methodology based on the best available data to assign the serious injury and mortality according to the relative abundance of the stocks. When this is not possible, serious injury and mortality should remain unassigned to avoid arbitrary determinations.

Response: The revised guidelines direct that in data poor situations with mixed stocks, when relative abundances are unknown, the total unassigned mortality and serious injuries should be assigned to each stock within the appropriate geographic area. NMFS and workshop participants recognize that this approach effectively would repeatedly "count" the same deaths and serious injuries against multiple stocks. However, this approach is considered to be the most conservative in terms of ensuring that the most severe possible impacts were considered for each stock. The revised guidelines instruct that when deaths and serious injuries are assigned to each overlapping stock in this manner, the Reports will contain a discussion of the potential for over-estimating stock-specific mortality and serious injury.

Comment 31: NMFS's proposal to identify transboundary or high seas stocks with no available population data is contrary to the MMPA.

Response: NMFS did not propose to identify transboundary or high seas stocks with no available population data. Rather, the workshop discussions involved estimating range-wide abundance and PBR for transboundary stocks, and specifically, addressing the problem of managing transboundary marine mammal stocks for which PBR is estimated based on abundance from only a portion of each stock's range (for example, PBR levels for transboundary stocks being estimated based on abundance surveys that occur only within the U.S. EEZ). Although it is inappropriate to simply extrapolate abundance estimates to an unsurveyed area, the revised guidelines allow for the use of model-based density estimation to fill gaps in survey coverage and estimate abundance and PBR over broader areas as appropriate and supported by existing data. In such cases, the Report should provide justification for use of interpolation and associated measure of uncertainty.

Comment 32: NMFS must ensure that it prioritizes collection of data necessary to support interpolations when full assessments are not possible. In cases where a partial survey is conducted and methods of interpolation or modeling are not incorporated, serious injuries and mortalities should only be counted if they occur in the portion of the stock that was surveyed.

Response: NMFS agrees surveys should ideally cover the entirety of the stock range. When this is not possible, N_{min} is defined under the MMPA as an estimate of the number of animals in a stock that provides reasonable assurance that the stock size is equal to or greater than the estimate, so a partial survey can be used to calculate N_{min} and PBR. All human-caused mortality and serious injury needs to be accounted for under the MMPA, so injuries or deaths that are known to come from a stock must be apportioned to that stock even if the abundance is underestimated. The solution to this mismatch is not to ignore human-caused mortality and serious injury (which is contrary to the MMPA), but to conduct adequate surveys or develop models to obtain complete abundance estimates.

Comment 33: The apportionment of PBR to foraging grounds between surveyed and un-surveyed areas appears to be a significant problem in the absence of data and lacks scientific justification. It appears that this will be based on untested assumptions regarding stock distributions. Assuming uniform distribution will have animals present where they may not exist or exist only seasonally.

Response: NMFS agrees that it is not appropriate to assume uniform distribution between surveyed and unsurveyed areas, and as such discourages the use of extrapolation. The workshop participants discussed this issue, and the background paper on this topic suggested that informed modeling exercises may sometimes be appropriate or necessary for management decisions and to ensure that stocks remain as functioning elements of the ecosystem. Therefore, the revised guidelines state, "abundance or density estimates from one area should not be extrapolated to unsurveyed areas to estimate range-wide abundance (and PBR). But, informed interpolation (*e.g.,* based on habitat associations) may be used to fill gaps in survey coverage and estimate abundance and PBR over broader areas as appropriate and supported by existing data."

Comment 34: Given the known lack of general data and uncertainty of existing data, it appears that it will be difficult to accurately use separate PBRs for marine mammal populations with multiple feeding grounds. To the extent that this is understood, information pertaining to separate feeding

aggregations should be noted in the stock assessment reports, but separate PBRs should not be used for stocks with multiple feeding grounds. There is a significant risk that "unassigned mortality and serious injury" could be wrongly assigned and result in erroneous estimates to one or more populations. To avoid arbitrary assignments, when this is not possible, serious injury and mortality should remain unassigned.

Response: See response to Comment 26.

Comment 35: The section on apportioning PBR among feeding aggregations does not provide clear guidance for cases like eastern Pacific gray whales and whether the Pacific Coast Feeding Group is a stock or not, a case where there may be mitochondrial differences between feeding areas but all animals go to a common breeding area.

Response: The current Guideline revisions do not address apportioning PBR among feeding aggregations. See response to Comment 26.

Comment 36: Separate PBRs for stocks with multiple feeding grounds should not be used. Separating PBR among feeding stocks is complicated and data-intensive, and is unlikely to improve management. NMFS is rarely able to adequately determine which portion of the stock was involved in a human interaction.

Response: See response to Comment 26.

Comment 37: There is concern that failure to estimate a population-wide PBR in the assessments will lead to the reliance on the proposed default of assuming the population is in decline. The agency should develop an assessment methodology based on the best available data and devise a statistically sound interpolation algorithm to fill in gaps in survey coverage and estimate abundance over the range of the population. If this is not developed then there is a very strong possibility that assessment scientists will discount or not utilize historical estimates derived from multiple surveys spanning multiple geographic regions in one year, and/or limited surveys the following year.

Response: NMFS recognizes the need to estimate population-wide PBR for marine mammal stocks, which is why the revised guidelines allow for the use of informed interpolation (*i.e.,* model-based abundance estimation) to fill gaps in geographical survey coverage. Where interpolation is employed, the Reports should include a statement about the level of uncertainty surrounding the estimates.

Comment 38: Priority for research should be given to stocks for which serious injury and mortality exceeds PBR and for which additional management action is required under take reduction plans. In cases where this is not possible, NMFS must consider the availability of data for interpolation or informed modeling exercises to obtain abundance estimates for the full range of the stock. This strategy requires careful coordination with Canada for transboundary stocks. If timely and robust data are not available, NMFS should not make stock assessment determinations.

Response: Staffs from NMFS Science Centers, Regional Offices, and Headquarters Offices communicate regularly to discuss science needed to support management and to help prioritize research efforts. This includes discussion of stocks for which human-caused mortality and serious injury exceed PBR and take reduction planning needs. The revised guidelines allow for the use of informed interpolation (*e.g.,* based on habitat associations) to fill gaps in survey coverage and estimate abundance and PBR, as appropriate and when supported by existing data.

Comments on Topic 5: Reporting of Mortality and Serious Injury

Comment 39: The Commission recommends that NMFS require a summary of all human-caused mortality and serious injury in each stock assessment report. Efforts to meet that requirement will almost certainly vary, perhaps markedly. With that in mind, the Commission encourages NMFS to re-examine those report sections after one to two years to identify the most effective reporting strategies that could then be used to develop a consistent and informative reporting approach.

Response: Section 117 of the MMPA requires that all sources of human-caused mortality and serious injury be included in stock assessments. NMFS makes every effort to include these sources of anthropogenic mortality and serious injury in each stock assessment, whether the mortality or serious injury is systematically recorded by fishery observer programs or through opportunistic records, such as strandings, where the cause of death or serious injury can be linked to human-related causes. NMFS understands that clearly presenting these mortality and serious injury data in the SARs is an important part of allowing the public to interpret the status of marine mammal stocks. Every effort will be made to continue to improve the way in which mortality and serious injury are reported in the SARs.

Comment 40: The Alaska SRG believes that extensive tabling of interactions between marine mammals and commercial fisheries should be confined to an Appendix, with only a summary table that includes mortality in the various Federal groundfish fisheries, state water fisheries, and international transboundary fisheries included in the body of the assessment. The strategy of summarizing fishery interactions should lead to a single clearly-documented estimate of mortality and associated variance for all fisheries combined with easy access to details available preferably in an online appendix.

Response: NMFS makes every effort to present fishery interaction data simply in the body of each SAR, whether in the text, tabular form, or both. The agency feels that it is valuable to have all interaction data appear within the SAR itself (although some regions also currently include a separate Appendix describing those fisheries that interact with marine mammals). NMFS also produces stand-alone injury determination and bycatch papers by region, which has reduced the amount of information that needs to go into the SARs, as they are incorporated by reference. The agency will continue to improve the clarity of how interaction data are presented within the SARs.

Comment 41: The SARs tend to lag approximately two years behind in incorporating available observer bycatch data. For some fisheries that have 100-percent observer coverage such as the Hawaii-based swordfish fishery, such bycatch data are available in near real-time. Review of new data should be conducted promptly given that PBR, the zero mortality rate goal, and strategic status for stocks are all based on the most recent SAR.

Response: Bycatch data for most fisheries are not available in real-time and every effort is made to produce and incorporate new bycatch estimates from observer data in a timely manner into the draft SARs. SARs are typically drafted in the autumn of each year, with previous calendar year observer data representing the most up-to-date full-year information. For example, draft 2016 SARs will be prepared in the autumn of 2015 for review by regional Scientific Review Groups in early 2016. These draft 2016 reports will utilize bycatch data from calendar year 2014 if available, thus the 2-year time lag between the year the reports are published and the year of the most recent bycatch data.

Comments on Topic 6: Determining When Stock Declines Warrant a Strategic Designation

Comment 42: In an apparent attempt to interpret the MMPA definition of strategic stock, the proposed guidelines suggest that a "strategic stock" is a stock that "is declining and has a greater than 50 percent probability of a continuing decline of at least five percent per year." However, in reality, a stock that "has a greater than 50 percent probability of a continuing decline of at least five percent per year" would not necessarily qualify as "threatened" in all cases. Rather, the determination of "threatened" status under the ESA requires a species-specific analysis of specific factors that are expressly set forth in the ESA. While NMFS may have the discretion to develop a general guideline for determining "strategic" status, NMFS may not mechanically apply the "strategic stock" definition set forth in the proposed guidelines.

Response: NMFS acknowledges this comment and has not made this revision to the guidelines. See Response to Comment 43.

Comment 43: The Commission recommends that NMFS consider any marine mammal stock that has declined by 40 percent or more to be strategic. Additionally, the Commission and the Humane Society of the United States recommend that stocks declining with more than 50 percent probability of continuing decline (by at least five percent/year) should be treated as strategic with the aim of reducing and reversing the stock's decline before a depleted designation is required.

Response: Section 3(19) of the MMPA defines a "strategic stock," as one: "(A) for which the level of direct human-caused mortality exceeds the potential biological removal level; (B) which, based on the best available scientific information, is declining and is likely to be listed as a threatened species under the Endangered Species Act of 1973 within the foreseeable future; or (C) which is listed as a threatened species or endangered species under the Endangered Species Act of 1973 (16 U.S.C. 1531 *et seq.*), or is designated as depleted under this Act." NMFS has not adopted the workshop-recommended revisions regarding a quantitative interpretation of strategic status per section 3(19)(B) but will continue to analyze how to interpret "likely to be listed as a threatened species under the (ESA) within the foreseeable future." However, NMFS has finalized the revision regarding declines in abundance: "Stocks that have evidence suggesting at least a 50 percent decline, either based on previous abundance estimates or historical abundance estimated by back-calculation, should be noted in the Status of Stocks section as likely to be below OSP. The choice of 50 percent does not mean that OSP is at 50 percent of historical numbers, but rather that a population below this level would be below OSP with high probability."

Comment 44: The Alaska SRG supports the quantitative recommendations for determining when non-ESA listed stocks should be considered as "strategic." We also find the rationale for using 15 years as "the foreseeable future" a reasonable default because it is based on a five percent decrease over a 15-year period resulting in a 50 percent decline.

Response: At this time, NMFS is not adopting the recommended changes related to strategic status of stocks that are declining and likely to be listed as a threatened species under the ESA within the foreseeable future.

Comment 45: The Alaska SRG agrees with the working group's recommendation that a Recovery Factor scaled from 0.1 to 0.5 be associated with stocks that are declining and likely to be listed as a threatened species under the ESA within the foreseeable future. In some cases where a decline is steep and ongoing or where the uncertainty about the population or causes of the decline are high a lower recovery factor could be warranted. We also recommend that there be a more formal process for NMFS to regularly review non-ESA listed stocks of concern to determine their status.

Response: As we are not finalizing the recommended changes regarding strategic stock designation (sec. 3(19)(B) of the MMPA), above, we have decided not to revise the guidelines regarding recovery factors under such situations at this time. Each time a SAR is reviewed, the status of the stock is evaluated.

Comment 46: While the revisions in the guidelines are a step toward developing criteria for a strategic designation, and using the threatened species recovery factors seems prudent, this revision falls short of setting timeframes to evaluate whether a stock should be reclassified.

Response: It is unclear whether the commenter is referencing evaluation timeframes under the MMPA (sec. 117(c)(1)) or the ESA (relative to the interpretation of sec. 3(19)(B) of the MMPA). Stock assessments are reviewed by NMFS every three years for non-strategic stocks or every year for strategic stocks. This sets the timeframe for evaluating whether a stock's status should be revised. See response to Comment 45 regarding MMPA sec. 3(19)(B).

Comment 47: The Pacific SRG supports the revision of when stock declines merit a strategic designation but suggests wording changes that give NMFS more flexibility surrounding the obligation to determine when a stock is depleted prior to classifying it as strategic. The SRG recommends that the NMFS regularly review whether a "depleted" status is warranted for (1) unlisted stocks of marine mammals that are declining and (2) stocks listed as depleted that are recovering.

Response: NMFS acknowledges this comment, and agrees that the depleted status of marine mammal stocks should be reviewed periodically to ensure that designations are appropriate. We are currently evaluating information contained within a review of the SARs conducted by the Commission and will, as a part of this evaluation, consider whether there is more that NMFS should to do enhance consistency and accuracy with regard to depleted status of marine mammal stocks on a more regular basis.

Comment 48: Given the challenges facing NMFS to collect timely data covering the full range of stocks already designated as strategic, NMFS should not adopt new guidelines to take on the responsibility of delineating strategic stocks that are not designated under the ESA. There is already an acceptable federal process under the ESA to designate strategic stocks.

Response: The ESA does not designate stocks as strategic or non-strategic. Rather, the MMPA directs stocks be considered strategic if ESA-listed (*i.e.,* threatened or endangered), depleted, or human-caused mortality exceeds PBR. Additionally section 3(19)(B) allows for strategic designations of a stock that is declining and is likely to be listed as a threatened species under the Endangered Species Act of 1973 within the foreseeable future. At this time, we are not finalizing the recommended changes regarding strategic stock designation (sec. 3(19)(B) of the MMPA).

Comments on Topic 7: Assessing Stocks Without Abundance Estimates or PBR

Comment 49: The Alaska SRG supports the suggested guideline modifications relating to the use of trend monitoring. However, small changes to the guidelines will do very little to improve the situation. More substantive changes and new approaches are needed and have been described.

Response: NMFS agrees that it would be valuable to identify alternative

approaches for assessing stock status, apart from reliance on abundance survey data, in regions where regular surveys are cost-prohibitive. As noted in the guidelines, such approaches could include trend monitoring at index sites. However, developing guidelines for alternative assessment methods was not a focus of the GAMMS III workshop. NMFS will make efforts to consider how alternative sets of information could be used to aid its marine mammal stock assessments. See responses to Comment 3 and Comment 4.

Comment 50: Based on the statutory mandate to use the PBR formula, NMFS should prioritize gathering data for any stocks with insufficient information to calculate levels of abundance, trends, or mortality. NMFS should not consider approaches other than those that are mandated and should provide admonition that stocks should not automatically be determined to be non-strategic in the absence of information. Absence of data on the degree of impact to stocks is not the same as data on the absence of impacts to stocks.

Response: NMFS does prioritize its data collection based upon what it perceives to be the most critical information gaps. NMFS does not make the default assumption that a stock is strategic or non-strategic until demonstrated otherwise. See response to Comment 20.

Comment 51: If a significant data shortage makes it difficult to identify unit stocks, then NMFS should make it a high priority to remedy this uncertainty that seems crucial to determine "population status." What has NMFS done to improve "best available science" on marine mammal abundance and stock structure?

Response: NMFS agrees that it is a high priority to improve the identification of unit stocks. Consistent with this, the GAMMS III workshop participants recommended a national workshop be held to review and summarize information that is relevant to population structure. NMFS convened such a workshop and has begun developing an internal procedure for identifying and prioritizing stocks in need of examination for potential revisions that would complement and be integrated into the stock delineation workshop outputs and the existing SAR process.

Comment 52: Given that the MMPA provides significant latitude in data sources for affected species and to the extent that "anecdotal information" and "unpublished information" are used, "trend monitoring" information from the fishermen who are out there every day should be used in stock assessments.

Response: Various sources of information could be used to estimate trends as long as the information is credible and compatible with existing statistical or modeling frameworks.

Comments on Topic 8: Characterizing Uncertainty

Comment 53: The Commission recommends that NMFS include all relevant sources or measures of uncertainty in stock assessment documents. Such indicators of uncertainty are essential for readers to form reliable conclusions regarding the status of the affected stocks and the factors affecting them.

Response: NMFS agrees that information on key sources of uncertainty should be made explicit in the Reports, and this has been added to the revised guidelines.

Comment 54: The Pacific SRG has strived over the years to make the SARs models of conciseness, and the proposed guidelines could reverse these efforts. SARs should be summaries of significant results and conclusions and not lengthy discussions including detailed descriptions of methods and repetitive caveats. The recommendation to include statements regarding uncertainty about parameters affecting PBR has been made by the Pacific SRG previously, which envisioned a brief separate "Uncertainties" section summarizing significant sources of uncertainty in the stock assessment. Lengthy discussions of uncertainty embedded in each SAR section reduce clarity and readability. Additions such as points of contact could be placed in an appendix to each set of SARs, but not be placed in each individual SAR.

Response: NMFS agrees that discussions of uncertainty should be added in a way that will not detract from the clarity and readability of the stock assessment reports and will not add appreciably to the length of those reports. The workshop participants' recommended addition of providing a point of contact has not been incorporated.

Comment 55: The Alaska SRG supports changes to guidelines that would help ensure that SARs provide adequate evaluations of uncertainty. We recommend a 'report card' format as suggested by workshop attendees that will likely be more user-friendly and promote consistency between regional SARs. Additionally, this format would be more concise than the text additions recommended in the GAMMS III proposed guidelines. This report card could include the proportion of fisheries monitored within the last five years that might be interacting with strategic stocks.

Response: NMFS agrees that quantitative criteria should be used to evaluate the uncertainty in marine mammal stock assessment reports and that a "report card" may be a good format for presenting this information. The quantitative criteria and format for this has not yet been finalized and is not specified in the revised guidelines. The workshop participants also saw merit to the report card, but there was general agreement that such information would be better conveyed as a periodic publication, such as in a NOAA Technical Memorandum, which could be considered by the SRGs.

Comment 56: The Alaska SRG supports including a characterization of uncertainty in the Status of Stocks section, and recommends that it be described as "reliable," "moderately reliable," or "unreliable" as a clear way to characterize the overall utility of the status determination. We also support the suggestion that an overall assessment of the quality of SARs be conducted periodically and reported as Tech Memos, but not as a substitute for the "report cards" in the individual SARs.

Response: Uncertainty comes in many gradations, and the method of determining PBR for human-caused mortality and serious injury was specifically designed to be effective at achieving management objectives in the face of many sources and levels of uncertainty. Furthermore, the revised guidelines recommend that the most prevalent sources of uncertainty in determining stock status and PBR levels be identified so that future research can be better directed at reducing these sources of uncertainty.

Comments on Topic 9: Expanding SARs To Include Non-Serious Injury and Disturbance

Comment 57: The Commission recommends that NMFS require sections in stock assessment reports that identify and characterize non-lethal factors that may affect population status.

Response: Section 117(a)(3) requires NMFS, in consultation with the appropriate regional scientific review group, to include other factors that might be causing a decline or impeding recovery of a strategic stock, including effects on marine mammal habitat and prey. While inclusion of non-lethal factors may be a useful qualitative approach, such factors cannot be compared to PBR to assess population status. Furthermore, other environmental documents such as

environmental assessments or impact statements required under the National Environmental Policy Act would contain that information, where known. Consistent with SRG recommendations, NMFS is trying to keep the SARs concise.

Comment 58: NMFS should revise the guidelines to delete any suggestion that a mere "disturbance" or "non-serious injury" is sufficient to be included in SARs. SARs should only include events—in particular commercial fishing events—which cause mortality or serious injury, or which can be shown to cause the decline or impede the recovery of a strategic stock. This has been NMFS' position in the past, it is correct, and it should not be changed.

Response: The MMPA requires SARs to include an estimate of all sources of human-caused mortality and serious injury, not just an estimate of commercial fisheries mortality. See response to Comment 57.

Comment 59: The Alaska SRG agrees that SARs should include the annual levels of mortality and serious injury reported through take authorizations and research permits in the "Other Mortality" section.

Response: NMFS acknowledges this and is finalizing this text within the revised guidelines under the Annual Human-caused Mortality and Serious Injury section.

Comment 60: The MMPA allows for SAR comments on non-lethal factors affecting recovery for strategic stocks, and it seems reasonable that SARs for non-strategic stocks should also evaluate such factors. However, because there is a high degree of uncertainty regarding population-level effects of non-lethal injury and disturbance, it is inappropriate to include estimates of those takes in the SARs unless there is evidence they are affecting stock recovery. Disturbance and non-serious injury do not constitute "Potential Biological Removal." While it may be useful for NMFS permit users or others to compare their potential for disturbance/injury to a stock's PBR, this falls outside the intent of the MMPA-mandated PBR process for managing interactions with commercial fisheries.

Response: The revised GAMMS specify that SARs contain information on other factors that may be causing a decline or impeding recovery strategic stocks, which we have interpreted as including non-lethal effects. As discussed in response to Comment 9, we would report on all activities found to be having a detrimental effect on a stock or its habitat. Within the SARs, PBR is only compared to takes that are determined to be serious injuries or mortalities.

Comment 61: The guidelines should require a "Habitat Concerns" section in all new stock assessments. If there are no known habitat issues, this should be stated.

Response: The previous (2005) guidelines direct that if substantial issues regarding the habitat of the stock are important, a separate section titled "Habitat Issues" should be used. Specifically, "If data exist that indicate a problem, they should be summarized and included in the Report. If there are no known habitat issues or other factors causing a decline or impeding recovery, this should be stated in the Status of the Stock section." This section of the guidelines was not changed in this revision.

Dated: February 26, 2016.

Perry F. Gayaldo,

Deputy Director, Office of Protected Resources, National Marine Fisheries Service.

[FR Doc. 2016–04537 Filed 3–1–16; 8:45 am]

BILLING CODE 3510–22–P

DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

Submission for OMB Review; Comment Request

The Department of Commerce will submit to the Office of Management and Budget (OMB) for clearance the following proposal for collection of information under the provisions of the Paperwork Reduction Act (44 U.S.C. Chapter 35).

Agency: National Oceanic and Atmospheric Administration (NOAA).

Title: Greater Atlantic Region Logbook Family of Forms.

OMB Control Number: 0648–0212.

Form Number(s): NOAA 88–30 and 88–140.

Type of Request: Regular (extension of a currently approved information collection).

Number of Respondents: 4,337.

Average Hours per Response: 5 minutes per Fishing Vessel Trip Report page (FVTR); 12.5 minutes per response for the Shellfish Log; 4 minutes for a herring or red crab report to the IVR system; 2 minutes for a tilefish report to the Interactive Voice Response (IVR) system; 30 seconds for voluntary additional halibut information; and 5 minutes for each Days at Sea (DAS) credit request.

Burden Hours: 11,508.

Needs and Uses: This request is for an extension of a currently approved information collection.

Under the Magnuson-Stevens Fishery Conservation and Management Act, the Secretary of Commerce (Secretary) has the responsibility for the conservation and management of marine fishery resources. Much of this responsibility has been delegated to the National Oceanic and Atmospheric Administration (NOAA)/National Marine Fisheries Service (NMFS). Under this stewardship role, the Secretary was given certain regulatory authorities to ensure the most beneficial uses of these resources. One of the regulatory steps taken to carry out the conservation and management objectives is to collect data from users of the resource. Thus, as regional Fishery Management Councils develop specific Fishery Management Plans (FMP), the Secretary has promulgated rules for the issuance and use of a vessel Interactive Voice Response (IVR) system, a Vessel Monitoring System (VMS) and vessel logbooks (VTR) to obtain fishery-dependent data to monitor, evaluate, and enforce fishery regulations.

Fishing vessels permitted to participate in Federally-permitted fisheries in the Northeast are required to submit logbooks containing catch and effort information about their fishing trips. Participants in the herring, tilefish and red crab fisheries are also required to make weekly reports on their catch through IVR. In addition, vessels fishing under a days-at sea (DAS) management system can use the IVR system to request a DAS credit when they have canceled a trip for unforeseen circumstances. The information submitted is needed for the management of the fisheries.

Affected Public: Business or other for-profit organizations.

Frequency: Weekly, monthly and on occasion.

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Sarah Brabson,

NOAA PRA Clearance Officer.

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POSSIBLE MIGRATION ROUTE OF THE GRAY WHALE ON THE COAST OF JAPAN

HIDEO OMURA

Whales Research Institute, Tokyo.

ABSTRACT

The gray whale occured on the south coast of Wakayama and Kochi prior to the turn of the century. The calving ground of this stock was possibly in the Seto Inland Sea. It migrated to and from the feeding ground in the Okhotsk Sea, along the east coast of Japan. With the increasing industrial development and boat and ship traffic this stock of the gray whale was driven from the Inland Sea and probably joined to the Korean stock or even to the California stock. A case of stranding of the blue whale is also reported.

INTRODUCTION

Occurrence of the gray whale on the coast of Japan is described by many authors of old Japanese books and picture scrolls of whales. In Geishi (The treatise of the whale), written by Jiemon Kandoriya of the castellany of Wakayama in 1758 and printed in 1760, which is the earliest printed monograph of the cetacea in Japan, is shown a drawing of Kokujira with a brief description (Fig. 1). This whale is drawn rather slender, but it has a series of knobs instead of a dorsal fin and bears many circular and semicircular scars on the surface of the body and tail flukes. It has bristles spreading over the entire head. He also describes that this species is the smallest among whales. He has a reason because the minke whale was not taken in these days (see Table 1).

Kiyonori Otsuki (1773–1850), a famous scholar in the Tokugawa era, left an undated manuscript on whales and whaling, entitled Geishiko (A draft of a history of the whale). It remained unpublished till 1925, when it was printed in a series of various collections in Sendai. It is by far the most systematic survey of whales and whaling that was written in the Tokugawa period (Hawley, 1958). In this book he notes that Kokujira has baleen plates of white in color. Other descriptions agree in general with those in Geishi, but he mentions the body form of Kokujira is more fat than the drawing in Geishi and gives two figures of Kokujira which resemble more to the gray whale (Fig. 2).

From the above it may safely be concluded that Kokujira is identical with the gray whale (*Eschrichtius robustus*) and it had occurred in the past at least on the coast of Wakayama. Further there remains some statistical data which show Kokujira or the gray whales were taken on the coast of Kochi, southern part of Shikoku, by the so-called net whaling prior to this century.

Modern whaling was introduced to Japan in 1897. Operation of this type

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of whaling was firstly conducted on the east coast of Korea under the permission of the said government. After several years it was introduced to the coast of Kyushu, Kochi and Wakayama, gradually replacing the net whaling, and then to the northeast coast of Japan and off Hokkaido. But there is no record of the gray whale taken by modern whaling on the coast of Kochi and Wakayama, except one reported by Andrews (1914), refered from records of whaling company. This whale, a male of 40 feet long, was taken at Oshima, Wakayama, on 9 February 1910.

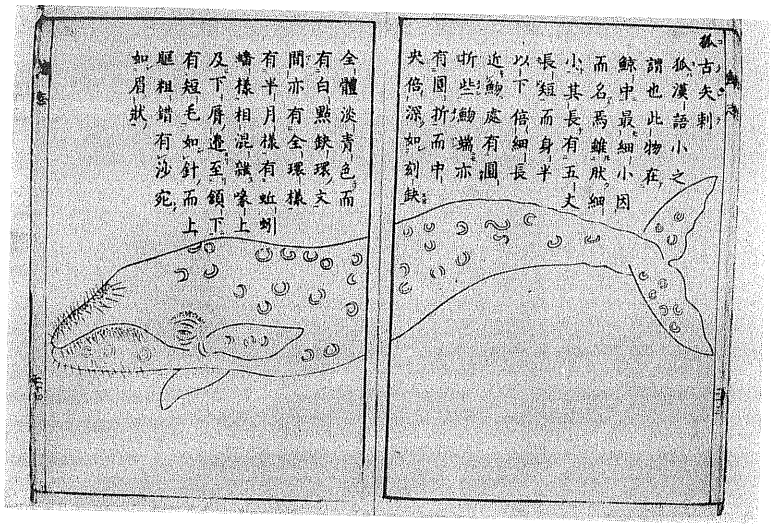

Fig. 1. Kokujira in Geishi, 1760. Cited from Hawley, 1958.

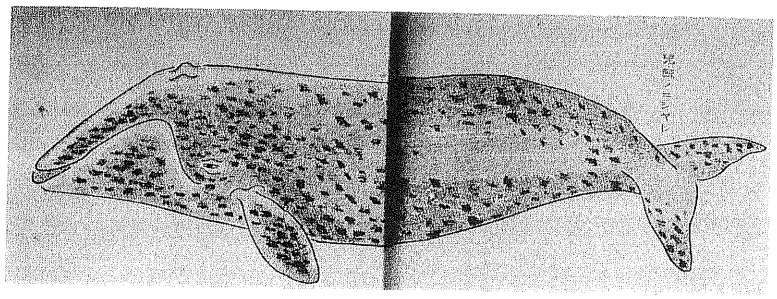

Fig. 2. Kokujira in Geishiko (Share).

In April of the year he stayed at Oshima, but no gray whale was observed at this landstation by him (Andrews, 1916). On the other coast of Japan the gray whale was taken rarely, as reported by Mizue (1951). What happened with the gray whale on the coast of Japan? This problem is discussed in this paper in relation to the supposed calving ground of this species.

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CATCH OF THE GRAY WHALE IN THE DAYS OF NET WHALING

The method of taking whales by net was invented by Kakuemon Taiji in 1677 at Taiji of the castellany of Wakayama (now Wakayama-ken), and then it spread to fishing villages on the south and west coast of Japan, including Shikoku and Kyushu, where whales came in shore in winter.

This method is a combined method of driving, netting and harpooning. When a whale was sighted by Yamami (watch on the hill), they make a signal informing species, position and swimming direction of the whale with flags or rockets. Various kinds of boats waited and went into action in orderly fashion as soon as the commander gave the order. The basic organization of whaling fleet was as follow.

Sekobune (for driving and killing whales). One group of about ten boats or more, 13 m long and 2.2 m wide with 8 oars, occasionally with sail. Crew consists of 15 men.

Amibune (netting boats). One group of about 6 boats, 13 m long and 3.5 m wide with 8 oars. Crew of 10 men.

Mossobune (tug boats). A group of 4 boats, nearly same as Sekobune but with a little broader beam. Crew of 13 men.

Sekobunes drive the whale to the place called Amiba (netting place) near the shore, producing underwater sounds with wooden hammer, where Amibunes are waiting to set the nets. Net is set sometimes two or three-fold in order to prevent the whale's escape and to check its action by entanglement.

Various kinds of harpoons, made of iron, were used. Their weights are not heavy and usually 1.0–2.0 kg in weight. Attached with harpoon a slender wooden pole and a rope with float at its end. Harpoons are thrown high up in the air so that they drop on the back of the whale from the air. When the whale has been sufficiently weakened by a number of harpoons, and later by the help of heavy swords thrown to the thorax, a sailor swims and climbs up on it and makes a hole at the blowholes with his knife in order to pass a rope through it. Then the whale is wound by several strands of rope around the body in order to tie the whale body between two Mossobunes before the whale was finally killed. Then it is stabbed at the heart with long swords.

In this way not only the right whale but also the balaenopterid whales were taken by the net whaling. This type of whaling was conducted by villagers forming groups. In these days two groups were in operation on the coast of Kochi and four groups in Wakayama. Shibusawa (1930) gives catch statistics of Ukitsu-gumi, one of these groups in Kochi, during 22 years from 1875 to 1896, by species of whales (Table 1). As seen in this table 64 whales or 17 percent among the total of 370 whales taken during this period were gray whales. From this table it is clear that the gray whale was hunted regularly at least until 1896 in these regions, as stated briefly by Nishiwaki and Kasuya (1970).

Further Hattori (1888) presents some data on details of operation and sighting of whales by the same whaling group in three years of 1880, 1882, and 1883 (Table

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2). A total of 43 gray whales were sighted in these years, in which 12 were taken, 24 escaped from taking and 7 were not pursued due to unfavorable weather.

In general the rate of the catch against total whales sighted is very low and this is thought to be the main reason why the net whaling could survive more than 200 years. Among whale species other than the gray in Table 1 were also taken later by the modern whaling on the coast of Kochi and Wakayama.

TABLE 1. CATCH OF WHALES BY UKITSU WHALING GROUP, 1875–1896.
(Cited from Shibusawa, 1939)

Year	Blue	Fin	Bryde's	Humpback	Right	Gray	Total
1875	3	—	4	2	1	1	11
1876	2	2	5	6	—	2	17
1877	—	—	3	19	—	11	33
1878	3	—	4	4	6	1	18
1879	1	—	2	9	3	7	22
1880	5	1	8	2	1	6	23
1881	1	—	5	10	2	5	23
1882	3	—	2	4	—	3	12
1883	—	—	3	7	1	3	14
1884	5	1	2	1	2	1	12
1885	4	1	4	5	2	3	19
1886	1	9	3	6	—	1	20
1887	5	—	4	13	—	4	26
1888	1	3	4	6	—	1	15
1889	2	—	7	4	—	2	15
1890	—	3	4	—	—	1	8
1891	5	—	—	9	—	1	15
1892	2	—	3	1	1	1	8
1893	4	—	1	3	1	4	13
1894	1	—	4	3	1	1	10
1895	2	1	5	6	—	3	17
1896	5	2	4	6	—	2	19
Total	55	23	81	126	21	64	370

Note: Japanese name of the above whale species in these days are:
Blue whale—Nagasukujira, Fin—Nosokujira, Bryde's—Iwashi or Katsuokujira,
Humpback—Zatokujira, Right—Semikujira, Gray—Kokujira.
But now the blue whale is called Shironagasukujira, and the fin Nagasukujira. Iwashikujira means usually the sei whale, but Iwashikujira in these districts is possibly the Bryde's whale.

SUPPOSED CALVING GROUND IN THE SETO INLAND SEA

Shindo (1970) proposes the "east Kyushu migration route" of whales. He is a clinical doctor, but concurrently a historian and has much interest on whales and whaling, especially on whales in the Seto Inland Sea. His conclusion is based upon his study of tombs and memorials of whales and old documents concerning these whales. He also visited villages and made interviews with people concerned.

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In old days it was a general custom to erect a tomb or a memorial when a whale stranded on the beach or occasionally killed by fishermen, like human being following after buddhism. These tombs or memorials are most abundantly remaining on the northeast coast of Kyushu and west coast of Shikoku (Fig. 10). Among 34 tombs or memorials, he investigated all over Japan, 15 are situated in these districts. They were erected within a period of about 100 years from 1809 to 1907. It is suggested from these facts that whales have passed frequently this strait and some of them were killed occasionally or stranded.

TABLE 2. SIGHTING AND WHALING OPERATION BY UKITSU WHALING GROUP, 1880, 1882, AND 1883.
(Cited from Hattori, 1888)

	Year	Blue	Fin	Bryde's	Humpback	Right	Gray	Total
1880:	Catch	5	1	7*	2	1	6	22*
	Escaped, A	1	2	5	—	—	4	12
	„ B	9	3	15	4	2	8	41
	„ C	—	—	—	—	—	—	—
	Not operated, D	5	6	4	4	4	3	26
	„ E	14	—	3	5	—	—	22
	Total, sighted	34	12	34	15	7	21	123
1882:	Catch	3	—	2	4	—	3	12
	Escaped, A	3	—	6	2	—	4	15
	„ B	4	2	11	1	4	1	23
	„ C	—	—	—	—	1	—	1
	Not operated, D	3	1	4	3	4	1	16
	„ E	2	—	1	6	—	—	9
	Total, sighted	15	3	24	16	9	9	76
1883:	Catch	—	—	3	7	1	3	14
	Escaped, A	1	—	6	5	—	2	14
	„ B	9	—	22	16	—	5	52
	„ C	—	—	5	—	—	—	5
	Not operated, D	3	—	2	26	—	3	34
	„ E	5	1	6	46	—	—	58
	Total, sighted	18	1	44	100	1	13	177

* One whale difference from Table 1.
Escaped, A—breaking net, B—beneath net, C—round net.
Not operated, D—due to rough weather, E—offshore.

He (1968) also ascertained that Beppu-wan, a small bay on the northeast coast of Kyushu, was a calving ground of whales. Fishermen applied in vain several times for permission of whaling to the local government. These documents are remaining, but the reason of the rejection has not been made clear. Coming of whales to this bay has lasted until about 1887. With regard to the whale species he notes as Nagasukujira, mainly based on old papers left in Usuki, a city facing to a small bay next to Beppu-wan, and where a memorial of a stranded whale remaining. The story of this stranding is described later in this report.

Waters around Iwaijima, Yamaguchi-ken, was also a calving ground of whales.

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This is supported by Higashi (1944), who writes " Nearby waters of Iwaijima was a calving ground of Nagasukujira and 60–70 whales have gathered yearly in these waters. Sometimes dead calves were washed ashore ". In Onoda, a city located westward of Iwaijima in Yamaguchi-ken, whaling was conducted in small scale in winter with hand harpoons and without using net. The whaling group was consisted of 15–20 fishing vessels. The whale species is not known, but most of them were accompanied by calves. The whaling group was dissolved in some years around 1877.

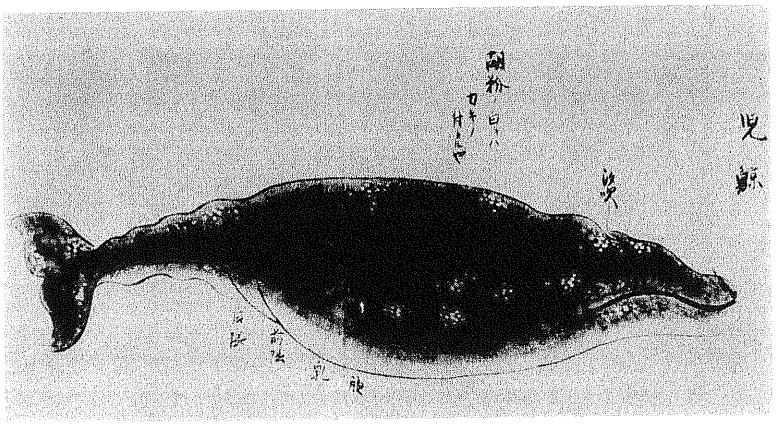

Fig. 3. Kokujira in Yakuyoki, Kawanoe. First whale.

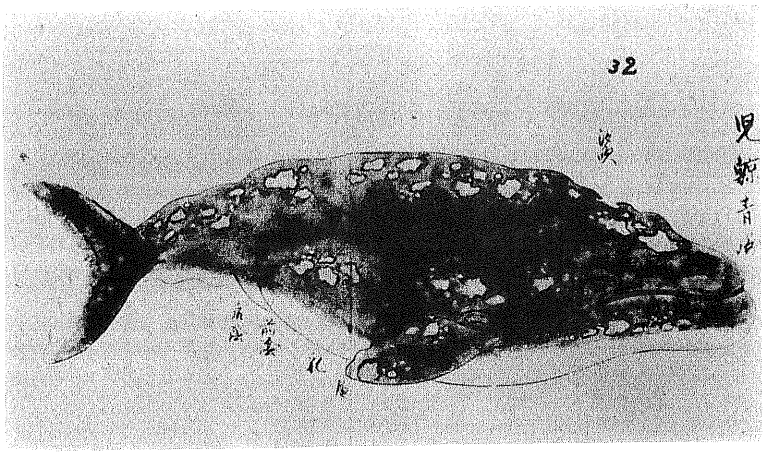

Fig. 4. Kokujira in Yakuyoki, Kawanoe. Second whale (Aosagi).

Above are the basis why Shindo (1970) proposes the " east Kyushu migration route " of whales. He concludes that there are good evidences of whales coming into Beppu-wan and came in shore of the south coast of Yamaguchi-ken and the purpose of this migration was for calving. For the whale species he notes the pos-

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sibility of the balaenopterid whales, but this is hardly be thought. No baleen whales other than the gray whale give birth to a calf in such shallow coastal waters. It is highly possible, therefore, that the Shindo's proposal of migration route is only applied for the gray whale. There is a possibility of other species entering into the Seto Inland Sea through this passage, but it is not for calving. In fact a skull of a balaenopterid whale was dug out from sea bottom off Onoda in 1926. This skull was identified as a minke whale by Dr. T. Ogawa (Shindo, 1968).

Shindo (1968) reports two gray whales were taken at Kawanoe, Ehime-ken, in 1864. The official records or diary of the local government (Yakuyoki) in these days are still being kept at the city library. The first whale was taken on 20 February 1864 by nets and harpoons. This whale came in shore of the city several days before the hunting was done, during which period villagers prepared catching equipment. Shortly after the catch of the first whale the second whale came and this whale was taken on 26 February of the same year.

Attached with the official records there remains sketches of two whales (Figs. 3 and 4). Both are without doubt the gray whale, having several knobs instead of a dorsal fin and the head is small and not arched, unlikely to the right whale. The first whale was marked with white color on the dark gray of the body the infection of barnacles, but lacking the pale patches. The second whale bears pale patches all over the body, in addition to the barnacles. The body length of the first and the second whales were recorded as having 4 Hiro (1 Hiro approximately 1 Fathom) and 6 Hiro respectively. This length does not mean the total length, because it was a custom in Wakayama and Kochi to measure the length of the whale body from the blowholes to the insertion of the tail flukes. In any case the first whale was smaller and younger than the second whale. The first whale is noted as Kokujira, but the second whale as Kokujira or Aosagi. Two types of Kokujira were noted in these days. One is Aosagi and another is Share, but the difference between two types is not clearly described in most of the old books. Should the first whale grouped as Share, then the difference is based on the color pattern of the whale body caused by the infection of barnacles, or it can be said that Share is younger than Aosagi. Both whales are thought to be females, because teats are noted in addition to navel, genital grooves, anus and blow holes in their right positions.

One scapula from one of these whales has been preserved. It has been kept at Hachiman shrine in the city (Fig. 5). There is a custom in Japan to donate Ema to a shrine in memory of big event or from some other reasons. Usually Ema is a painting on a wooden plate. In this case a scapula was used instead of wooden plate. At the center of the scapula a big Japanese (or Chinese) character which means a whale is written with powdered gold. On both sides and below this character a brief descriptions of this whale is also written with paint by small characters. This Ema has been hanged more than a hundred years on the wall of the shrine with other wooden Emas.

These two whales were the only whales taken at Kawanoe in the history, but at Takuma, a small town east of Kawanoe, whaling had been conducted with nets

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and harpoons annually, taking about three whales in average, at least in a period from 1889 to 1897. The species of whale are not known, but the size of whales is said to be 5–7 Hiro, which are the comparable size with the Kawanoe whales.

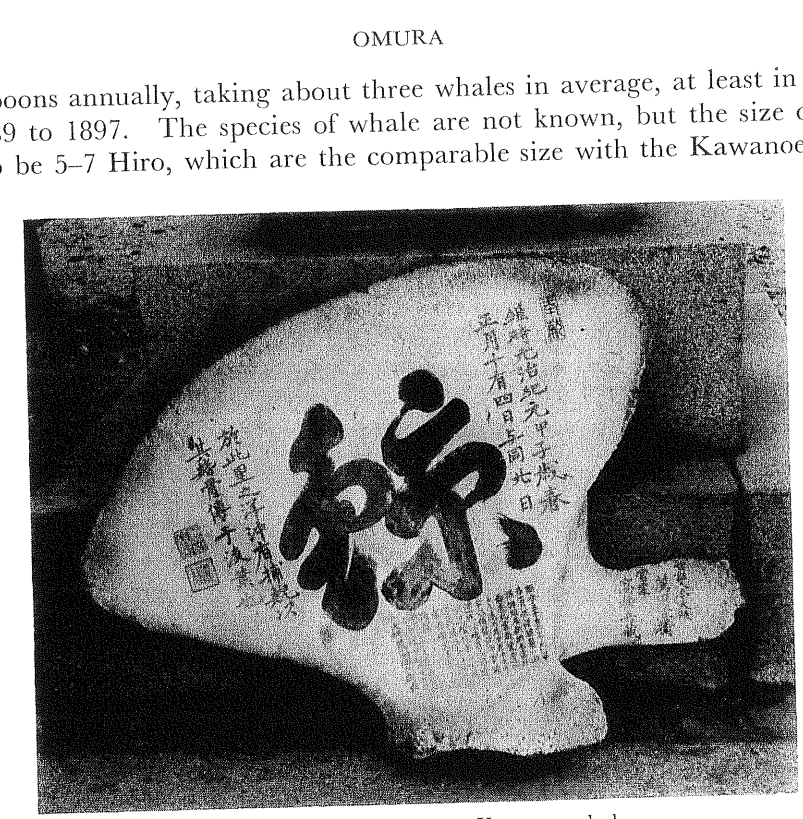

Fig. 5. Left scapula of the Kawanoe whale.

OBSERVATION OF SCAPULAE AND OTHER BONES

Shindo (1970) reports a scapula, a tympanic bulla and one of ribs of the stranded whale at Usuki also have been preserved in the city. These are private posession of persons living there. I had a short trip in April 1974 to Usuki and Kawanoe in order to examine these bones. It may be of some interest to note here the story of the stranded whale briefly. The village of Odomari, now included in Usuki city, constructed fishing harbor (Fig. 6) in 1868, but the cost has remained as a big burden of debt. On 1 February 1870 a big whale came into the harbor and finally stranded. This whale was sold, after being dismembered by all hands of the villagers, and the amount of money earned could cover all of the cost needed for the construction of the harbor. The villagers constructed a memorial (Fig. 7) and on 1 February of the following year they held a buddhistic ceremony for the whale. Since then the ceremony is being held on 1 February every year, including 1974.

On arrival at Odomari, Usuki city, I knew that another scapula has also been preserved at a family. They also said some of the baleen plates of the whale were remained until about five years ago, when they were finally burned, not knowing the value of such precious sample. In Table 3 measurements of the scapulae of the Usuki and Kawanoe whales are shown, together with measurements of other

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authors. The scapula of the Kawanoe whale (Fig. 5) agrees in general with the descriptions by Andrews (1914), being intermediate between the wide, low blade of *Balaenoptera* and the high, narrower and more symmetrically fan-shaped scapula of *Eubalaena*. The superior margin is quite evenly convex and the glenoid border is almost straight except for a short concavity where it rises from the glenoid fossa. The acromion is wide, but it is not expanding towards its distal end, contrally to the description of Andrews and the photograph shown by Nishiwaki and Kasuya

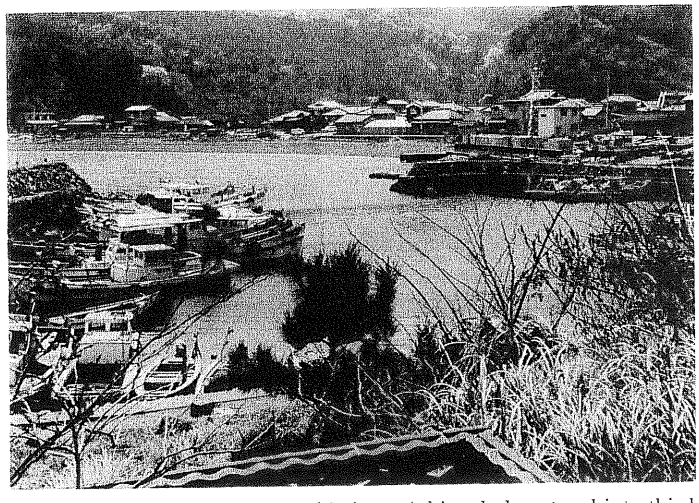

Fig. 6. Odomari fishing harbor, Usuki city. A big whale entered into this harbor and finally stranded in 1870.

(1970). But this is thought to be caused by abrasion of the extreme end. The coracoid is thick and massive and directed somewhat upward from the margin of the glenoid fossa. The external face of the scapula is quite strongly concave. This scapula is smaller than that reported by Andrews (1914), but larger than those reported by Nishiwaki and Kasuya (1970). The former whale is an old male of 1250 cm long, and the latter is a young female of 900 cm in length. This scapula is thought to be taken from the second whale, and the size of this whale is possibly between the two lengths.

The scapulae of the Usuki whale (Fig. 8) differ from that of the Kawanoe whale, being more broader and less massive, as shown in the table expressed by thickness of the superior margin of the fan. The acromion and the coracoid are shorter than in the Kawanoe whale. The external face is quite different from the Kawanoe whale, having no concavity, a characteristic feature of the gray whale. On the rear surface it has several shallow grooves radiating from the center of the fan. Without doubt these scapulae came from one of the balaenopterid whales. The tympanic bone, 129 mm in length, is broken at its margin, but this also suggest this and the outline of this bone resembles to that of the blue whale from the North Pacific (Fig. 9). The remaining rib is thought to be one of the latter half

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ribs. Its head is rounded and it measures 147 cm in straight line, but its distal end was cut off by knife. This bone has lesser value for the identification of the species.

After returning to Tokyo I sent three baleen plates, each one from the blue, fin and Bryde's whales, to Usuki for their identification, not informing them the species. They told me the color of the baleen plates was black, but the scapulae

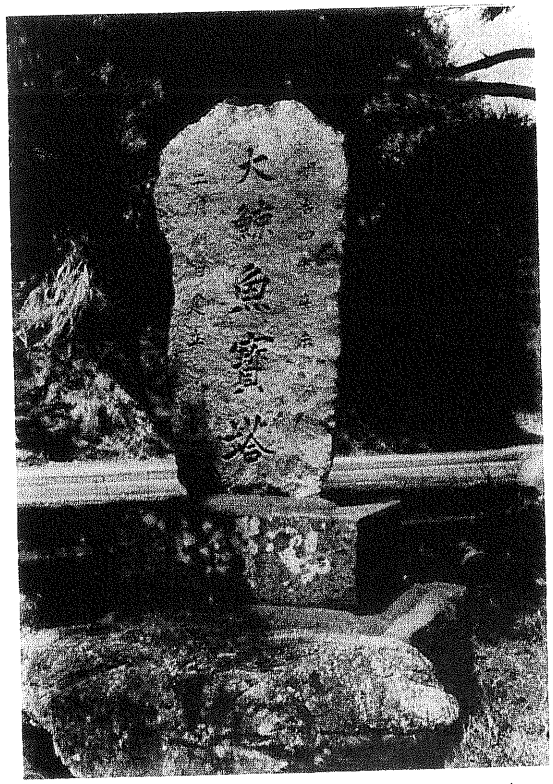

Fig. 7. Memorial of the big whale at Odomari.

are without doubt not from a right nor a humpback whale, and there is less possibility of the sei whale in these regions. The reply was that the whale was a blue whale. Tomilin (1957) describes the ratio of breadth of the scapula against the height is 1.5–1.6 in the blue, 1.65 in the fin, and 2.0 in the sei whale. This value of the Usuki whale is around 1.6 and very close to the value for both blue and fin whales.

In conclusion above the Usuki whale was possibly a blue whale and this was a rare case of the stranding of this species. The size of the scapulae are relatively small. The body length of this whale was recorded as having 15 Hiro which means roughly 75 feet (2250 cm.). This is clearly too big, even if this means the total length. Possibly the size of this whale was smaller than 20 m and probably around 17 m. The sex of this whale was male, because there remains a record that both

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eyes, penis, and bones in the loin (pelvic bones?) were burried beneath the memorial, sealed in a pot.

TABLE 3. MEASUREMENTS OF SCAPULAE OF THE USUKI AND KAWANOE WHALES. (in mm)

Measurements	Usuki whale		Kawanoe whale	Gray A		Gray B
	Right	Left	Left	Right	Left	
Greatest breadth	980	970	990	757	761	1125
Greatest height	615	600	740	495	514	856
Length of acromion, inferior	260	220	290	193	190	335
Breadth of acromion, distal end	121*	120*	139	132	145	180
Length of coracoid	40	55	100	58	62	146
Length of glenoid fossa	235	220	210	253	245	268
Thickness of superior margin						
at anterior end	29	29	27			
at middle	9	8	15			
at posterior end	42	44	52			
Ratio of breadth against height	1.59	1.62	1.34	1.53	1.48	1.31

* Greatest.
Gray A. Cited from Nishiwaki and Kasuya, 1970.
Gray B. Cited from Andrews, 1914.

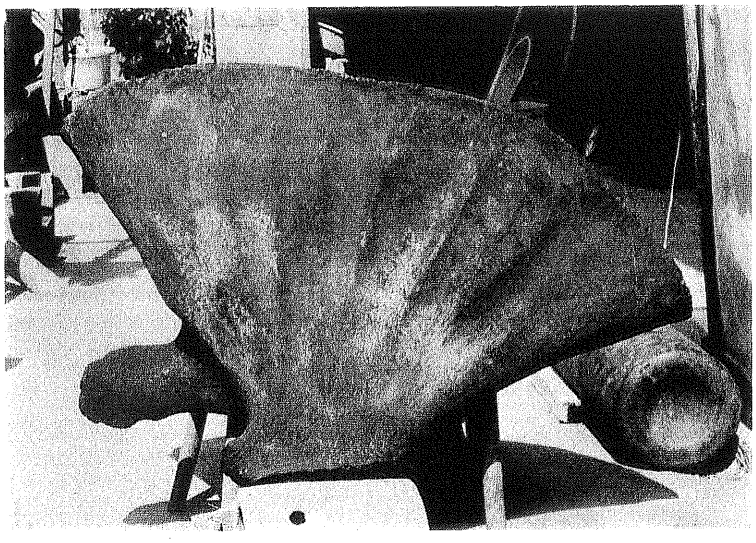

Fig. 8. Right scapula of the Usuki whale.

DISCUSSION

Although practically nothing was described by Andrews (1914), Mizue (1951) and Rice and Wolman (1971), the gray whale occured on the coast of Wakayama and Kochi in the days of the net whaling as already stated. It is possible that they

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entered into the Seto Inland Sea for calving, along the west coast of Shikoku. Their calving grounds were at least in the Beppu-wan and on the south coast of Yamaguchi. Possibly some of them then turned to east and reached as far as Kawanoe and Takuma. There is less possibility that the whale entered into the Seto Inland Sea along the west coast of Wakayama. One reason for this is the

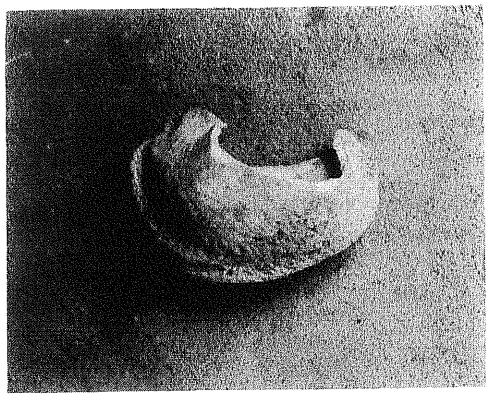

Fig. 9. Tympanic bulla of the Usuki whale.

fact that no tomb or memorial is remaining on the west coast of Wakayama and east coast of Shikoku. Fishermen who engaged in the net whaling believed that whales come straight from off Shionomisaki, the southmost point of Wakayama, to the coast of Shikoku. Supposed migration route is shown in Fig. 10.

With the increasing of industrial development along the coast of the Seto Inland Sea and boat and ship traffic the species has been driven from there since some time prior to this century. This might be the most possible explanation why practically no gray whale has been taken by modern whaling on the coast of Japan. Mizue (1951) reports, after investigating available catch records of whaling companies in seven years from 1911 to 1932, three were taken at Ayukawa and one at Nemuro, Hokkaido. Nishiwaki and Kasuya (1970) describe two recent occurences off Wakayama.

The feeding ground of the Japanese stock of the gray whale was probably in the Okhotsk Sea as in the case of the Korean stock (Rice and Wolman, 1971). The migration route to and from the feeding ground was possibly on the east coast of Japan, as already stated by Nishiwaki and Kasuya (1970). After driven from the calving ground in the Seto Inland Sea it probably has joined to the Korean stock. Further a possibility of joining to the California stock in the Bering Sea can not be denied. The original size of this stock is thought to be small and less than a thousand at the largest.

At Omijima, a small island on the north coast of Yamaguchi, or in the Sea of Japan, the gray whale was also taken in the days of the net whaling (Kimura, 1956). There remains catch records during a period from 1802 to 1850, by species. Annual catch, inclusive of all species, was fluctuated from one to fifteen whales.

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The total catch during this period was consisted of the fin (38%), the humpback (34%), the right (19%), and the gray whale (9%). The catch of the gray whale has decreased since 1812. A question remains whether these gray whales belong to the Korean stock or they are stragglers from the Japanese stock.

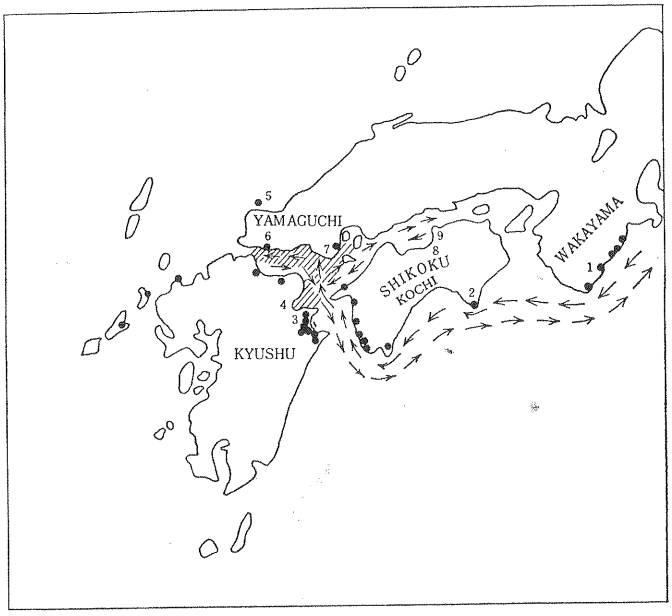

Fig. 10. Possible migration route of the gray whale on the coast of Japan.
Hatched area: Supposed calving ground.
Black dots: Positions where whale tombs or memorials located.
Names of the places refered to in the text are following.

1. Taiji	2. Ukitsu	3. Usuki	4. Beppu
5. Omijima	6. Onoda	7. Iwaijima	8. Kawanoe
9. Takuma			

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Sincere thanks are due to Dr. N. Shindo who helped me greatly in this study. He joined my trip to Usuki and Kawanoe and made all possible arrangements for me. My thanks are also due to Mr. S. G. Brown of the Institute of Oceanographic Sciences, England. He gave me the old Japanese book, he found at an old book store in London, and from which Table 2 in the text was refered.

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POSTSCRIPT

After completion of the manuscript I read a paper on the Korean stock of the gray whale by Bowen (1974). The author states that the 1968 specimen (Nishiwaki and Kasuya, 1970) resembled members of the California stock in morphological features, without mentioning the character in question. As seen in Table 3 the ratios of breadth against height of scapulae in three specimens of the gray whale are: the Kawanoe whale 1.34, Gray A (Nishiwaki and Kasuya, 1970) 1.48–1.53, and Gray B (Andrews, 1914, Korean stock) 1.31. Thus in this respect the Kawanoe whale resembles more to the member of the Korean stock than the whale reported from the coast of Japan. But the latter whale is a young female and this is thought to be a difference due to the growth.

As regards the distribution of the Korean stock Dr. K. Uchida (1964) describes a gray whale sighted by him towards the end of May 1930 on the west coast of Korea, in the Yellow Sea, at a position close to 38°N.

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The Gray Whale
Eschrichtius robustus

Edited by

Mary Lou Jones

Steven L. Swartz

Cetacean Research Associates
San Diego, California

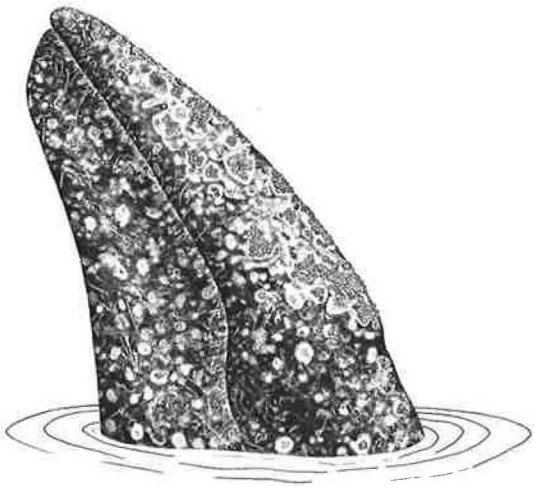
Stephen Leatherwood

Hubbs–Sea World Research Institute
San Diego, California

with illustrations by

Pieter Arend Folkens

Oceanic Society
San Francisco, California



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Introduction

The occurrence of gray whales in the coastal waters of Japan prior to the turn of the century was described by Omura (1974). He referred to a population occurring in the south of Wakayama and Kochi prefectures and very briefly to the presence of another population occurring off the north coast of Yamaguchi prefecture, in the Sea of Japan, and off the west coast of Kyushu, in the East China Sea. Catches were made from both populations in the days of net whaling (1675–1890).

The Wakayama/Kochi population is thought to have followed a migration route along the east coast of Japan (Nishiwaki and Kasuya, 1970; Omura, 1974). The Yamaguchi/Kyushu population is thought to have been a portion of the Korean stock. This stock migrated down the east coast of Korea in winter. The majority turned west along the south coast of Korea (Andrews, 1914) but a fraction is assumed to have continued southward until they reached the north coast of Yamaguchi prefecture (near Kayoi, a present Nagato city) and then to have turned along the west coast of Kyushu.

Subfossil mandibles excavated some years ago from the city of Ichikawa were recently identified as belonging to a gray whale. This further supports the contention that this species occurred in coastal waters of Japan.

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Brief History of Old Whaling in Japan

Whaling off Japan appears to have a very long history. A poem describing the catching of whales by a small boat is dated prior to the tenth century. Nothing is known, however, about the method and gear used or about the species of whales taken.

In the years of Genki (1570–1573), whaling in Mikawa and Qwari districts (now Aichi prefecture) facing Ise Bay was conducted by villagers who formed teams of 7–8 vessels and used hand harpoons (Otsuki, 1808; Fukumoto, 1960; Hashiura, 1969; Nagasaki, 1981). It can be assumed this whaling began as bay whaling and its center was Morosaki (see Fig. 7). Nothing is known about the species of whales taken, but there is a possibility that gray whales were the target. In the Edo era (1603–1867), gray whales en route to the Seto Inland Sea were thought to enter Ise Bay, passing sufficiently close to shore to become accessible to fishermen.

In years of the Bunroku (1592–1595), a skilled harpooner from Morosaki named Sukebei Mase came to Misaki (now in Kanagawa prefecture) and began whaling (Hashiura, 1969). The species of whales taken are not known, but a considerable number of whales was taken and local fishermen were stimulated to begin whaling with the same technique. It was reported this period did not last more than 20 years, because of a scarcity of whales.

There are grounds to believe that the harpoon method of whaling was transferred to Katsuyama, the village opposite Misaki across Tokyo Bay in Chiba prefecture. According to Yoshihara (1976a), new whaling started there in the years of the Keicho (1596–1603). This was the origin of the small cetacean whaling now in operation in Chiba prefecture, which takes mainly Baird's beaked whales (*Berardius bairdii*) and some other small toothed whales but no gray whales. Hand harpoons, and after 1907 small harpoon guns, were used for killing whales. Nets were not used at all in this fishery, contrary to the practice in other whaling sites in western Japan. The whaling grounds were later shifted to the east coast of Chiba prefecture.

Hand-harpoon whaling originated in Morosaki and spread to the south along the coast of Ise and Kumano districts (present Mie and Wakayama prefecture). In the eleventh year of Keicho (1606), Yorimoto, head of the then powerful Wada clan, established five whaling groups at Taiji, Kumano. He took command of the operation in the Taiji area, consulting with two fishermen, Denji from Morosaki and Jiemon from Sakai near Osaka (Hashiura, 1969). It is thought Denji, possibly a harpooner, assisted Yorimoto with the technical aspects and that Jiemon handled the commercial aspects of whaling. In 1618 a skillful harpooner named Yoheiji, from Onoura, near Morosaki, was employed at Taiji and given the name of Hazashi (chief harpooner), showing superior status to that of any other whaling crew.

In 1675, Yoriharu Wada, a grandson of Yorimoto later renamed Kakuemon Taiji, invented a new method of whaling using nets. Whales trapped and entangled by many folds of nets were easily harpooned. Straw nets were used at first, but they were too weak and were replaced in following years by hemp.

The use of nets was a revolutionary event in the history of whaling in Japan, allowing takes of humpback whales, other balaenopterid whales, and right whales, none of which could have been taken by hand harpoon previously. This method, however, required more fishing boats, more manpower, and a coordinated cooperative operation. At Taiji, five whaling groups were reorganized into one and Yoriharu Wada took the command.

The basic organization of the net-whaling fleet consisted of the following groups:

1. Seko-bune or beater boats (for driving and killing whales), one group of about 15–20 boats, 13 m long and 2.3 m wide, with eight oars. The crew of each boat consisted of 15 men, namely 1 captain, 13 sailors, and 1 apprentice.
2. Ami-bune or netting boats, one group of 6 boats, 13 m long and 3.5 m wide, with eight oars and a crew of 10 men.
3. Mosso-bune or tug boats, a group of 4 boats, nearly the same as beater boats but with a broader beam, and a crew of 1 captain and 12 sailors.

From a hillside hut commanding a wide view, watchmen scanned the sea surface for whale blows. When a whale was sighted within range, the watchmen sent signals with flags or rockets informing the boat crews of the species, position, and swimming direction of the whale. The boats described above waited in scattered positions and moved into action in an orderly fashion when the commander gave the order.

The beater boats surrounded the whale from a distance and drove it toward the netting boats which moved into proper position to set their nets. Nets were sometimes set two or three deep to prevent the whale's escape and to reduce its struggle. The netted whale was harpooned from the beater boats. When the whale was sufficiently weakened by a number of harpoons, a sailor jumped into the water and climbed onto the head of the whale with his knife to make a hole on the septum of the blowholes through which a rope was passed. Another hole was made in a similar way near the dorsal hump. In both cases the sailor stayed on the slippery surface of the whale body by grasping the handle of a struck harpoon. These harpoons also prevented the nets from slipping off.

The invention of net whaling was a major event in the economy of Japanese fishing villages. Whaling supported many hundreds of people, including workers processing the whale carcass, making nets, or engaged in other related activities, as well as sailors at sea.

Net whaling was soon introduced at Koza, a town close to Taiji, and at other places in Kumano district (part of the present Mie and Wakayama prefectures). In 1683 this method was transferred to Tosa (in the present Kochi prefecture), where the two whaling groups of Ukitsu and Tsuro were already in operation. In the following year a whaling boss named Gidayu Fukazawa from Omura, west Kyushu, came to Taiji and learned this method from Yoriharu (Hashiura, 1969). When Fukazawa returned to Kyushu, net whaling soon spread over the west coast of Kyushu and the north coast of Yamaguchi prefecture.

Descriptions of Gray Whales in Old Literature

Old Japanese whaling flourished in the Edo or Tokugawa era (1603–1867). Several books and picture scrolls of whales and whaling published during this period are useful because they contain such information on the whales migrating to Japanese waters as their species composition, migratory pattern, and catch statistics.

"Geishi" (the Treatise of the Whale), written in 1758 and printed in 1760 by Jiemon Kandoriya, the castellany of Wakayama, is the earliest printed monograph of the cetacea of Japan. It contains a drawing and brief description of the gray whale (Fig. 1), named Kokujira from *ko* meaning small and *kujira* meaning whale. The gray whale was so called because it was thought to be the smallest species among whales. There is evidence to suggest that at that time the minke whale was not identified as an independent species of baleen whale.

Kokujira had no dorsal fin but was illustrated as having several knobs in the posterior portion of the back. On both upper and lower jaws there were many hairs that spread over the entire head. This agrees with the description by Andrews (1914) who states "they (hairs) are more widely and more uniformly spread over the entire head, than in any other baleen whales."

The body color of Kokujira is described as pale blue, and there are many circular or

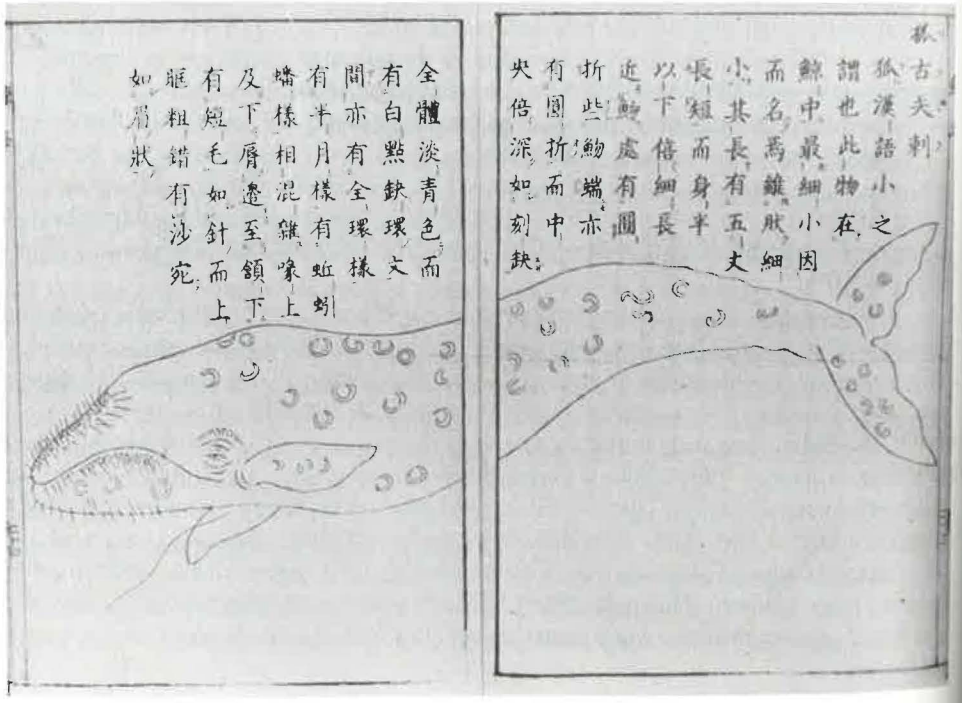

Fig. 1. *Kokujira in Geishi, 1760 (from Hawley, 1958).*

various stages of semicircular markings on the body surface. These are thought to be scars left by detached barnacles (*Cryptolepas* sp.). These barnacles embed themselves deeply in all parts of the body as well as the flukes and pectoral fins. When a barnacle detaches, it creates a circular grayish wound which in time becomes white as it heals (Andrews, 1914).

Another drawing of Kokujira (Fig. 2) appears in a scroll appended to "A History of Whaling at Taijiura, Kumano," by the Committee for the Compilation of the History of Whaling at Taijiura (Hashiura, 1969). It is assumed this scroll was made during the early years of Kambun (1661–1673), 100 years before "Geishi" was printed. These two drawings are quite similar, except for the shape of markings on the surface which is shown as pale blue in color. In both there are needle-like white hairs approximately 6 cm long. In the second (Fig. 2), barnacles and lice are shown attached to the body. The positions of blowholes, eye, ear hole, mouth, flippers, navel, genital aperture, anus, and tail flukes are all correctly indicated by arrows.

Kiyonori Otsuki (1773–1850), a famous scholar in the Tokugawa era, left an undated manuscript on whales and whaling entitled "Geishiko (A Draft of a History of the Whale)." It was written perhaps in 1808, but remained unpublished until 1925 when it was printed in a series of various collections in Sendai. In March, 1951 this book was reprinted by the Japan Whaling Association. It is by far the most systematic survey of whales and whaling written in the Tokugawa period (Hawley, 1958).

The author of the "Geishiko" refers to various books on whales and whaling which

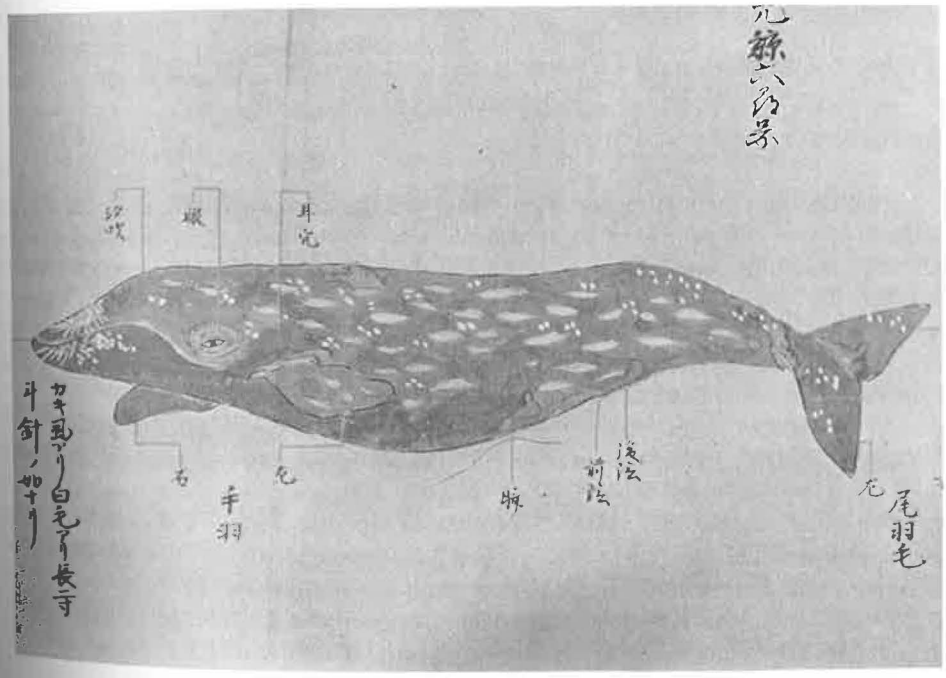

Fig. 2. *Kokujira drawn in 1661–73 (from Hashiura, 1969).*

were then available to him. Kokujira was also called Chikokujira, *chiko* also meaning small. The baleen plates of Chikokujira were described as being white. Two kinds of Kokujira were reported, one called *Aosagi* and the other *Share*. Aosagi was preferred to Share because its oil was white. However, interpretation of this old description became somewhat confused in later years. Andrews (1914) states

> The blubber is thick and fat, and varies in color from red to flesh pink. Because of this the Japanese recognized two kinds of gray whale, the 'Aosaki' (red blubber) and the 'Shirasaki' (white blubber). Although specimens with blubber strongly red, almost white, and of every intermediate shade, were taken during my stay at Ulsan, I could detect no difference, other than those purely individual, between them.

In Andrews' description, *Aosaki* is the same as Aosagi. There is only a slight difference in pronounciation of the two words, and Aosagi means blue heron.

I have been unable to find the names of *Shirasaki* or *Shirasagi* in any of the old books on whales and whaling. The only two kinds of Kokujira named are "Aosagi" and "Share." And, contrary to the above description, the color of blubber in Aosagi is said to be white. Hattori (1887–1888) thought that Share were young animals and Aosagi full-grown adults. This may be the correct interpretation. The individual differences in color of the blubber may be due to the different foods they took, as suggested by Andrews (1914). There is a description (Anonymous, 1890) in which the bigger whales which come from the west are called Aosagi (at Kawajiri). If this statement is correct, Aosagi referred to whales that were migrating from the calving ground to feeding grounds.

Biological Evidence of Occurrences

SUBFOSSIL EVIDENCE

In 1966, both mandibles, some vertebrae, and ribs of a whale were excavated from a depth of 4 m in a sand stratum in Ichikawa city, a neighboring city of Tokyo, during construction of the Ichikawa Telegram and Telephone Office. This stratum contained fossil shells, which were radiocarbon dated to 6000 years BP, or the time of the Jomon Sea Regression. The whale was erroneously identified as the sei whale, *Balaenoptera borealis*. The skeleton was then mounted with an artificial skull, vertebrae, and ribs, and exhibited in the main hall of the Ichikawa Municipal Museum.

In March, 1982 I visited the museum, with Dr. T. Kasuya of the Ocean Research Institute, University of Tokyo, and Mr. H. Kato of the Whales Research Institute and positively identified the specimen to be a gray whale. In gray whales the "lower jaws are massive, wide, and without coronoid processes: their inner surface somewhat concave at the proximal part" (Tomilin, 1967). There was no difficulty with the identification, because these features are very prominent even at a glance (Fig. 3).

Both mandibles of the Ichikawa whale have been broken anteriorly. The straight-line length of the right bone from broken tip to posterior end is 2.22 m. The height is 35

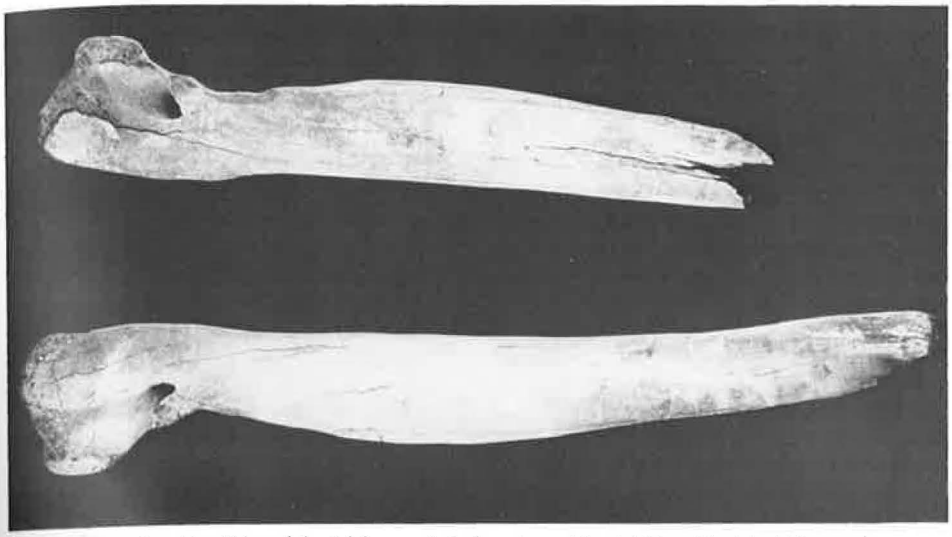

Fig. 3. *Mandibles of the Ichikawa whale (courtesy of the Ichikawa Municipal Museum).*

cm at the articulation, 21.5 cm at the lowest part just in front of articulation, and 29.7 cm at the top of the remaining part. Total length of this mandible is estimated to have been about 2.5 m and the body length of the whale approximately 12 m.

Ichikawa city is situated at the innermost part of the Tokyo Bay. The positive identification of this specimen is direct evidence that gray whales once occurred in the eastern coastal waters of Japan.

RECENT HISTORICAL EVIDENCE

In 1864 two gray whales were taken in the Seto Inland Sea, at Kawanoe, Ehime prefecture, the first on February 20 and the second on February 26. These whales were reported first by Shindo (1968) and then by Omura (1974). It is not necessary to describe them here in detail, but I wish to mention briefly their relationships to Aosagi and Share. Drawings of these whales are kept at the Kawanoe City Library (Figs. 4 and 5).

The first whale is smaller than the second and possibly would have been referred to as Share, although nothing was noted on the drawing (Fig. 4); the second whale (Fig. 5) was labeled as Aosagi. The body surface of the first whale was slightly infested with barnacles. The second whale bears heavy white markings of barnacle infestation, suggesting it was older than the first. A left scapula, possibly from the second whale, has been preserved at Hachiman shrine in the city, presented as Ema in memory of the whaling event (Fig. 6). The scapula of *Rhachianectes* (*Eschrichtius*) is distinctive in being intermediate between the wide, low scapula of *Balaenoptera* and the high, narrower, and more symmetrically fan-shaped scapula of *Eubalaena* (Andrews, 1914). Measurements of

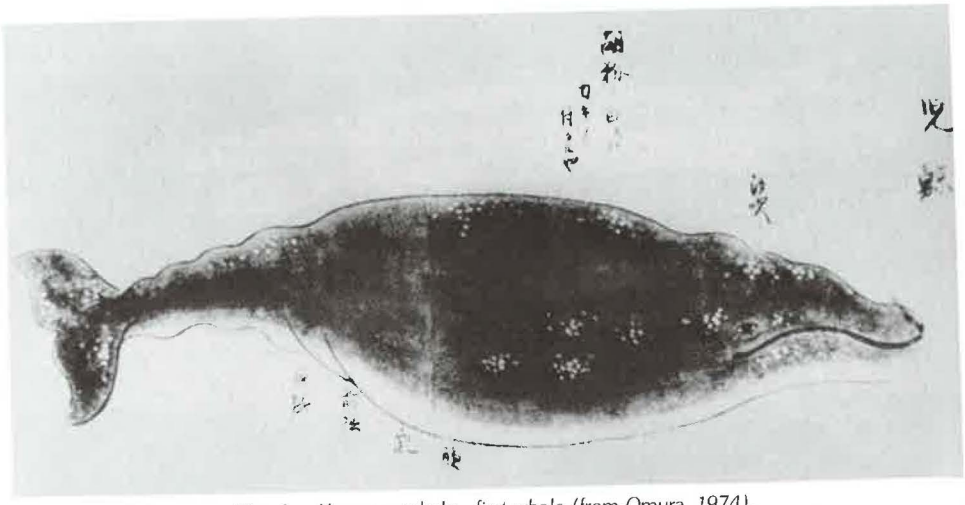

Fig. 4. *Kawanoe whale—first whale (from Omura, 1974).*

the at Hachiman shrine scapula were given by Omura (1974). Greatest breadth and greatest height are 99 and 74 cm, respectively, and the ratio of breadth to height is 1.34.

Omura (1974) thought the nearby waters of Iwaijima in the Seto Inland Sea was a calving ground of the gray whales, which occurred on the south coast of Japan. According to Saito (1977), Engelbert Kaempher, a German traveler and physician, sighted small whales in the waters near Mitajiri on April 30, 1691, while he was returning from a visit to the Shogun's capital of Edo (Tokyo). Mitajiri is close to Iwaijima and not far from Shimonoseki, the western entrance to the Inland Sea. Kaempher referred to these

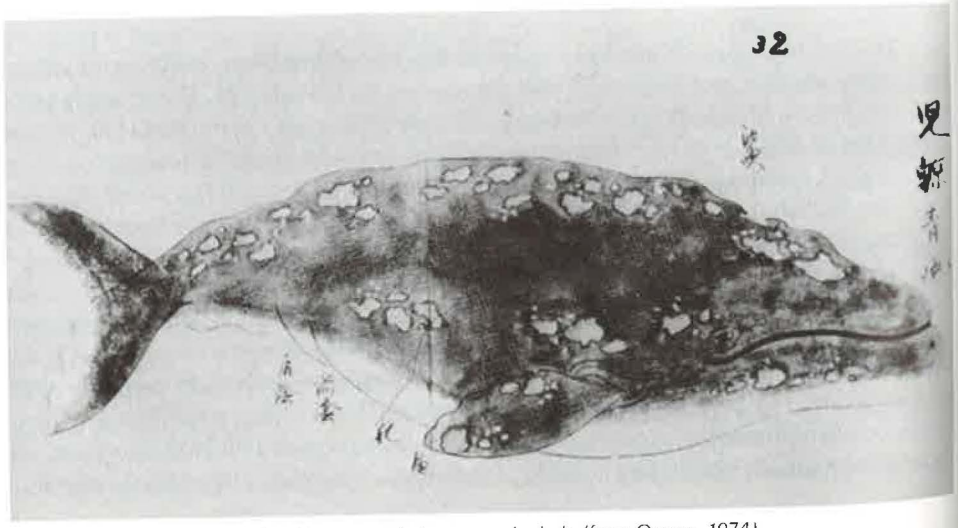

Fig. 5. *Kawanoe whale—second whale (from Omura, 1974).*



Fig. 6. *Left scapula of the Kawanoe whale (from Omura, 1974).*

whales as "Nordcaper," which means right whale, a species not reported from the Inland Sea; he further describes them as small whales. It is possible the whales he sighted were in fact gray whales. Gray whales and right whales have often been confused, even by gunners of modern whale catcher boats.

Nishiwaki and Kasuya (1970) report the accidental catch of a young female gray whale in 1968 at Shingu, Wakayama prefecture (the skeleton of this whale is maintained at Taiji Whale Museum). They also reported the sighting, by a skillful gunner of long experience, of a gray whale in nearby waters around 1959.

Catches of Gray Whales

Net whaling flourished nearly 200 years in the Edo era (1603–1867), during which time gray, right, humpback, and other species of whales were taken. The gray whales were usually taken without nets, because of their relatively smaller size (Taiji, 1937).

Practically no catch statistics exist for Wakayama and Mie prefectures. At Taiji, whaling continued after the Meiji Revolution (1868) until a tragedy occurred in 1878. In

that year more than 100 people were killed by a heavy storm while they pursued a right whale accompanied by a calf. This incident was practically the end of old whaling at Taiji.

There remain at Taiji some fragmentary records of the catch. For example, from December 24, 1799 to January 15, 1800, a total of 9 whales was taken, including 1 right, 6 humpback, and 2 gray whales. However, because most of the records were lost by fire or during several floods, it is not clear whether this was an exceptionally good season. This seems to have been a good catch, but further comparison of catch records is not possible.

Whaling on the coast of the Sea of Japan, at Ine, Kyoto prefecture, had been conducted since very ancient times, probably as early as Tenmon (1532–1554). The methods were somewhat different from those used in other places. The village of Ine is located on a small inlet, called Inewan, into which whales occasionally swam. When this happened the fishermen of Ine blocked the entrance of the inlet with nets and then caught the whale using hand harpoons and nets. Catch records of the Ine whaling operation during a period from 1656 to 1913 are available by species (Yoshihara, 1976b). During this time a total of 357 whales, including 167 humpback, 149 "fin" (including minke), and 41 right whales, was taken. No gray whales were taken, evidence that gray whales did not occur on the east side of the Sea of Japan at that time.

Whaling was conducted, however, in several villages on the north coast of Yamaguchi prefecture, including Kayoi in the east and Kawajiri in the west (Tokumi, 1957; Tada, 1978). At Kayoi, at present Nagato city, there is a temple named Koganji where notes are preserved which contain the Buddhist names of each whale taken and from which catches of species have been summarized (Kimura, 1956). Japanese people were given special names from a Buddhist priest when they died, and in this respect the whales were treated somewhat like human beings. The first volume of the Koganji notes is missing, but from remaining volumes catch figures are available for about 50 years, from 1802 to 1850. During this period a total of 308 whales, including 116 fin, 105 humpback, 59 right, and 28 gray whales, was taken. The average catch per year was 6.3 animals; gray whales comprised 9% of the catch.

For Kawajiri, catch statistics arranged by species and by 10-year increments are available from 1699, when whaling was started, until 1888 (Anonymous, 1890). Yearly figures for the 8 years from 1894 to 1901 were given by Tada (1978) (Table I). For a period of 50 years, from 1769 to 1818, only the total number of catches was reported, but catches by species can be compared for the periods 1699 to 1768 and 1819 to 1888. Catches of gray whales increased from 12% in the former period to 16% in the latter. Both figures are greater than proportions of gray whales in catches at Kayoi. Catches of right and humpback whales decreased as those of "fin" whales (again possibly including minke whales) increased, possibly due to decrease of the former two species. Tada (1978) states that no right whales were taken after 1884. Catch statistics at Kawajiri in the later years are given by Tada (1978) for a period from 1894 to 1901. The decline of gray whale catches and the increase of "fin" whale catches during this period are remarkable. Whaling at Kawajiri was virtually terminated in 1902.

In addition to Kayoi and Kawajiri, whaling was conducted at several villages including Mishima (Tada, 1968), a small island about 45 km northwest of Hagi city. Whaling in

these villages began around 1680 and lasted until near the end of the nineteenth century. Unfortunately, details of the catches are not available.

On the west coast of Kyushu, whaling was conducted at various places. Otsuki (1808), for example, listed 68 localities. This does not mean, however, that 68 whaling groups existed in Kyushu; rather, it represents the total number of places where whales,

Table IA
Catches of Whales at Kawajiri, Yamaguchi Prefecture: 1699–1888[a]

Years	Gray	Right	Humpback	Fin	Others[b]	Year total
1699–1708	11	29	94	2	7	143
1709–1718	17	17	103	14	9	160
1719–1728	21	29	103	3	9	165
1729–1738	12	31	92	3	2	140
1739–1748	21	26	93	—	—	140
1749–1758	13	20	48	—	—	81
1759–1768	15	14	58	—	1	88
Species totals	110	166	591	22	28	917
Average per year	1.6	2.4	8.4	0.3	0.4	13.1
Percentage	12.0	18.1	64.4	2.4	3.1	100
1769–1778						140
1779–1788						136
1789–1798						117
1799–1808						84
1809–1818						105
Species totals						582
Average per year						11.6
1819–1828	8	19	55	—	37	119
1829–1838	10	29	27	—	72	138
1839–1848	18	48	59	4	—	129
1849–1858	37	23	88	24	—	172
1859–1868	34	2	55	32	7	130
1869–1878	44	4	34	65	—	147
1879–1888	19	3	49	130	—	201
Species total	170	128	367	255	116	1036
Average per year	2.4	1.8	5.2	3.6	1.7	14.8
Percentage	16.4	12.4	35.4	24.6	11.2	100

[a]Anonymous (1890).
[b]Species were not noted.

Table IB
Catches of Whales at Kawajiri, Yamaguchi Prefecture: 1894–1901[a]

Year	Gray	Humpback	Fin	Others	Total
1894	0	3	10	1	14
1895	0	0	4	1	5
1896	4	1	7	1	13
1897	0	4	9	2	15
1898	1	4	10	1	16
1899	0	2	8	0	10
1900	2	1	4	1	8
1901	0	13	3	2	18
Species totals	7	28	55	9	99
Average per year	0.9	3.5	6.9	1.1	12.4
Percentage	7.0	28.3	55.6	9.1	100

[a]Tada (1978).

especially right whales, were taken. These numbers were reduced to only 3 a few years before the turn of the century, due to heavy reduction in numbers of right whales migrating there (Takahashi, 1899).

Whaling in Kyushu also started as a small enterprise using hand harpoons. After the invention of net whaling, this method spread over the west coast of Kyushu, and whaling flourished there more than in any other place (Anonymous, 1980). Whaling in Kyushu was operated by several groups, such as the Nakao group of Yobuko and Ogawajima (Saga prefecture), the Toi group of Iki Island (Nagasaki prefecture), and the Masutomi group of Hirado and Ikitsuki (Nagasaki prefecture). Among them the Masutomi group was the largest. From 1725, the year when the group was formed by Matazaemon Masutomi, to 1874, a total of 21,790 whales was taken (Yoshihara, 1977), a yearly average of 150 whales for all locations combined. The group operated at several locations in Kyushu, and sometimes at Mishima and Kayoi (both in Yamaguchi prefecture) as well. It was said this whaling group employed 3,000 people and about 200 fishing vessels when in operation.

Whaling at Ogawajima survived long after the introduction of modern whaling (Anonymous, 1980). A hut called Yamami, or lookout, was built on the top of a hill. When the watchmen sighted a whale he telephoned to a modern catcher waiting in the port of Yobuko. The catcher then pursued and killed the whale and returned it to the village, where it was processed by the villagers using traditional methods. This type of whaling lasted until 1948.

It is possible that gray whales were also taken in the waters west of Kyushu, but there are no catch statistics by species. Catch figures of whales at Iki Island in the 16 years from 1845 to 1860 are shown in Table II. Whaling from Iki Island was conducted by two whaling groups, Masutomi and Kuramitsu, operating at Katsumoto one season and

Table II
Catches of Whales at Iki, 1845–1860[a]

Year	Katsumoto	Maeme	Year totals
1845	60	78	138
1846	40	45	85
1847	42	32	74
1848	34	40	74
1849	14	11	25
1850	19	19	38
1851	22	19	41
1852	7	14	21
1853	12	4	16
1854	9	20	29
1855	10	14	24
1856	7	7	14
1857	19	Unknown	19
1858	Unknown	7	7
1859	Unknown	7	7
1860	4	7	11
Species totals	299+	324+	623+
Average per year	21.4	21.6	38.9+

[a]Anonymous (1890).

Maeme the next. The catches of whales at Iki decreased after 1849, probably because of the decrease of right whales.

In Tosa (present Kochi prefecture) whaling with hand harpoons dates from the years of Kanei (1624–1643) (Izukawa, 1943), and net whaling from 1683 when it was introduced from Taiji. Two groups of whalers, Ukitsu and Tsuro, operated on the coast of Tosa, splitting their activities between an east and a west whaling ground. There are two peninsulas in Kochi, the Muroto Peninsula in the east and the Ashizuri Peninsula in the west. The east whaling grounds were on the east side (in winter), and west side (in spring) of the Muroto Peninsula. The west ground was on the east side of the Ashizuri Peninsula in both winter and spring.

Each year the Ukitsu whaling group operated in one ground and the Tsuro whaling group on the other, and the two alternated grounds each year. Both groups left good catch records by year, from which general trends of the whaling in Kochi can be detected (Table III).

Table IIIA shows the total catches of whales by the Tsuro group in the years 1693–1712, inclusive. The average catch per year was 20.6 whales, but no species breakdown was available. For the 35 years from 1800 to 1835 (Table IIIB), the Ukitsu group took 959 whales, or 27.4 whales per year. Humpback whales comprise more than one-half of the total catch. In the years 1849 and thereafter (Tables IIIC, D, and E), right whales decreased considerably, while catches of Bryde's, blue, and fin or balaenopterid whales increased. Catches of gray whales appear to have been rather stable.

Table IIIA
Catches of Whales in Kochi Prefecture: Tsuro Group, 1693–1712[a]

Year	Catch	Year	Catch
1693	26	1704	11
1694	14	1705	32
1695	30	1706	16
1696	5	1707	26
1697	23	1708	26
1698	11	1709	26
1699	25	1710	21
1700	21	1711	22
1701	22	1712	22
1702	12		
1703	21		
		Total	412
		Average per year	20.6

[a]Anonymous (1931).

Table IIIB
Catches of Whales in Kochi Prefecture: Ukitsu Group, 1800–1835

Year	Gray	Right	Humpback	Bryde's	Others	Year total
1800	5	2	4	—	1	12
1801	0	1	5	—	2	8
1802	5	2	6	1	3	17
1803	1	4	17	—	—	22
1804	2	4	29	—	1	36
1805	0	11	17	—	—	28
1806	3	3	23	—	1	30
1807	2	5	15	—	—	22
1808	5	5	29	—	1	40
1809	4	11	11	—	—	26
1810	3	2	11	—	—	16
1811	1	7	20	—	—	28
1812	4	7	14	—	—	25
1813	6	5	10	—	—	21
1814	5	8	5	2	2	22
1815	6	3	41	—	—	50
1816	2	4	8	—	—	14
1817	4	5	13	—	—	22
1818	4	8	12	—	1	25
1819	4	3	10	—	6	23
1820	6	7	6	—	1	20
1821	4	5	9	—	5	23
1822	5	10	3	1	1	20

(continued)

Table IIIB (*Continued*)

Year	Gray	Right	Humpback	Bryde's	Others	Year total
1823	5	7	18	—	1	31
1824	3	8	20	—	—	31
1825	3	11	27	—	—	41
1826	1	16	8	—	—	25
1827	4	10	17	—	—	31
1828	2	5	12	—	—	19
1829	4	9	15	—	—	28
1830	7	9	25	—	2	43
1831	6	10	21	—	—	37
1832	7	12	16	1	—	36
1833	6	11	10	—	—	27
1834	7	15	4	—	2	28
1835	8	14	10	—	—	32
Species total	144	259	521	5	30	959
Average per year	4.0	7.2	14.5	0.1	0.8	26.6
Percentage	15.0	27.0	54.3	0.5	3.1	100

[b]Prepared from Yoshihara (1974).

Table IIIC
Catches of Whales in Kochi Prefecture: Tsuro Group, 1849–1865[c]

Year	Gray	Right	Humpback	Bryde's	Others	Year total
1849	4	—	10	3	—	17
1850	8	4	14	4	—	30
1851	6	1	25	—	—	32
1852	5	—	11	1	—	17
1853	5	1	22	—	—	28
1854	5	1	9	5	—	20
1855	8	2	10	2	—	22
1856	5	—	7	3	—	15
1857	2	—	14	1	—	17
1858	9	—	9	3	2	23
1859	6	1	8	1	1	17
1860	5	1	21	—	2	29
1861	9	1	3	1	1	15
1862	10	—	14	2	—	26
1863	6	3	7	5	—	21
1864	7	4	18	1	—	30
1865	1	—	7	3	—	11
Species total	101	19	209	35	6	370
Average per year	5.9	1.1	12.3	2.1	0.4	21.8
Percentage	27.3	5.1	56.5	9.5	1.6	100

[c]Prepared from Anonymous (1937).

Year total
12
8
17
22
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(*continued*)

Table IIID
Catches of Whales in Kochi Prefecture: Tsuro Group, 1874–1896[d]

Year	Gray	Right	Humpback	Bryde's	Others	Year total
1874	9	2	4	4	2	21
1875	5	—	5	2	—	12
1876	4	1	6	2	4	17
1877	5	3	6	—	2	16
1878	5	—	14	1	1	21
1879	7	—	5	2	—	14
1880	9	2	13	3	1	28
1881	4	2	—	1	3	10
1882	8	7	9	4	—	28
1883	3	—	1	3	3	10
1884	9	—	10	3	2	24
1885	2	1	2	1	1	7
1886	2	1	11	7	1	22
1887	3	1	5	2	5	16
1888	5	1	8	4	3	21
1889	1	—	2	—	3	6
1890	1	—	7	2	2	12
1891	2	2	3	4	3	14
1892	3	—	3	8	2	16
1893	2	—	—	1	4	7
1894	4	—	7	2	8	21
1895	4	—	4	3	4	15
1896	2	—	9	13	2	26
Species total	99	23	134	72	56	384
Average per year	4.3	1.0	5.8	3.1	2.4	16.7
Percentage	25.8	6.0	34.9	18.7	14.6	100

[d]Anonymous (1937).

Table IIIE
Catches of Whales in Koch: Prefecture: Ukitsu Group, 1875–1896[e]

Year	Gray	Right	Humpback	Bryde's	Others	Year total
1875	1	1	2	4	3	11
1876	2	—	6	5	4	17
1877	11	—	19	3	—	33
1878	1	6	4	4	3	18
1879	7	3	9	2	1	22
1880	6	1	2	8	6	23
1881	5	2	10	5	1	23
1882	3	—	4	2	3	12
1883	3	1	7	3	—	14
1884	1	2	1	2	6	12
1885	3	2	5	4	5	19

Table IIIE (*Continued*)

Year	Gray	Right	Humpback	Bryde's	Others	Year total
1886	1	—	6	3	10	20
1887	4	—	13	4	5	26
1888	1	—	6	4	4	15
1889	2	—	4	7	2	15
1890	1	—	—	4	3	8
1891	1	—	9	—	5	15
1892	1	1	1	3	2	8
1893	4	1	3	1	4	13
1894	1	1	3	4	1	10
1895	3	—	6	5	3	17
1896	2	—	6	4	7	19
Species total	64	21	126	81	78	370
Average per year	2.9	1.0	5.7	3.7	3.5	16.8
Percentage	17.3	5.7	34.0	21.9	21.1	100

[e]Shibusawa (1939).

Discussion and Conclusions

Except for a few stragglers, gray whales do not occur in the coastal waters of Japan at present. Prior to the turn of the century, however, they were found in two regions, one on the Pacific side of Japan, from Tokyo Bay to Kochi prefecture, and the other on the west side of Japan off Kyushu, including the north coast of Yamaguchi prefecture. This conclusion is supported by subfossil mandibles excavated from Ichikawa city, old books on whales and whaling, and catch statistics of old whaling operations in the Edo era (1603–1867). The whales in these two regions may represent different populations of gray whales. The latter (the Kyushu group) is clearly a portion of the Korean stock. Distribution of the two populations in the waters off Japan and Korea is shown in Fig. 7. The two populations may have intermingled in the Seto Inland Sea. If so, then both populations belong to the Korean stock.

In summer, the Korean stock of gray whales occupies, or at least formerly occupied, the northern Okhotsk Sea (Rice and Wolman, 1971). It is not clear whether or not the gray whale population occurring off the south coast of Japan also spends the summer in Okhotsk Sea mingling with the Korean stock. Bowen (1974) states that the young female gray whale accidentally taken in 1968 at Shingu (Nishiwaki and Kasuya, 1970) resembled members of the California stock in morphological features and should be regarded as a stray from the Bering Sea. There still exists the possibility, however, that the two populations occurring in the coastal waters of Japan intermingle with each other in the Seto Inland Sea.

The annual catch of gray whales in Kochi prefecture in the days of net whaling was rather small (Table III). The largest catch was 11 in 1877 by the Ukitsu group; the yearly

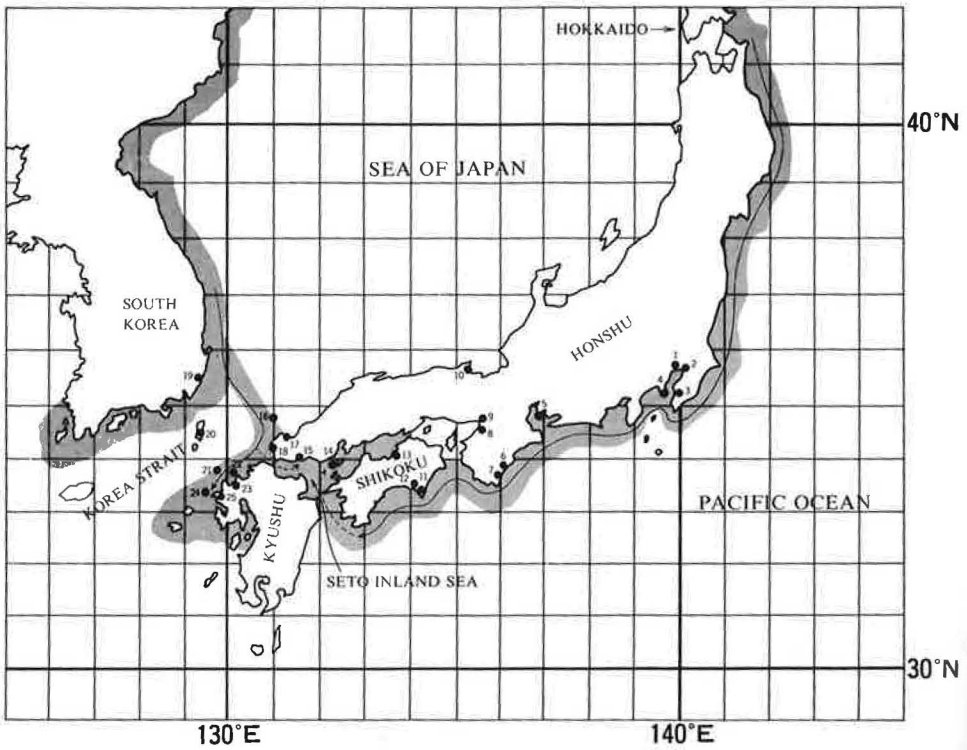
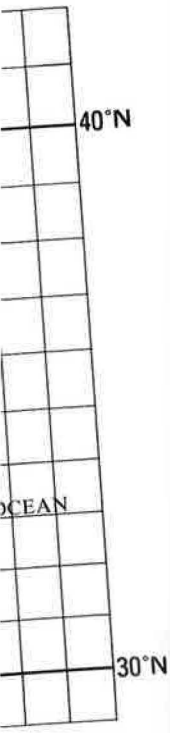


Fig. 7. *Map showing the distribution of gray whales in the coastal waters of Japan and Korea. Place names appearing in the text are indicated by numerals as follows: (1) Tokyo, (2) Ichikawa, (3) Katsuyama, (4) Misaki, (5) Morosaki, (6) Taiji, (7) Koza, (8) Sakai, (9) Osaka, (10) Ine, (11) Tsuro, (12) Ukitsu, (13) Kawanoe, (14) Iwaijima, (15) Mitajiri, (16) Mishima, (17) Kayoi, (18) Kawajiri, (19) Ulsan, (20) Tsushima, (21) Iki, (22) Ogawajima, (23) Yobuko, (24) Ikitsuki, (25) Hirado. Solid arrow, migration routes and area of distribution of Gray whales; broken arrow, movements uncertain.*

average was 2.9–5.9, and there were no remarkable differences between the two whaling groups or among different years. The total yearly catch of gray whales by the two groups in Kochi prefecture is estimated to have been around 10 whales. This suggests gray whales occupied a less important position than right and humpback whales.

Catch figures of gray whales in Wakayama and Mie prefectures are not known. Presumably gray whales were taken in numbers such as in the Kochi prefecture. If one assumes that equal numbers were taken in each of these prefectures, then the total catch of gray whales from the population would have been 30 per year. The catch of gray whales from this population appears to have been rather stable (Table III), suggesting that the catch rate from this population was not high.

The catch of gray whales at Kawajiri, Yamaguchi prefecture during the period of 1699–1768 totaled 110 whales, or an average of 1.6 whales per year (Table I). In the third



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period, 1819–1888, the corresponding figures are 170 total and 2.4 whales per year, indicating an average increase in take of 0.8 whales per year. These catches are very low compared with the corresponding figures in Kochi prefecture. For the period 1894–1901, the average catch per year was 0.9, less than in previous years. Kimura (1956) also shows a reduction in gray whale catch at Kayoi after 1831.

It is not known how many gray whales were caught on the west coast of Kyushu. It is assumed, however, these catches were far more dependent on availability of right, humpback, and fin whales, as in Kawajiri and Kayoi, and that gray whales were caught only secondarily to the whaling there. It is assumed as many as 20–30 gray whales were taken per year but the catch of gray whales decreased towards the end of net whaling around 1900 and these stocks were finally extirpated.

This reduction does not necessarily mean a reduction of the Korean stock. Mizue (1951) reports heavy catches of gray whales at Ulsan, Korea after 1910. Therefore, the decrease of gray whales migrating to the coast of Yamaguchi and to the west coast of Kyushu may have resulted in a change in migration route.

Modern-type whaling in Japan commenced in 1898, when the first catcher Hokamaru, built of wood, caught three whales (Akashi, 1910). After that year, whaling operated first on the east coast of Korea, the west coast of Kyushu, and the south coast of Japan, and then shifted to the northeast coasts of Japan and Hokkaido. As pointed out by Mizue (1951), only a few gray whales were taken during modern whaling, except in Korea and Tsushima. Omura (1974) speculated the gray whale population on the Pacific side of Japan was driven from its calving ground in the Seto Inland Sea sometime prior to this century by the increase in boat traffic and industrial development on the coast. It now appears this matter is more complicated and that additional material is needed to support firm conclusions.

Summary

Prior to the turn of the century, two populations of gray whales migrated to the coastal waters of Japan, one to the southern coast of Hokkaido and Honshu and the other to the west coast of Kyushu via the north coast of Yamaguchi prefecture. The former migrated along the east coast of Japan from the north and entered the Seto Inland Sea, the supposed calving ground for this population. The latter, considered to be a portion of the Korean stock, migrated along the east coast of Korea and then to southwest Honshu and northwest Kyushu. Intermingling of the two populations in the Seto Inland Sea cannot be denied.

The annual catch of gray whales in the days of net whaling (1675–1890) was approximately 30 whales from the former population and 20–30 from the latter. Virtually no gray whales, however, have been observed in the waters around Japan since about 1898 when modern-type whaling was introduced.

The southern coast population was probably driven from the Inland Sea sometime

prior to this century due to increased industrial development and boat traffic on the coast. The matter is complicated, however, and additional material is needed before final conclusions can be drawn.

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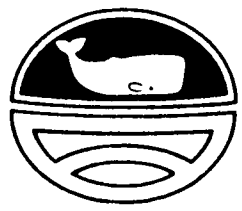

International Whaling Commission

Gillnets and Cetaceans

INCORPORATING THE PROCEEDINGS OF THE SYMPOSIUM AND WORKSHOP ON THE MORTALITY OF CETACEANS IN PASSIVE FISHING NETS AND TRAPS

EDITED BY

William F. Perrin
Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
PO Box 271, La Jolla, California 92038, USA

Gregory P. Donovan
International Whaling Commission
The Red House, Station Road, Histon
Cambridge CB4 4NP, UK

and

Jay Barlow
Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
PO Box 271, La Jolla, California 92038, USA

Series Editor
Gregory P. Donovan

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Preface

This volume represents the culmination of over four years work, beginning with the organisation of a Symposium and Workshop held in La Jolla in 1990. It includes the report of that Workshop, the IWC Scientific Committee's report on stocks of small cetaceans that are subjected to 'significant' directed and incidental takes submitted to the 1992 UNCED and over 50 papers either presented to the Workshop, subsequent IWC Scientific Committee meetings or requested to address important relevant issues not covered by the presented papers. The papers herein represent the most complete and current account of a problem that probably represents the most serious threat to cetaceans today. Unfortunately, despite some progress in documenting the problems, we are still a long way from arriving at solutions for many regions and fisheries around the world. I hope that publication of this book stimulates Governments to address the issues highlighted here in a prompt and determined manner. This will involve: encouraging research in the wide range of disciplines necessary, including cetacean biology, fish biology, population dynamics, management science, and fishing gear technology; and, not least, the participation of fishermen in the process.

G.P. DONOVAN
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Cover photograph
Gray whale (*Eschrichtius robustus*) entangled in gillnet, California.
Courtesy of Steve Leatherwood.

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Introduction

The International Whaling Commission's Scientific Committee first recognised the potential threat to cetacean populations posed by incidental kills in fisheries in 1972, when it

> 'discussed and expressed concern over the large incidental kill of porpoises and dolphins in the US tuna fishery, reported to be about 250,000 per year' (IWC, 1973, p.37).

In that same year, the Committee recommended that a sub-committee on small cetaceans be established, to improve data collection on world catches and to review species and stock identification and other problems; much of the subsequent review and scientific discussion in the Committee of incidental fishery kills and their impact has taken place in this sub-committee. The founding chairman of the sub-committee was Edward Mitchell, who deserves great credit for bringing the related issues of small cetaceans and incidental kills (of cetaceans both large and small) to the fore in the Committee and the Commission.

In 1972 the Committee also recommended that member nations

> 'engaged in killing small cetaceans provide information on their controls on these operations and also include information on catch and incidental kills in future progress reports' (IWC, 1973, p.42).

The Commission formally implemented this recommendation in 1976 (IWC, 1977, p.26) and information on incidental kills and associated research began to appear in national progress reports that year (e.g. Anonymous, 1977).

The sub-committee on small cetaceans met for the first time in Montreal in 1974 and conducted a comprehensive review across species, regions, fisheries and problems (Mitchell, 1975). It emerged that cetaceans of many species were being killed incidentally in gillnets, including Dall's porpoises, pilot whales and Baird's beaked whales, all also taken in commercial directed fisheries. The major net fisheries involved were the salmon driftnet fisheries of the North Pacific and North Atlantic, shark gillnet fisheries in several regions and coastal gillnet fisheries in South America. Thousands of Dall's porpoises were being killed in the Japanese salmon driftnet fishery alone (Ohsumi, 1975). The sub-committee recommended that further statistics on these and other kills be collected.

The FAO ACMRR Working Party on Marine Mammals conducted a large international consultation in Bergen, Norway in 1976 (Anonymous, 1978). In their conclusions, they stressed the potential importance of incidental kills and the need to document the distribution of gillnet fisheries relative to that of cetaceans, the extent of the mortality and the impact of this mortality on cetacean populations. They suggested that research on behaviour, particularly with respect to feeding and echolocation, be undertaken with the goal of modifying fishing gear or practices to reduce entanglements.

The conference that formed the basis for the present volume had its beginnings in 1984, when the sub-committee on small cetaceans proposed that an expanded session of the sub-committee should be convened in 1985 to review new and expanding gillnet fisheries that have or may have an impact on small cetacean poulations, with invitations to be extended to outside experts on gillnet fisheries and gillnet fishing gear (IWC, 1985, p.137). Because of budgetary limitations, the review did not occur in 1985, but a workshop separate from the annual IWC meeting and expanded to include the large whales (specifically gray, humpback and right whales) was proposed by the Committee for late 1986 (IWC, 1986, p.37). The Committee stressed that the meeting's scope should be limited to scientific and technical matters related to cetacean entanglement in gillnets. The participation of a behaviourist, a sensory physiologist, a fisheries development officer and a gear expert were to be encouraged. Funds for the meeting were to be sought outside the Commission. Funds were not found and the meeting did not materialise in 1986.

The meeting was subsequently included in the 1988–1992 action plan of the IUCN Cetacean Specialist Group (Perrin, 1988) and an offer to host the meeting was extended to the Commission by the Southwest Fisheries Science Center in La Jolla, California (IWC, 1988, p.123). The invitation was accepted, and in 1988 a Steering Group was established consisting of W.F. Perrin (convener), R.L. Brownell Jr., L. Jones, D.P. DeMaster, J.S. Leatherwood and J. Barlow (IWC, 1989, p.62). The scope of the meeting was extended to include a symposium of contributed papers and consideration of incidental kill in traps and other passive fishing gear, and terms of reference were drawn up (Perrin and Brownell, 1989). The Commission approved the terms of reference but again postponed the meeting because of budgetary constraints. Meanwhile, additional reports of kills in gillnet, driftnet and trap fisheries surfaced: sperm whales, humpbacks, minke whales, gray whales, right whales and many species of small cetaceans in fisheries in the Mediterranean, at the Azores, off California, in the Baltic, in the Northwest Atlantic, off the Pacific coasts of Canada and Alaska, in Japanese waters and in other regions (Perrin, 1990).

In 1989, partial funding was offered by World Wildlife Fund – Sweden. Promises of support soon followed from the United Nations Environmental Programme, the New Zealand Department of Conservation, the US Marine Mammal Commission, the Australian Fisheries Service, the US National Oceanic and Atmospheric Administration, the Southwest Fisheries Science Center and World Wildlife Fund – USA; and the Conference was

set for October 1990 in La Jolla. The support provided by these agencies and NGOs was also sufficient to pay over half of the publication costs of this volume.

The Report of the Workshop was presented to the Scientific Committee and the Commission in 1991. It then became publicly available and was circulated to relevant member and non-member nations of the IWC. Partly in response to the need for the meeting and its subsequent report, the Commission passed two Resolutions requesting the Scientific Committee to draw together available information on the status of those stocks of small cetaceans that are subjected to 'significant' directed and incidental takes (IWC, 1991) and to forward that information to the 1992 United Nations Conference on Environment and Development (IWC, 1992).

We have decided to include both the Report of the Workshop and the Report to UNCED in this volume because the latter places the threat posed by incidental mortality in passive fishing gear into the context of overall threats to small cetaceans throughout the world.

The production of this extensive volume has been a major task. For a number of reasons, including communication with authors and reviewers from every continent (except Antarctica) and a full publication schedule for IWC volumes, production has taken longer than we originally anticipated. For this reason we have taken the opportunity to:

(1) encourage authors to update their papers to include data and information from after the 1991 IWC meeting when the report first became publicly available;
(2) include papers that originated in part in response to recommendations made in the Report of the Workshop.

Although this resulted in a slight additional delay to the volume, we believe that this has been worthwhile in that the included papers now represent the most complete and current account of the worldwide situation of a problem that probably represents the most serious threat to cetaceans today – some of the papers include data collected as recently as October 1994.

The contributed papers published in this volume each received at least two anonymous peer reviews. Some of the symposium and workshop papers are not included here because they were not submitted for publication (for various reasons, such as publication elsewhere) or did not pass peer review. Abstracts are included for those papers not published.

Many people made the conference and this volume possible. In particular we would like to thank those scientists who gave up their time to review papers in the volume, including: A. Aguilar, D. Ainley, W. Au, D. Aurioles-Gamboa, F. Awbrey, R. Baird, N. Bartoo, H. Benke, P. Berggren, P. Boveng, R.L. Brownell, Jr., J. Calambokidis, M. Cawthorn, I. Christensen, P. Clapham, V. Cockcroft, J.M. Coe, A. Collet, E.A. Crespo, S. Dawson, A. Di Natale, T. Gerrodette, D. Goodson, P. Hammond, D. Hanan, M-P. Heide Jørgensen, J.E. Heyning, A.A. Hohn, T. Jefferson, L. Jones, T. Kasuya, P. Kleiber, S. Kraus, F. Larsen, J.S. Leatherwood, C. Lockyer, J. Maigret, A. Martin, M.K. Marx, N. Miyazaki, K.S. Norris, G. Notarbartolo-di-Sciara, M. Pawson, M.C. Pinedo, T. Polacheck, L. Popov, R. Praderi, J. Prado, A. Read, R.R. Reeves, G.J.B. Ross, C. Smeenk, T.D. Smith, B. Taylor, A.M. Teixeira, P. Tyack, O. Vidal, G. Waring, W. Watkins, H. Whitehead, B. Würsig and K. Wynne. S. Smith and C. Blair assisted with the initial editing of some of the papers at the Southwest Fisheries Science Center. Special thanks must go to: Helen Coulson who keeps track of the manuscripts and who prepares and types in many of the revised manuscripts; Stella Duff for proof reading; Julie Creek who typesets all the tables; Helen Richardson who prepares the artwork and helps with the proof reading; and the staff of Black Bear Press. Those who helped find and shepherd funds for the meeting included J.R. Twiss, G. Anderson, R. Gambell, A.T. Brough, S.J. Holt, M. Harvey, M. Sutton, M.F. Donoghue, I. Barrett, and T. Arnbom. D.P. DeMaster, J. Sisson, J. Kashiwada, J. Ortiz, B. Remington and C. Ratcliffe assisted with the organisation and logistics of the meeting. We thank all of these people and anyone we may have inadvertently missed.

The papers in this volume reveal that some progress has been made towards addressing some of the recommendations coming out of the Conference. We hope that publication here will stimulate scientists, managers and Governments to greater efforts to further address and resolve this most important issue.

W.F. Perrin, G.P. Donovan and *J. Barlow*
Cambridge, 16 November 1994

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Report of the Workshop on Mortality of Cetaceans in Passive Fishing Nets and Traps

The Workshop was held in La Jolla, California, USA from 22 to 25 October 1990. Plenary sessions were held in the La Jolla Village Inn and sub-groups met at the Southwest Fisheries Science Center. A list of participants is given in Annex A. Perrin convened and chaired the Workshop.

1. WELCOME AND INTRODUCTION

Gambell outlined the background to the Workshop and stressed the importance of its findings, which would not only provide advice to member governments of the IWC but would also form a major part of the IWC's contribution to UN deliberations on the impacts of driftnetting (IWC, 1991a).

2. TERMS OF REFERENCE AND ADOPTION OF AGENDA

The Scientific Committee adopted terms of reference for the Workshop at its annual meeting in 1988 (Perrin and Brownell, 1989). It was stressed by the Committee that the meeting's scope should be limited to scientific and other technical matters related to cetacean entanglement in gillnets and other static fishing gear. The main charges were:

(1) to identify and describe new and expanding net and trap fisheries which take cetaceans;
(2) to investigate how and why entanglement occurs;
(3) to the extent possible, to estimate mortality and assess its impact on cetacean populations; and
(4) to consider possible ways of reducing levels of net-caused mortality.

The resultant report was to include:

(1) a list and summary descriptions of gillnet and trap fisheries that take or potentially could take cetaceans, with lists of the species involved;
(2) a species-by-species summary, listing cetacean takes by population and fishery and assessing the impacts of the takes;
(3) an analysis of the causes of entanglement and assessment of technology and alternatives for reducing the incidental takes; and
(4) recommendations for (a) documentation of takes, (b) research to develop methods for reducing takes and (c) management actions.

Invited and selected unsolicited papers were presented at a two-day open symposium immediately preceding the Workshop. Abstracts of the symposium papers are available from the Secretariat. Working papers for the Workshop are listed in Annex B.

The Agenda adopted is given as Annex C.

3. ARRANGEMENTS FOR THE MEETING

Donovan served as rapporteur for the plenary sessions.

The Workshop agreed to form three sub-groups (see Annex A) assigned the tasks of: conducting a global review of fisheries; assessing impacts; and reviewing causes and solutions. The Workshop agreed to reconvene in a plenary session on the last day, to review the reports of the sub-groups and reach agreement on conclusions and recommendations. It was agreed that the sub-group reports would form the body of the Workshop report. The sub-groups met at the Southwest Fisheries Science Center the afternoon of 22 October and all day on 23 and 24 October. Compilation of the final report was co-ordinated by Donovan and Perrin and agreed by the participants by post.

The report was submitted to the full Scientific Committee at its 1991 Annual Meeting. The Committee approved the Report and its Recommendations (IWC, 1992, p.53) after which the Report became publicly available and was circulated to relevant Governments and organisations. As this is an agreed report it has been left unaltered. Developments since its adoption by the IWC in 1991 are discussed by Donovan (this volume, pp.609–614) and in many of the published papers.

4. GLOBAL REVIEW OF GILLNET AND TRAP FISHERIES

Perrin chaired the sub-group conducting a global review of passive net and trap fisheries which take marine mammals. Barlow, Northridge and Read served as rapporteurs, and Sisson assisted with preparation of this section of the workshop report.

In addition to the terms of reference given above to identify and describe new and expanding net and trap fisheries which take marine mammals, the sub-group further agreed to provide quantitative estimates of cetacean and other marine mammal mortality where available. In the discussions of the sub-group, the world's oceans were divided into 21 coastal regions and 5 major ocean basins. The discussions and conclusions are summarised below. The sub-group agreed on the most important items to include in the summaries.

Most of the information is taken from the regional review documents, although some is from responses to a questionnaire circulated by Lien to national fishery agencies before the meeting or from other personal communications to members of the group. Where necessary, additional information from the literature and from unpublished sources was added during the editing of the report, but time did not allow an exhaustive review of the very large 'grey' fishery literature. Unless otherwise

noted, fish landings are in metric tonnes and their values are based on the price paid to fishermen, converted to US dollars. Effort is expressed as kilometres of net per day (KND). Common names are used throughout the Report. Latin names are given in Annex G.

4.1 Mediterranean region

The Mediterranean and Black Seas are bordered by 28 countries: Albania, Algeria, Bulgaria, Cyprus, Egypt, France (Mediterranean coast and Corsica), Gibraltar, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Morocco, Rumania, Spain, Syria, Tunisia, Turkey, the former USSR (now Russian Federation, Ukraine and Georgia) and the former Yugoslavia (now Slovenia, Croatia, Serbia, Bosnia Herzegovina and Montenegro). Available fishery information varies considerably among these. Passive net fisheries in this region are of four basic types: a trap net fishery for tuna in shallow coastal waters; a drift gillnet fishery for small pelagic fish; a pelagic driftnet fishery for swordfish and tuna; and a coastal set net fishery. Significant marine mammal mortality is primarily limited to the pelagic driftnet fishery. Summaries of these four fisheries are given below. Additional information on Black Sea fisheries may be available in older FAO reports not consulted at the meeting. Detailed information on the Mediterranean is given by di Natale and Notarbartolo-di-Sciara (SC/O90/G34).

4.1.1 Trap net fishery for tuna

Trap nets for bluefin tuna are found in coastal waters in several localised areas of the Mediterranean. These anchored nets are made of natural or artificial fibres. The effort is not well quantified, but there are believed to be more than 10 traps and less than 1,000 participating fishermen. The fishery is believed to be stable in size. Fishing occurs approximately 60 days per year. Catches are greater than 1,000 tonnes for bluefin tuna and greater than 50 tonnes for swordfish; the value of these catches is approximately $4m and $0.7m, respectively. Ranges of annual cetacean catches are 0–1 minke whales, 0–1 killer whales, 0–5 bottlenose dolphins and 0–1 common dolphins.

4.1.2 Drift gillnet fishery for small pelagic fish

This fishery is found in coastal waters around the Mediterranean basin. Target species include bullet tuna, little tuna, skipjack tuna, Atlantic bonito, chub mackerel and Atlantic mackerel. Typically nets are multifilament nylon or monofilament with mesh sizes of 4–9cm and lengths of 0.2–1.5km. Vessels range from 4–14m. There are about 100–1,000 vessels and 250–3,000 fishermen operating in this fishery. The fishing season is not known, but is likely to range from 10–100 days per year. Based on this, estimates of 100–1,000 nets and a mean net length of 850m, total effort is likely to be between 850–85,000KND per year. Ranges of annual cetacean catches are 1–10 Risso's dolphins, 10–50 bottlenose dolphins, 0–2 common dolphins and 0–5 striped dolphins.

4.1.3 Drift gillnet fishery for swordfish and albacore

Vessels are from Italy, Spain, Morocco, France, Greece, Turkey, Malta and Algeria. Some countries fish in localised areas and others cover the entire Mediterranean. Multifilament nylon nets for swordfish have 36–52cm mesh and are 2–40km length, with a typical length of 12–15km. Similar nets are used for albacore, with a mesh size of 16–20cm and a total length of 9–15km. Vessels are approximately 7–26m long. The number of vessels rapidly increased to over 1,020 by July 1990. After an offshore drift gillnetting ban by Italy, this number dropped to 120 vessels in August 1990. Approximately 4,000 people fished prior to the ban and approximately 300 after the ban. Based on a mean net length of 12.6km, 1,020 vessels and a fishing season of 57 days, the total effort would have been approximately 750,000KND prior to the Italian ban. The most recent annual landings were about 9,000 tonnes for swordfish and 1,500 tonnes for albacore and were worth $130m and $8m, respectively. Prior to the Italian ban, annual catches of cetaceans were 0–1 fin, 0–1 minke, sperm 20–30, Cuvier's beaked <10 and long-finned pilot whales 50–150, and Risso's 30–80, bottlenose 50–200, striped 5,000–10,000, common 1–30 and rough-toothed dolphins 0–10. These estimates were based on specimens stranded on Italian beaches showing evidence of net entanglement. Di Natale reported that R. Ktari-Chakroun obtained observations of four of a group of 10 minke whales off North Africa entangled in driftnets.

4.1.4 Coastal set gillnet fisheries

This fishery is found all around the Mediterranean over coastal shelf regions. Target species include benthic fish, lobsters and small pelagic schooling fish. Vessels are small, typically 4–16m in length. There are approximately 50,000–100,000 such vessels fishing in the Mediterranean and approximately twice that number of fishermen. There are no data on fishing effort or the economic value of the fishery. It is thought that the fishery may be increasing moderately. Likely annual ranges of marine mammal mortality are 0–2 minke whales, 0–1 sperm whales, 1–10 Risso's dolphins, 0–5 common dolphins, 50–200 bottlenose dolphins, 1–20 striped dolphins, 0–1 rough-toothed dolphins and 0–5 Mediterranean monk seals.

4.1.5 Recommendations

(1) It is **recommended** that actions similar to the ban instituted by Italy are encouraged elsewhere. International co-operation and action by the General Council for Mediterranean Fisheries (CGPM) are required to ensure that large scale driftnet fisheries do not restart from other nations, or that reflagging for the purpose of continuing the fishery does not occur.
(2) There is little information on set gillnet and small pelagic driftnet fisheries in the Mediterranean. It is therefore **recommended** that further efforts be made to investigate the nature and extent of these fisheries and their impacts on marine mammals of the region.
(3) The action of Italy in banning driftnets has had an immediate impact on several thousand fishermen. It is **recommended** that wherever possible the consequences of such actions are studied, the economic impacts on the fishing community are appraised and the subsequent development of alternative fishing methods are monitored.
(4) It is **recommended** that information on gillnet and trap fisheries be collected for the Black Sea, including information on incidental catches of small cetaceans.

4.2 Baltic region

This region is taken to include what are commonly referred to as the Baltic and Kattegat Seas. Coastal states include Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden and the Russian Federation. In this region, cetaceans are commonly found only in the Kattegat and the only common species is the harbour porpoise.

Cetacean mortality presently occurs mostly in bottom set net fisheries and pound-net fisheries. Both are described below, along with a pelagic driftnet fishery in the central Baltic. Burkanov reported that information also exists on fisheries and their bycatch of seals in Latvia, Lithuania, Estonia and the western USSR. Detailed information is given by Kinze (SC/O90/G25). Estimates of total cetacean mortality do not exist.

4.2.1 Coastal set gillnet fishery

Vessels from Denmark, Sweden and Germany participate in a bottom set net fishery for cod and (secondarily) plaice. Vessels are typically 5–20m long. Gillnets are typically 6–17cm in mesh size and are set in water depths of less than 40m; mean net lengths were not available at the meeting. The number of vessels fishing by this method is 750 for Denmark and 565 for Germany; the number for Sweden is not known. The amount of fishing effort for Denmark is stable or decreasing slightly. Harbour porpoise mortality is largely limited to the Kattegat Sea and is probably less than 500 animals per year. Harbour seal mortality is limited to the Kattegat and the southern Baltic; no estimates of seal mortality are available.

4.2.2 Pound-net fishery for eels

A small-scale pound-net fishery for eels is found along the eastern coast of Denmark. These nets are in shallow waters of less than 15m depth. Little information is available on the level of effort in this fishery, but effort is believed to have been decreasing in recent years. Harbour porpoises are occasionally captured in these traps, but are usually released alive.

4.2.3 Pelagic driftnet fisheries

Pelagic drift gillnets are used in the central Baltic by fishermen from Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden and the Russian Federation. No details about this fishery were presented at the meeting. Nets are likely to take harbour, ringed and gray seals. Harbour porpoise mortality is likely to be uncommon because the species is very rare in the area of the fishery. This fishery mortality may, however, be sufficient to affect harbour porpoise recovery in the Baltic.

4.2.4 Recommendations

(1) It is **recommended** that captures of marine mammals in Baltic fisheries be monitored at an international level, as it is likely that a single harbour porpoise population is being impacted by the fisheries of several nations in this area.

(2) In this connection it is **recommended** that further research be carried out to improve understanding of harbour porpoise stock identities in the Baltic and North Seas.

4.3 Eastern North Atlantic region

Thirteen coastal states are included in the eastern North Atlantic region, including Belgium, Denmark (west coast), the Faroe Islands, France (north coast), Germany (North Sea coast), Iceland, Ireland, Netherlands, Norway, Portugal, Spain (Atlantic coast), United Kingdom and the Russian Federation (western Arctic). There is a long tradition of fishing in this entire area and much large- and small-scale fishing occurs there. In Norwegian coastal waters, set gillnets are used for migrating cod and drift gillnets for salmon. Although gillnets are used in Iceland, no information was available during the meeting. Detailed information is given by Northridge (SC/O90/G35) and Sequeira *et al.* (SC/O90/G47).

4.3.1 Portuguese gillnet fisheries

Around 3,300 Portuguese vessels are licensed to use gillnets for hake, other gadoids and demersal species along the Portuguese continental shelf. The mean length of nets and type of netting material varies considerably among vessels. Incidental catches of some tens of cetaceans, mainly common dolphins, harbour porpoises, striped dolphins and possibly bottlenose dolphins, are recorded.

4.3.2 Portuguese trap fisheries

Over 1,300 vessels are licensed to fish for octopus, crustaceans and some fish with basket traps and pots. There are no data on the numbers of fishermen involved, nor on the value of the catch or total landings. There are records of three minke whales having drowned in such fisheries.

4.3.3 Coastal set net fisheries in other western European countries

Set nets are used throughout European waters by a large proportion of inshore boats. Statistics on the activities and dimensions of this fleet are largely unavailable. There are over 5,500 fishing vessels of less than 16m registered in French Atlantic ports. There are more than 5,000 vessels working in British coastal waters, more than 3,000 in Norwegian waters and around 750 working in Danish North Sea coastal waters. Numbers in Spain, Iceland, Ireland, Belgium, the Netherlands and Germany are not available. The total number of coastal vessels (<20m) in western European waters is likely to be between 15–20,000 and perhaps more. An unknown but significant proportion of these are using gillnets for at least part of the year. Mesh sizes vary depending on the target species and net lengths are highly variable, from a few tens of metres for some small boats to several tens of kilometres. In some areas, notably the North Sea and English Channel, there are large amounts of netting set by fleets of vessels more or less dedicated to net fishing. In the southwest of England some of these vessels may set nets of 80km or more and increasingly large vessels have been used in recent years.

In Norway, coastal set net fisheries regularly take harp seals. Around 10,000 were caught annually for the period 1978–1981, but by the winter of 1987/88 this had reached 60,000. Harbour porpoises are taken in set gillnets throughout their range, but apparently most frequently in the North Sea. Common dolphins are also taken, notably in the English Channel. These fisheries are complex and few reliable statistics are available on effort.

4.3.4 Irish salmon driftnet fisheries

More than 700 salmon licenses were issued in Ireland in 1988, but the actual number of vessels using driftnets for salmon is unknown, as there is also a large illegal driftnet fishery. Cetaceans reported taken include common dolphins and harbour porpoises. No further details were available at the meeting.

4.3.5 Norwegian salmon driftnet fishery

In 1988 there were 582 vessels (5–12m) licensed to fish for salmon in Norwegian coastal waters. The total fishing period was about 12 weeks in 1988. During this period, 96 harbour porpoises were recorded caught in salmon nets. The fishery is now banned.

4.3.6 Spanish driftnet fishery
Approximately 40 vessels from Spain have fished for tuna and billfish in the area around the Straits of Gibraltar since 1988, under a Moroccan/EEC fishing agreement. Most of these fish in the Atlantic area, although an unknown number occasionally also fish in Mediterranean waters (Aguilar, 1990). Information on bycatches was not available to the meeting.

4.3.7 Other driftnet fisheries in northwest Europe
Small driftnet fisheries exist in a number of other locations, but information was not available to the meeting. These include driftnet fisheries for salmon and for bass in the UK, for herring in England and Wales and for mackerel in southern Norway.

4.3.8 Recommendations
(1) There is little information on the nature and extent of numerous coastal gillnet fisheries in this area. It is **recommended** that the collection of statistics on gillnet fisheries should be improved in all countries of the region and that the European Community and the International Council for the Exploration of the Sea (ICES) also give increased attention to the collection of statistics on gillnet fishing activities.
(2) There are inadequate data to assess the impact of incidental catches of cetaceans in this area. It is **recommended** that the collection of data be improved and co-ordinated. Countries that do not yet have adequate systems for recording incidental catches are urged to implement them. Again, ICES and the European Community should play important roles in facilitating these activities. Several fisheries should receive a high priority. These include the Irish salmon driftnet fishery, the Danish set net fishery in the North Sea, the English and French set net fisheries in the western English Channel, the French albacore driftnet fishery and Portuguese coastal gillnet fisheries.

4.4 Western North Atlantic region
The western North Atlantic region includes Bermuda, Canada (Atlantic provinces), Greenland (Denmark), St. Pierre and Miquelon (France) and the USA (Atlantic and Gulf states). Ten distinct fisheries have been shown to result in at least some cetacean mortality. These are summarised below. Of particular concern with regard to cetacean mortality are the several fisheries which each take hundreds to thousands of harbour porpoises per year from Greenland to the Gulf of Maine, the large-mesh drift gillnet for swordfish along the US coast and the gillnet and trap fisheries which entangle right and humpback whales. Detailed information is given by Read (SC/O90/G6), Earle (SC/O90/G42), Drew (SC/O90/G38) and Payne (SC/O90/G41).

4.4.1 US east coast swordfish drift gillnet fishery
This fishery is found along the continental shelf break from north of Cape Hatteras to Block Island. The target species are swordfish and other large pelagic fish. The 1–1.5 mile (1.6–2.4km) nets have an 18–24" (46–61cm) mesh and are set 2–6m below the surface. Approximately 10–15 vessels participate in this fishery and fishing effort has been increasing rapidly. An observer programme has determined that the incidental catches include (in order of importance) common dolphins, bottlenose dolphins, Risso's dolphins, beaked whales, pilot whales, Atlantic spotted dolphins and striped dolphins.

4.4.2 Greenland and eastern Canada surface gillnet fishery for salmon
This fishery is primarily in the inshore waters of western Greenland, Labrador, Newfoundland and the Gulf of St. Lawrence. The target species is *Salmo salar*. Nets are either anchored or (in Greenland only) drifting. A mesh size of approximately 5" (13cm) is used in Canada and 13–15cm in Greenland. There are approximately 549 fishermen in Newfoundland and Labrador and approximately 2,196 nets in Newfoundland. Mean net length is approximately 100m in Newfoundland. The level of effort may be decreasing. Total salmon landings in 1987 were 963 tonnes in Greenland, 481 tonnes in Labrador, 794 tonnes in Newfoundland and 306 tonnes in the Gulf of St. Lawrence. Incidentally caught cetaceans include harbour porpoises (probably several thousands per year), long-finned pilot whales, humpback whales and minke whales.

4.4.3 Bay of Fundy and Gulf of Maine herring weirs
Herring weirs are large fish traps designed to catch schools of pelagic fishes moving parallel to the shoreline. Weirs are found primarily in the Bay of Fundy and northern Gulf of Maine, although a few are scattered along southern New England shores. The target species are Atlantic herring and mackerel. There are more than 250 active weirs at present, but this number is slowly decreasing. Harbour porpoises and humpback, minke and right whales have been reported trapped inside weirs. Large whales are almost always removed alive, but some harbour porpoises are either shot or die during seining. Approximately 70 porpoises become trapped each year and, on average, 27 die as a result of the entrapment.

4.4.4 Atlantic Canada cod traps
Cod traps are found scattered along the shores of southern Labrador, Newfoundland and the Gulf of St. Lawrence. There are also a few cod traps in operation along the coast of western Greenland. Atlantic cod are captured as they move into inshore waters during the summer. The traps are essentially rectangular boxes of net, with a leader extending from the mouth to the shoreline. There were approximately 3,121 cod traps operating in Newfoundland alone during 1979. Harbour porpoises and white, long-finned pilot, humpback, right and minke whales all become entangled in cod traps, more often with the leader than with the trap itself. Mortality rates of large whales in this gear are fairly low, at least in Newfoundland waters, largely due to the efforts of the entrapment assistance programme run by Memorial University. In 1989, there were reports of 22 humpbacks and six minke whales entangled with Newfoundland cod traps, although a much larger number of collisions go unreported.

4.4.5 Atlantic Canada and Gulf of Maine demersal gillnets
This fishery operates throughout the inshore waters of southern Labrador, Newfoundland, the Gulf of St. Lawrence, the Bay of Fundy and Gulf of Maine. The target species are primarily Atlantic cod, pollock and hake. Gill nets are constructed of 14–23cm monofilament mesh, are between three and four metres deep and vary in length from 450 to 2,000m. Each vessel sets between four and six nets each day. The nets are anchored on the bottom in depths of 30 to 100m. The fishery operates year-round in the southern Gulf of Maine, but is highly seasonal in more northerly waters. In 1989, there were 325 vessels operating in US waters. The number of active vessels in Canadian waters is not known, but is in the thousands. Effort data are

being collected by the National Marine Fisheries Service (NMFS) in US waters; preliminary data suggest that gillnet vessels made over 14,000 day trips in 1989. Assuming 5 net sets per day trip of 1km each, total fishing effort would be approximately 70,000KND. Fishing effort is increasing, at least in US waters. There are no data on fishing effort in Canada.

A large number of cetacean species are entangled in these demersal gillnets, including harbour porpoises, white-sided and white-beaked dolphins and long-finned pilot, white, humpback, minke, fin and right whales. Many large whales survive entanglement, although they may carry off portions of gear. Entanglement is almost always fatal for smaller cetaceans. Harbour porpoises are the most frequently killed cetacean in these nets and annual mortality estimates are: Bay of Fundy – approximately 100; Gulf of Maine – 600 to 1,000; Gulf of St. Lawrence – approximately 1,500. There is no estimate from Newfoundland, although large numbers of porpoises are known to be taken in that area. The demersal fishery in the Gulf of Maine has been classified as Category I under 1988 amendments to the US Marine Mammal Protection Act. Observers placed on gillnet vessels in 1989 and 1990 witnessed 15 harbour porpoises killed in 247 fishing days, believed to represent between 1 and 3% of total effort. Sampling effort for this observer programme was not proportional to fishing effort or corrected for seasonal movements of porpoises.

4.4.6 Florida shark driftnet fishery

This is a small and poorly documented fishery operating along the northeastern coast of Florida. Nets are constructed from 8 – 12" (20–30cm) mesh and allowed to drift within 10 miles offshore. The primary target species is blacktip shark, although a variety of pelagic species are taken. There is no information on incidental catches of cetaceans in this fishery, although it is likely that bottlenose dolphins are taken. The fishery operates within the winter range of the endangered northern right whale population.

4.4.7 US east coast shad gillnets

These gillnets are set in estuarine and coastal waters to intercept anadromous movements of shad. Most nets employ 13–15cm mesh and vary from approximately 100–1,000m in length, depending on local regulations. Several thousand nets are used each spring, but the fishery is in gradual decline. Bottlenose dolphins and harbour porpoises are occasionally taken and there are two records of humpback whale mortality in these nets.

4.4.8 US east coast trap and pound net fisheries

A variety of pound, fyke and trap nets are used in coastal areas from Massachusetts to North Carolina. The nets are anchored near shore and are usually constructed of fine mesh, designed to capture a variety of coastal species including striped bass, tautog, bluefish and mackerel. The only reported cetacean entanglement was of a minke whale killed in a Rhode Island fish trap during 1976.

4.4.9 Atlantic Canada and US east coast bait gillnets

A large number of gillnets are used to take small pelagic fish in the waters of eastern Canada and the northeastern USA. Target species include Atlantic herring, mackerel and menhaden. The nets are usually constructed of fine mesh (2–3", 5–8cm) and are no more than 100–200m in length. These nets are either allowed to drift or are anchored, but all fish at the surface. The fish are used variously for direct consumption, roe, or bait for lobster or crab traps. Harbour porpoises, white-sided dolphins, short-finned pilot whales, humpback whales and fin whales are occasionally entangled in these nets. The only fishery that takes significant numbers of cetaceans is a small driftnet fishery for mackerel in Cape Cod Bay. Most porpoises and dolphins entangled in this fishery, however, are released alive.

4.4.10 US east coast mixed species demersal gillnets

A large number of fisheries utilise demersal gillnets along the US coast from Rhode Island to Louisiana. Coastal gillnets have been banned in South Carolina, Georgia and Texas waters for fisheries conservation reasons. These fisheries use a variety of mesh sizes, from 9–35cm, depending on the target species. Most nets are fairly short, less than 1km in length, although individual fishermen may set several at a time. Harbour porpoises and bottlenose dolphins are occasionally taken, although incidental catches have not been systematically examined.

4.4.11 Recommendations

(1) It is **recommended** that estimation of incidental catches of harbour porpoise made by groundfish gillnets in (i) Newfoundland and Labrador and (ii) the Gulf of St. Lawrence be undertaken. Such estimates will require an on-board observation programme, if accurate data on catch rates are to be obtained. An observer programme should be formulated as soon as possible, even with very low sampling intensity, to provide rough estimates of the magnitude of mortality. In addition, attempts should be made to improve the reporting of fishing effort.

(2) It is **recommended** that estimates be made of the magnitude of incidental mortality of harbour porpoises in the Greenland salmon driftnet fishery. As noted for (1) above, this will require accurate information on both catch rates and total effort.

(3) It is **recommended** that efforts to estimate incidental catch of harbour porpoise and fishing effort for the Gulf of Maine/Bay of Fundy groundfish gillnet fishery be continued. These efforts should ensure that future sampling intensity is statistically adequate and should explore the effects of variation in gear type and mode of operation on mortality rates. In addition, the level of incidental mortality should be assessed and data collected in previously unstudied areas, such as southwestern Nova Scotia.

(4) It is **recommended** that onboard observations of the swordfish driftnet fishery be continued at a level which is proportional to fishing effort. Consideration should be given to increasing sampling intensity because of (i) the large number of cetaceans killed and (ii) the relatively small size of the fishery in relation to other driftnet fisheries. It should be possible to sample a large proportion of all sets made, increasing the reliability of estimates of total mortality. Data on fishing effort should be obtained from ICCAT (International Convention for the Conservation of Atlantic Tuna).

(5) It is **recommended** that the magnitude of incidental mortality of cetaceans be assessed for several US east coast gillnet fisheries, including the Florida east coast shark driftnet fishery and the North Carolina sink net

fishery. A small observer programme would suffice to determine whether or not substantial incidental catches are incurred by these fisheries.

(6) The threat of gear damage is an excellent incentive to persuade fishermen to cooperate in programmes that release entangled large whales. It is **strongly recommended** that projects such as Memorial University's entrapment assistance programme be encouraged and supported.

4.5 Mexico, Central America and Caribbean region

This region is defined to include Anguilla, Antigua & Barbuda, Bahamas, Barbados, Belize, British Virgin Islands, Cayman Islands, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, French Guiana, Grenada, Guadaloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Netherlands Antilles, Nicaragua, Panama, Puerto Rico (US), St. Christopher & Nevis, St. Lucia, St. Vincent & The Grenadines, Surinam, Trinidad & Tobago, Turks & Caicos Islands, Virgin Islands (US) and Venezuela. Very little information is available on fisheries and their incidental catches in this large area. Most passive gear fisheries are based on small-scale coastal gillnets. These fisheries are divided into Pacific, Gulf/Caribbean and Amazon/Orinoco regions and are summarised below. Also included is limited information on large-scale driftnet fisheries operating in the Caribbean. Detailed information is given by Vidal *et al.* (SC/O90/G7).

4.5.1 Pacific small-scale gillnet fisheries

Small-scale and subsistence fisheries occur along the entire west coasts of Mexico, Central America and Colombia. The fisheries take a large number of fish species, including elasmobranchs, usually within a very short distance from shore. Gillnets range in length from 30–700m and from 8–30cm mesh sizes. Vessels are typically 4–12m in length. The number of vessels is available only for a few of the countries. Based on data from those countries, we know that the minimum number of boats is 7,550–8,550 and the minimum number of fishermen using gillnets is 5,500–12,000. The actual number is likely to be much greater and increasing. Cetacean species taken in these fisheries include the vaquita (at least 30–40 per year), common dolphins, bottlenose dolphins and gray whales. No estimates are available for the take of the latter three.

4.5.2 Gulf of Mexico and Caribbean small-scale gillnet fisheries

Small-scale and subsistence fisheries occur along the entire Gulf of Mexico and the Caribbean. The fisheries take a large number of fish, turtles and elasmobranch species. Gillnets range in length from 30–2,000m and from 4–40cm in mesh size. Vessels are typically 4–15m in length. Based on data from a few countries, we know that the minimum number of boats is 732 and the minimum number of fishermen using gillnets is 1,600. Fishing effort in these fisheries is generally increasing. Based on the few countries which report catch statistics, the minimum catch is 420 tonnes per year. Cetacean species taken include pygmy sperm whales, tucuxi, Risso's dolphin, bottlenose dolphins, Atlantic spotted dolphins, killer whales, clymene dolphins, spinner dolphins, rorquals and humpback whales. The annual take of cetaceans has not been estimated for any species or fishery.

4.5.3 Small-scale gillnet fisheries in the Amazon and Orinoco rivers

In the Colombian Amazon and in the Orinoco River basin, gillnets are used in artisanal fisheries. Target species include mainly pimelodid catfishes and characids but also other species. Vessels are typically 3–10m. Cetaceans killed include the boto (in the Amazon).

4.5.4 Drift gillnet fisheries for pelagic fish in the Caribbean

Gillnets are used to catch pelagic fishes in the vicinity of Trinidad & Tobago, Barbados, Grenada and along parts of the coast of Mexico. Target species include *Scomberomorus* spp., flying fish, large pelagic fishes (possibly including tuna) and possibly flying squid. Detailed information is only available for Trinidad. Driftnets with lengths of 100–150m and mesh sizes of 10–11cm are set from 10m vessels. There are 100–150 such vessels in Trinidad. The total catch of *Scomberomorus* in Trinidad is approximately 2,000 tonnes (including some other gear types). Marine mammal mortality has included killer whales and unidentified dolphins.

4.5.6 Recommendations

(1) It is **urgently recommended** that the incidental mortality of the vaquita be urgently addressed by (i) fully enforcing the ban on the totoaba gillnet fishery, (ii) reconsidering the issuance of experimental totoaba gillnet fishing permits and (iii) monitoring and evaluating the incidental mortality of the vaquita in the shark gillnet fishery.

(2) It is **recommended** that new and expanding driftnet fisheries in this area be identified and the occurrence and magnitude of cetacean bycatch determined. This should be accomplished through national and regional international programmes.

(3) It is **recommended** that education programmes be designed and implemented to increase the awareness of fishermen and the general public to the problems faced by cetacean populations interacting with gillnet fisheries.

(4) The tucuxi is especially vulnerable to population depletion because of its restricted coastal and riverine habitats and the possible existence of isolated and locally adapted populations. It is **recommended** that incidental mortality of this species receives particular attention in the Caribbean.

4.6 Brazil region

For discussion in this report, Brazil is divided into five regions: the north coast (2°33′S to 4°52′S); the northeast coast (4°52′S to 18°20′S); the southeast coast (18°20′S to 23°16′S); the south coast (23°16′S to 33°45′S); and the Amazon. Detailed information is given by Pinedo (SC/O90/G3), Cannella and Ximenez (SC/O90/G26) and da Silva and Best (SC/O90/G27).

4.6.1 Net fishery for red porgy and Brazilian shrimp

No details about this northern region fishery were available at the meeting, but Lodi *et al.* (1990) noted the take of tucuxi in this fishery.

4.6.2 Gillnet fishery for croakers, weakfish and marine catfish

This fishery is found in the north, northeast and southeast. At least 83 fishing villages operate gillnets year round (Lodi *et al.*, 1990). No additional information was available about the fishery, but recorded marine mammal takes

include approximately 90 tucuxi, 29 franciscana, 3 rough-toothed dolphins, 2 common dolphins, 1 false killer whale and 1 Atlantic spotted dolphin.

4.6.3 Lobster trap fisheries in northeast region
Baited traps are used to catch lobsters in northeast Brazil. No marine mammal mortality has been reported, but in other parts of the world, large whales have been entangled in crustacean trap lines.

4.6.4 Artisanal gillnet fisheries in northeast region
Gillnets are used (along with other gear) to catch a variety of coastal fishes in northeast Brazil. Nets are typically set from small (4–8m) sail-rigged open boats called *jangadas* or *saveiros*. Data are not available on effort for these fisheries. Tucuxi are occasionally caught in gillnets (Barros and Teixeira, 1994). These dolphins are used as bait and for human consumption (Capistrano *et al.*, 1990; Taveres de Almeida, pers. comm. to Ximenez; Nerees do Reis, pers. comm. to Ximenez).

4.6.5 Longline fishery in northeast region
Longlines are used to catch tuna, marine catfish, half beaks, ballyhoo, tarpon and other species in coastal areas of northwest Brazil. There are approximately 30,000 small boats. Other small vessels carry iced fish between the fishing vessels on the open sea and the home ports. At least 275 tonnes of fish product are landed in Maranhão state alone. No information is available regarding marine mammal mortality.

4.6.6 Gillnet fisheries in southeast region
Gillnets and trap fisheries are used to catch a variety of fish species in southeastern Brazil. Gillnets are 146–2,000m long with mesh sizes of 3–20cm (Capistrano *et al.*, 1990). No additional information is available about the fishery operation. Reported cetacean bycatch in gillnets has included 17 tucuxi, 7 franciscana and one unidentified dolphin (Capistrano *et al.*, 1990). Three dolphins have also been reported taken in trap fisheries (Monteiro Filho, 1990). Tucuxi have been reported to be used for bait and human consumption (Lodi, pers. comm.).

4.6.7 Gillnet fisheries in southern region
Gillnets are used to catch a variety of fish species in southern Brazil. Nets are fished up to 30 n.miles offshore. Approximately 1,600 vessels are licensed to fish in the Rio Grande area. Each vessel fishes up to 3km of net each day for a total of 300 days per year. If all vessels are fishing, total effort is approximately 1,500,000KND. Records of marine mammal mortality include 867 franciscana, 1 tucuxi, 3 rough-toothed, 4 bottlenose, 5 Atlantic spotted and 2 common dolphins, and 1 false killer and 1 minke whale.

4.6.8 Recommendation
All the gillnet fisheries of Brazil require systematic monitoring in order to assess the level of incidental catches of small cetaceans, especially those from the north, northeast and southwest and it is **recommended** that this be initiated as soon as possible. Mortality of the tucuxi and the franciscana urgently requires monitoring.

4.7 Southwest Atlantic region
The Southwest Atlantic region consists of Argentina, the Falkland Islands/Islas Malvinas and Uruguay. Gillnet fisheries include shark fisheries in both Uruguay and Argentina, a croaker fishery in Argentina and a mixed-species trammel net fishery in Argentina. These are summarised below. Detailed accounts are given by Crespo (SC/O90/G2) and Praderi (SC/O90/G1).

4.7.1 Gillnet fishery for sharks in Uruguay
Bottom-set gillnets are used to catch soupfin sharks, other shark species and bony fish along the coast of Uruguay. Twenty vessels (each approximately 8m long) fish out of five fishing villages along the Uruguay coast. Approximately 80 fishermen are employed in this fishery. Gillnets are approximately 1,200m long and have mesh sizes of 10cm, 20–22cm and 32–34cm. Based on an estimated 72km of net being used in 1989 and a fishing season of 60 days, total effort was approximately 4,356KND. Effort is currently estimated to be decreasing. The total annual value of the catch is approximately $200,000. Marine mammals killed incidentally include franciscanas (more than 100 per year) and, to a much lesser extent, bottlenose dolphins and Burmeister's porpoises.

4.7.2 Gillnet fishery for croaker species in Argentina
Gillnets are set on the bottom to catch several species of croaker (Sciaenidae) in the Samborombon Bay and Bahía Blanca regions of Argentina. Vessel sizes in these regions are 8–10m and 13–15m, respectively, and the number of vessels fishing gillnets 7–8 and 15–16, respectively. Gillnets in Samborombon Bay are typically 200m long and have mesh sizes of 10–30cm. For Bahía Blanca three types of nets are used with mesh sizes ranging from 2cm to 10cm. Given 8 vessels fishing 200m of net over a 60-day fishing season, total annual effort in Samborombon Bay is approximately 100KND. There are no effort data for the Bahía Blanca area. Effort is stable or increasing slightly. Cetacean mortality at Samborombon Bay includes approximately 50 franciscanas per year. No information on cetacean mortality is available for Bahía Blanca.

4.7.3 Gillnet fishery for sharks in Argentina
Set gillnets are used to catch soupfin and other shark species in the Necochea and Claromecó areas of Argentina. There were 21 vessels fishing in 1989 and 17 in 1988. Vessels are 8–45m in length and typically fish 1–4km of 19–21cm mesh gillnet. Approximately 150 fishermen are employed in this fishery. Total effort is approximately 6,700KND and is increasing. The catch is approximately 500 tonnes per year and is worth approximately $2 million. The annual cetacean catch includes franciscanas (approximately 70–80), Burmeister's porpoises (approximately 20) and common and dusky dolphins.

4.7.4 Other coastal gillnet fisheries
Gillnets are used to catch a variety of fish species, including robalo, silverside and hake, in the region of southern Patagonia and Tierra del Fuego. Nets include single-panel gillnets and 3-walled trammel nets with mesh sizes of 3, 12 and 30cm. Nets are set from shore with and without vessels. Little is known about the level of fishing effort, but it is believed to be increasing. Incidental cetacean catch has not been quantified, but includes Commerson's dolphins, spectacled porpoises, Peale's dolphins and Burmeister's porpoises.

4.7.5 Recommendations
(1) It is **recommended** that age and reproductive parameters of the franciscana continue to be monitored and that they be compared with those found

by Kasuya and Brownell during the 1970s (Kasuya and Brownell, 1979) and between populations within the area.

(2) It is **recommended** that Punta del Diablo be used as a location to estimate the size of the franciscana population off Uruguay. In Argentina, incidental mortality and abundance should be assessed at San Clemente del Tuyu, Nocochea, Claromecó and Bahía Blanca.

(3) It is **recommended** that samples be collected and analysed to examine genetic variability and stock structure in the franciscana.

(4) It is **recommended** that the purse-seine fishery in Buenos Aires Province be assessed for its impact on dusky and common dolphins.

(5) It is **recommended** that mortality rates and population sizes of cetaceans impacted by trawl fisheries in northern Patagonia be assessed.

(6) In southern Patagonia and Tierra del Fuego, the fisheries require further documentation, in terms of gears used and the amount of effort expended. It is **recommended** that such research begin. Mortality to cetaceans and population sizes of those species affected also need to be assessed in this region. A co-operative research programme should be established between Argentina and Chile for the Tierra del Fuego region.

4.8 Western Africa region

The western Africa region includes 22 coastal states, including Angola, Benin, Cameroon, Cape Verde, Congo, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mauritania, Morocco (Atlantic coast), Nigeria, Sao Tome & Principe, Senegal, Sierra Leone, Togo, Western Sahara and Zaire. Most of the gillnet fishing in this area is conducted from small vessels. Little information is available on catch, effort or bycatch. Summaries are provided for four such fisheries. More detailed information is given by Maigret (SC/O90/G5).

4.8.1 Drift gillnet fishery for tuna

A drift gillnet fishery for tuna and billfish is found off the Ivory Coast and the Moroccan coast. In Morocco, vessels are primarily small boats which previously fished with seines or hook and line. In the Ivory Coast and Ghana, small vessels called *pirogues* (10–15m long) fish with approximately 450m of 40–60cm mesh gillnet. There are approximately 30 vessels in the Ivory Coast. No information is available on the level of effort in Morocco, other than the fact that the number of vessels is rapidly increasing. The annual catch of tuna by all gear types is approximately 3,000 tonnes per year in Morocco. The gillnet catch in the Ivory Coast is approximately 200 tonnes and is sold in local markets. Approximately 100 'dolphins' are estimated to be caught per year in the Ivory Coast fishery. No information was available for Morocco.

4.8.2 Western Africa lobster set nets

Spiny lobsters (*Panulirus regius*) are taken in set nets from the Western Sahara to the Congo. Bottom entangling nets are set with small boats (8–12m). The fishery appears to be stable. Lobsters are sold domestically and are exported to Spain and France. No information is available on marine mammal mortality in most areas, but in the north approximately 10 dolphins and harbour porpoises are believed to be caught each year. Monk seals are also found in the area and may be caught.

4.8.3 Western Africa set gillnet fisheries

Bottom-set gillnets are used for a variety of fish species from Mauritania to Angola. Nets are set from small boats, with or without engines. A variety of sizes and types of gillnets are used, all of relatively short length. No quantitative estimates of effort are available, but this type of fishing is generally increasing in all countries. No information is available on marine mammal mortality, but these nets may occasionally capture Atlantic hump-backed dolphins and (in lagoons) manatees.

4.8.4 Small-scale drift gillnet fishery for small pelagic fishes

This fishery occurs along the coasts of Nigeria, Benin and Gabon. Small pelagic species (e.g., *Sardinella*) are taken with short (65–70m), small-mesh (5–6cm) gillnets which are deployed from small boats (only 10% of which may have outboard engines in Nigeria). There is no information on the effort or the catch. The catch is sold in local markets. There has been some documentation of the catch of unidentified 'dolphins'.

4.8.5 Recommendations

(1) There is very little or no expertise on marine mammals in the West African nations. It is **recommended** that a training programme for African scientists be implemented in order to facilitate the formation of a local network to study the problems of incidental catches in West African waters.

(2) More information on gillnet fisheries in this area is required than was available to the Workshop and it is **recommended** that this be collected and reviewed.

(3) The identity, size and status of cetacean populations in the eastern tropical Atlantic is unknown. It is **recommended** that these be investigated.

4.9 Southern Africa and southern Indian Ocean region

The southern Africa and southern Indian Ocean region includes the coastal waters of British Indian Ocean Territory, Comoros, Kerguelen (France), Malagasy Republic, Mauritius, Mozambique, Namibia, Reunion (France), Seychelles, South Africa and St. Helena (and dependencies Ascension Island and Tristan da Cunha, UK). Most of the coastal gillnet fishing in this area is artisanal and subsistence-type fishing. Data are completely lacking on most of the fisheries. Some information is summarised below for three fisheries. A small gillnet fishery for tunas is known to exist in the Seychelles, but no information is available on bycatches (Indo-Pacific Tuna Development and Management Programme, 1987). More detailed information is presented by Cockcroft (SC/O90/G20).

4.9.1 Shark gillnetting in Natal, South Africa

Gillnets are used to catch sharks (and presumably protect bathers) along beaches in Natal, South Africa. Nets are set along popular beaches within 500m of shore. Nets are constructed of multifilament nylon with stretched-mesh size of 34cm. There are 416 such nets which are left in a fixed position for most of the year apart from mid-winter when some may deliberately be lifted to avoid major entanglements of predators associated with the sardine run. Each net is 110m long. Total effort is 16,702KND per year and is stable. Shark catch and bycatch in the nets is

carefully monitored. The cetacean species most commonly caught include bottlenose, Indo-Pacific hump-backed and common dolphins. Bottlenose and hump-backed dolphin populations appear to be declining in this area.

4.9.2 Shrimp set netting in Mozambique

Very small mesh (1cm) gillnets are used to catch shrimp in an artisanal fishery in Mozambique and probably some areas of Madagascar. Almost nothing is known about this fishing method. Shore-based dugouts less than 8m long are used. Incidental cetacean catch is not known, but is probably marginal due to the small size of the nets and the small mesh size.

4.9.3 Artisanal gillnet fisheries in the Malagasy Republic, Mauritius, Mozambique, Reunion and Seychelles

Gillnets are used to take a variety of benthic and neritic fish species in coastal areas throughout the southwestern Indian Ocean and southeastern Atlantic. Nets may be set or drift types and may be fished at either the surface or the bottom. Mesh sizes vary between 5–15cm. Vessels range in size from dugouts to 10m sail or motorised boats. There are a minimum of 15,404 such vessels and more probably 20,000. There are more than 20,000 fishermen using these methods and possibly 40–50,000. Total effort is likely to be greater than 450,000KND days per year. Effort is probably increasing with population size. Such fisheries probably also exist in the other nations in the region, with the possible exception of the Comoros. There is no information available on cetacean bycatches.

4.9.4 Recommendations

(1) Where aid agencies have provided gillnets as part of development assistance programmes, it is **recommended** that the donors be encouraged to obtain information on the impacts of these gears on non-target species.
(2) In order to encourage fishermen to report incidental catches, it is **recommended** that regulations concerning marine mammals be devised which encourage rather than discourage reporting.
(3) It is **recommended** that the UN and other aid agencies be made aware of the potential effects of the development of gillnet fisheries.
(4) It is recommended that Regional fishery bodies be encouraged to place observers on board high seas driftnet vessels to collect information on incidental catches.
(5) In view of the mortality and depletion of Indo-Pacific hump-backed and bottlenose dolphins by incidental capture in shark nets, it is **urgently recommended** that an immediate reassessment of existing deployment of these nets be carried out.

4.10 East Africa, northwestern Indian Ocean and Red Sea region

This region includes Bahrain, Djibouti, Egypt (Red Sea coast), Ethiopia, Iran, Iraq, Israel (Red Sea coast), Kenya, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, Somalia, Sudan, Tanzania, United Arab Emirates and Yemen. Information from the region presented to the meeting was limited to a review of the fisheries of Pakistan by Niazi (SC/O90/G30). There are several important marine fisheries in the waters of Pakistan that are known to take cetaceans, although the magnitude of this problem has received little study to date. It is known that many fishermen attempt to avoid entangling dolphins and attempt to release them alive whenever possible. Of particular concern in Pakistan is a proposed refitting of 1,800 trawlers with gillnet gear. Such an expansion of existing gillnet fisheries could have a serious impact on coastal cetacean populations.

A shark gillnet fishery in the Gulf of Oman is known to take at least common dolphins and humpbacked whales (Papastavrou, 1990), but no further information was available to the meeting. A gillnet fishery for large pelagic species, mainly tuna, is described below; the information comes from Dudley (1989).

Information from the literature on gillnet fisheries of Iran, Kenya, Somalia, Tanzania and Zanzibar is also summarised below.

4.10.1 Large pelagic gillnet fishery in Pakistan

This fishery is conducted in offshore waters along the Sind and Baluchistan coasts and as far away as Oman, in depths of 25–100m. A variety of sharks, tuna and seerfish are taken by drift gillnets that are as long as 10km (Indo-Pacific Tuna Development and Management Programme, 1987). The mesh size of these nets varies between 15 and 25cm. Approximately 500 vessels are active in the fishery, each setting two nets. Assuming a 200-day fishing season, these 500 vessels each setting two 3km nets each day would have a combined effort of 600,000KND per year. Indo-Pacific hump-backed, bottlenose, spinner and spotted dolphins are among the cetacean species taken in unknown numbers by this growing fishery.

4.10.2 Bottom set gillnet fishery in Pakistan

These nets are used in coastal waters in Sind and Baluchistan in depths of 10–30m. A variety of groupers, grunts, croakers and other demersal species are taken in these set nets using mesh sizes of 10–12cm. A total of 2,500 vessels each set one to three nets of between 500 and 1,200m in length. Total fishing effort would be approximately 500,000KND based on each vessel setting 1km of net each day during a 200-day fishing season. This fishery is also growing and is known to take Indo-Pacific hump-backed dolphins, bottlenose dolphins, spotted dolphins and finless porpoises.

4.10.3 Artisanal fisheries in Pakistan

This category includes a large number of small-scale fisheries that employ a variety of gear, including fine mesh gillnets and stake nets. These fisheries operate year round and take most coastal shallow water fish species. More than 20,000 artisanal vessels are in operation in Pakistan around the year. Only the finless porpoise is known to be taken by these small scale fisheries.

4.10.4 Fishery for large pelagic species in Oman

The primary target species are *Scomberomorus commerson* (about 27,581 tonnes landed in 1988), *Thunnus tonggol* (15,669 tonnes in 1988) and other small tunas. Both set nets (some configured as traps) and driftnets of 1–2,000m are used. The fleet consists of a variety of vessels ranging from small fibreglass boats of less than 10m to large dhows. No information is available on effort or bycatches.

4.10.5 Driftnet fishery for tuna in Iran

Iran operates a gillnet fishery for tunas in the Indian Ocean, with total catches in 1986 of 5,071 tonnes (Indo-Pacific Tuna Development and Management Programme,

1987; Indian Ocean Fishery Commission, 1990). There are about 2,500 multipurpose artisanal vessels engaged in the fishery; most are wooden and range from 5 to 100 GRT. Some are fibreglass and range from 12 to 27ft (3.7–8.2m). The nets range in length from 0.5 to 7–8km; mesh size is 14–16cm. There is no information on incidental catches.

4.10.6 Artisanal gillnet fishery in Kenya

In 1987, 404 vessels (most less than 10m) operated bottom and surface gillnets, targeting sharks, rays, tunas and over 100 other species including needlefish, jacks, parrotfish, kingfish and rabbitfish; 2,288 tonnes of all species were landed in that year (de Sousa, 1988). Nets are 90m by 26 meshes; three are usually fished together by one boat. There is no information on incidental catches of cetaceans.

4.10.7 Artisanal driftnet fishery for sharks and large pelagics in Somalia

'Mesh nets' are employed in Somalian fisheries (Van Zelinge, 1988). Reported data on vessels and catches have not been broken down by gear type. No data are available on incidental catches.

4.10.8 Artisanal gillnet fisheries in mainland Tanzania

In 1986, a reported 8,842 'gillnets' and 3,590 'shark gillnets' were in use in mainland Tanzania (Nhwani, 1988). The reported data are not broken down by gear type. There is no information on incidental catches.

4.10.9 Gillnet fisheries for large pelagic fish and sharks in Zanzibar

Two vessels engaged in driftnetting for large pelagic fish in 1986 (Jiddawi and Pandu, 1988). The fleet in that year fished 5,622 gillnets for sharks and large pelagics. For the period 1974–76, 91,375 tonnes were landed from gillnets. Again, there is no information available on incidental catches of cetaceans.

4.10.10 Recommendations

(1) Further research effort into cetaceans in the region is required. In particular, the population status of the finless porpoise and factors controlling it need urgent attention; it is **recommended** that this begin as soon as possible. The causes of the decline in this species should be identified and steps taken to reverse the decline.
(2) Gillnet fisheries continue to be developed in Pakistan and elsewhere throughout the region. It is **recommended** that these fisheries not be further developed until evaluation of their effects on non-target species has been conducted.
(3) It is **strongly recommended** that distant water large mesh driftnet fleets operating in the Indian Ocean either be closely monitored or stopped.

4.11 Northeastern Indian Ocean region

This region includes Bangladesh, Myanmar, India, Maldives and Sri Lanka. Within this region, with the exception of the Maldives (Anderson, 1990), gillnets are the most common passive fishing gear. Literally millions of fishermen use this method. The vast majority of the effort is in small-scale artisanal or subsistence fisheries. For purposes of summary, all of these fisheries are considered collectively below. Details are given by Mohan (SC/O90/G22), Dayaratne and de Silva (1990) and Leatherwood and Reeves (1989).

4.11.1 Small scale artisanal gillnet fisheries of India, Bangladesh and Sri Lanka

Target species in these fisheries include many marine fish and elasmobranchs and freshwater catfish. Almost all coastal areas are fished. Nets include both drift and set type gillnets. Most vessels are small (5–15m). Of approximately 289,000 vessels, only about 8% are motorised. Approximately 2,500,000 fishermen are found in this region, most of whom fish with gillnets at least some of the time. There are estimated to be 216,000 gillnets in India. Although data are not available for the rest of the countries, the total number of nets is likely to be close to 350,000. Mean net length is approximately 400m and mesh sizes range between 2–30cm. Assuming each net is fished 150 days per year, the total effort is approximately 21,000,000KND per year in this region. Marine mammal mortality includes spinner, spotted, striped, common, bottlenose, Indo-Pacific hump-backed, Risso's and Ganges river dolphins and false killer, dwarf sperm and pygmy sperm whales. Total mortality has been estimated by statistical sampling in Sri Lanka and by fishery reporting systems in India. Total mortality of all cetacean species in Sri Lanka alone may exceed 40,000 per year, with a minimum additional catch of 2,000 dolphins in other areas of this region. Dolphin catches in portions of Sri Lanka have evolved from being a bycatch to being a directed catch for human consumption and for bait for the long-line fisheries.

4.11.2 Recommendations

(1) The fisheries of the region are generally poorly documented and it is **recommended** that a comprehensive survey be made of the fisheries of Bangladesh, Burma, Sri Lanka and India which are known or suspected to kill marine mammals.
(2) It is **recommended** that the nations in the region consider the establishment of marine mammal protection agencies.
(3) It is **recommended** that education programmes be initiated for fishermen, fishery officials and others to highlight the problems faced by cetacean populations interacting with gillnet fisheries. Cetacean awareness programmes should be instigated at the village level. Fishery co-operatives and local schools and colleges should be involved in the work, and where dolphins are being caught, a local college or school should be identified to protect the dolphins through public contact programmes.
(4) Because of the vulnerability and general depletion of river dolphins in Asia, it is **recommended** that particular efforts be made to collect information on the gillnet fisheries of the Ganges and Brahmaputra rivers and their involvement in entanglement of the Ganges susu.

4.12 Southeast Asia region

This region includes the coastal areas of Brunei Darussaalam, Kampuchea, Malaysia, Philippines, Singapore, Thailand and Vietnam. Most passive net fisheries in all of these countries are small-scale, artisanal type enterprises. Little information is available for some regions; no information is available for most. Malaysia, Thailand and the Philippines operate gillnet fisheries for

tunas, with reported catches in 1986 of 9,751 and 25,154 tonnes in Malaysia and Thailand, respectively, and 25,186 tonnes in the Philippines in 1985 (Indo-Pacific Tuna Development and Management Programme, 1987), but little information on vessels, gear, effort or bycatches was available to the meeting. The limited information available to the meeting on some areas in the Philippines and on Thailand is summarised below. More detailed accounts are given by Dolar (SC/O90/G29) and Sudara (SC/O90/G32).

4.12.1 Artisanal fishery for pelagic fish in Thailand
Gillnets are used to catch skipjack, Spanish mackerel and longtail tuna in the Gulf of Thailand and in the Andaman Sea. According to Bhatia *et al.* (1989), driftnetting accounted for about 1/3 of the catch of 95,679 tonnes in the Gulf of Thailand in 1987. There are approximately 10,000 small (6–8m) vessels in this fishery. Nets are typically less than 1km, but some are up to 5km long. Nets are either anchored or are allowed to drift. Marine mammals taken in these nets include dwarf spinner dolphins, Indo-Pacific hump-backed dolphins, Irrawaddy dolphins and dugongs.

4.12.2 Artisanal fisheries in the Philippines
Gillnets are used to catch a wide variety of small fish throughout the coastal waters of the Philippines. Boats are small, typically 3–6m in length. There are approximately 3–15,000 such vessels fishing with small (approx. 300m) gillnets. If fishing is practised 220 days per year, total effort would be in the range of 200,000–1,000,000KND per year. Cetacean mortality includes spinner, spotted and Fraser's dolphins. Based on a small sample observed in the Negros and Bohol Islands, estimated kill rates are 0.66 dolphins/km/year. Based on the above estimate of the number and length of nets, extrapolated cetacean mortality may be in the range of 600–2,000 dolphins per year.

4.12.3 Recommendations
(1) It is **recommended** that studies of cetacean populations and cetacean mortality in fishing operations should be initiated in Southeast Asia as a priority issue.
(2) It is **recommended** that national and international organisations develop educational programmes for fishermen, scientists, officials and the general public about cetaceans and their interactions with fisheries.

4.13 Australasia and Melanesia region
This region includes coastal waters of Australia, East Timor, Indonesia, New Caledonia, Papua New Guinea, Solomon Islands and Vanuatu. At this meeting, information on fisheries and marine mammal takes included only Australia. Four important net fisheries of Australia, the Taiwanese fishery operating in the Arafura and Timor Sea and the Indonesian tuna gillnet fishery are summarised below. Detailed information on the Australian fisheries was presented by Anderson.

4.13.1 Northern drift gillnet fishery for sharks
Surface driftnets are used to catch sharks, tuna and gray mackerel, 2–12km offshore along the Arafura Sea. Nets are 2.5km long and have a mesh size of 4–6" (10–15cm). There are 45 permits to fish this area, but only 10–12 vessels (approximately 30 fishermen) are actively fishing. Vessels are 10–17m long. Each vessel makes 5–10 trips of 7–21 days duration. Assuming 5–19 days of actual fishing, 7.5 trips per year and 12 vessels, the total effort is approximately 1–4,000KND per year. Bycatches of bottlenose dolphins, *Stenella* spp. and Indo-Pacific hump-backed dolphins are most likely. Cetacean catch rates are likely to range from 4–6 dolphins/100KND. Given this and the above effort estimate, total catches may be between 40–240 dolphins per year.

4.13.2 Southern set gillnet fishery for sharks
Bottom-set gillnets are used to catch gummy, whiskey and dusky sharks in Western Australia, South Australia, Tasmania, Victoria and southern New South Whales. Vessels are typically 10–20m long. The number of vessels is 172 in South Australia and 20 in Tasmania and is not known for the other areas. The total number of fishermen is approximately 500. Nets are approximately 2.5km long. Effort is generally increasing. Landings are worth approximately $20m. Reported dolphin takes are approximately 1–7 per year for the West Australia coast and are probably much lower for other areas. Species taken have not been reported, but they were probably bottlenose or common dolphins.

4.13.3 Inshore set gillnet fishery for barramundi
Set gillnets are used to catch barramundi and threadfin in estuaries and tidal areas of northeast, north and northwest Australia. Vessels include 17m net boats and 3.5m net tenders. There are approximately 23 of the mother vessels in the Northern Territories and 9 in West Australia. The number in Queensland is not known. Maximum net length is 1km and mesh sizes are typically 15–18cm. Total catches are in excess of 850 tonnes and are worth a minimum of $12m. Marine mammal catches probably occur, but data are not available.

4.13.4 Haul-net fishery in Tasmania
Haul-type nets are used to catch baitfish, arridis and mullet in inshore waters of Tasmania. Sometimes these nets are set to fish passively. Nets are set from small dinghies. There may be approximately 7,100 such nets. Nothing is known about levels of fishing effort. Marine mammal mortality included 6 common dolphins in 1980 and 9 in 1989.

4.13.5 Taiwanese driftnet fishery for sharks, billfishes and tunas
This fishery formerly operated in the 200-mile zone of Australia but was ejected from Australian waters in 1986 because of an unacceptably high dolphin bycatch (Harwood and Hembree, 1987; Anon., 1988). The fishery has continued in other waters to the north off Indonesia and Papua New Guinea (Liu, 1989), but there was no information available to the meeting on recent bycatches. Information is also lacking on bycatches outside Australian waters before 1986.

4.13.6 Indonesian tuna gillnet fishery
Approximately 200 gillnetters of 3–6 GRT with 40 HP engines operated out of Sumatra in 1987 (Uktolseja, 1989). The principal target species are skipjack and yellowfin tuna. Catches of tunas in 1988 totalled 902 tonnes; smaller amounts of sharks and billfish were also landed. Nets consist of 20 units each 60m long and 14m deep (total 1,200m), with mesh size of 4–5" (10–13cm). Vessels typically have a crew of 3–4. No information is available on cetacean bycatches.

4.13.7 Recommendations
(1) Improved documentation of the nature and extent of bycatch, including marine mammals, in southern and

western Australian shark set net fisheries and in the northern Australian driftnet fishery is required, as is an assessment of the cetacean populations involved. It is **recommended** that programmes to accomplish this be initiated.

(2) It is **recommended** that an assessment be made of the level of bycatch, including marine mammals, in commercial and other net fisheries for barramundi and threadfin bream in northern Queensland, Northern Territory and Western Australia.

(3) It is **recommended** that assessments should be made of the status of populations of small cetaceans, particularly Indo-Pacific hump-backed dolphins and Irrawaddy river dolphins, in inshore waters of the area where barramundi fisheries operate in northern Australia and in areas which shark fishing operations occur.

(4) It is **recommended** that other small scale and recreational gillnet fisheries in Australia which have a potential for impact on inshore cetacean populations be better documented.

(5) Throughout Melanesia, improved documentation of the level and distribution of net and trap fisheries and any cetacean catch or bycatch should be obtained and reporting procedures to maintain the flow of information should be developed. It is **recommended** that these begin as soon as possible. An initial assessment of the identity, distribution and abundance of cetacean populations in the Melanesian region should be made.

(6) Co-operation should be sought between nations of the area, to implement measures designed to increase the awareness of an need to reduce or eliminate incidental catches of cetaceans and other marine mammals and turtles. It is **recommended** that such efforts be initiated through existing regional cooperative bodies.

4.14 South Pacific region

For purposes of this workshop, the South Pacific is defined to include 13 island groups or territories which are loosely combined as follows: Norfolk Island, New Zealand, Fiji Islands, Tonga (including Niue and Tokelau), Western and American Samoa, the Cook Islands, French Polynesia (including Wallis and Uvea) and Pitcairn Island.

The area is predominantly characterised by islands with either fringing reefs or lagoons surrounded by low coral atolls. Two islands, Pitcairn and Norfolk, lack fringing reefs or coastal shelves; passive net or trap fisheries are not conducted there. New Zealand has a large coastal shelf and supports highly-developed fisheries, including set and driftnet fisheries.

Available fisheries information varies considerably throughout the South Pacific depending largely on the level of fisheries conducted. Passive net fisheries are primarily of three types: drift gillnets, deep and shallow set nets and reef-top and reef-passage set gillnets. Information is presented below for all areas for which it was available. Detailed descriptions of the fisheries were presented to the group by Cawthorn.

4.14.1 Set net fisheries in Fiji, Tonga, Samoa, Cooks and French Polynesia

Throughout these islands, set nets in lagoons and atop reefs are used in artisanal subsistence fisheries to collect migrating mullet and sedentary reef fishes for bait and human consumption. The nets are generally of monofilament or multifilament nylon with a stretched-mesh measurement of from 5–12.5cm. Nets are slung in 25–50m lengths and set either at the surface, submerged in reef passages or staked on the reef tops. In some areas, such as Tonga and Fiji Islands, gillnets are set from the beaches inside lagoons and staked to form fish fences to catch mullet and other small school fish on the change of tide. No data are available on the quantities of mullet or reef fishes taken by these methods. We are not aware of cetacean mortalities in any local fisheries in these islands. For islands other than the Marquesas, where drive fisheries for small cetaceans have been conducted historically (for meat and for teeth for use as currency and adornment), there is no history of fisheries targeting small cetaceans. A long-lived fishery for humpback whales in Tonga ceased in 1978. The Fijian practice of trading in sperm whale teeth did not relate to a local fishery.

4.14.2 Gillnet fisheries in New Zealand

There are commercial set and drift gillnet fisheries (366 boats, 455 permit holders in the 1989–90 fishing year) and amateur gillnet fisheries operating in both North and South islands. Species taken include mullet, reef and coastal demersal, flatfish, sharks, elephant fish, groupers, semipelagic species, kingfish and ling. Nets are braided synthetic or monofilament with variable mesh sizes which are regulated to target species. Nets are set inside harbours, on mud flats and on the coastal shelf to waters 200m deep. Commercial landings totalled 39,894 tonnes in 1989. Amateur catch is unreported. Between 1984 and 1987, the set net catch declined by about 60%; this was a result of the introduction of the ITQ (Individual Transferable Quota) management system and the resultant exclusion of many part time fishermen. Currently, 56% of the set net fishers registered are in the north of North Island.

The combination of commercial and amateur inshore gillnet fishing has had a significant impact on the population(s) of Hector's dolphins in the Banks Peninsula region of the south island. Results of recent studies of population status and catch rates led to the establishment of a sanctuary in this area and to increased attention to this species throughout New Zealand. A deep set net fishery for grouper at Kaikoura takes a substantial number of dusky dolphins annually. Ten to 25 pinnipeds are killed annually in bait nets set around the South island. To date, no cetacean mortalities have been documented in this fishery. In apparently isolated incidents, a right whale stranded following entanglement in a rock lobster pot-buoy line and reports of minke and sperm whales entangled with netting and/or line have been received. Recently, a trawler, fishing for jack mackerel with mid-water trawl in the western approach to Cook Strait reported taking 35 common dolphins.

4.14.3 Recommendations

(1) It is **recommended** that national and local island authorities be encouraged to monitor marine mammal fishery interactions systematically in all net fisheries.

(2) Fishing fleets of the area require better documentation. It is **recommended** that an improved flow of information on marine mammal fishery interactions be achieved, possibly through the South Pacific Regional Environment Programme, which could co-ordinate such data collection.

(3) It is **recommended** that the South Pacific Forum be encouraged to ensure that large scale driftnet fisheries do not operate in this area in view of the impact that such fisheries have had on local tuna stocks as well as their impact on cetaceans and other non-target species.

4.15 Micronesia and Central Pacific region

This region includes Guam, Federated States of Micronesia, Hawaiian Islands (US), Kiribati, Republic of the Marshall Islands, Nauru, Commonwealth of the Northern Mariana Islands (CNMI) and the Republic of Palau. Bottom-set gillnets are widely used in this area to catch a variety of lagoon, reef and nearshore fishes. Fishing operations are typically artisanal/subsistence or small-scale commercial. These fisheries are summarised below. Fisheries of the Hawaiian Islands are considered separately. Detailed information is given by Nitta (SC/O90/G33).

4.15.1 Artisanal and small-scale fisheries

Subsistence or small-scale commercial gillnet fisheries are found on Nauru, Kiribati, Guam, the Northern Mariana Islands, the Republic of Palau, the Federated States of Micronesia and the Republic of the Marshall Islands. Nets are typically bottom-set gillnets which are used to fish for reef fish, nearshore fish and lagoon fish. Common fish types include bigeye scad, mackerel, mullet, wrasses, goatfish and jacks. Nets are set by hand or from small skiffs, canoes or outboard-powered boats. Information on fishing effort is limited to Yap in CNMI where 3,483 gillnet trips were reported for 1987. The gillnet landings on Yap were 35 tonnes that year. The 1988 commercial (including but not exclusively gillnet-caught) landings of bigeye scad and reef fish on Guam were 61 tonnes (worth $215,219) and on CNMI were 4.5 tonnes (worth $19,364). The 1987 commercial landings of reef and lagoon fish for Tarawa (in Kiribati) was 3,628 tonnes (again including but not exclusively gillnet landings). No information was available at the meeting on landings or fishing effort in the other island nations. Some of the outer island villages and councils in the Federated States of Micronesia and the Republic of the Marshall Islands have banned the use of set gillnets in their jurisdictions. No incidents of incidental cetacean mortality in gillnets were reported at the meeting. It was noted, however, that small cetaceans had been taken in the past for subsistence purposes in Kiribati and the Marshall Islands.

4.15.2 Surround-net and gillnet fisheries in Hawaii

Inshore set gillnets are used to catch a variety of fish on reef flats, in bays and in nearshore areas around all of the main Hawaiian Islands. Species include bigeye and mackerel scad, squirrelfish, aholehole, goatfish, rudderfish, wrasse, parrotfish, surgeonfish and tangs. Surround nets are used to catch akule and opelu. Of 2,952 applications for commercial fishing licenses in Hawaii, 498 listed nets as their primary gear and 169 specified gillnets. The actual number of fishermen using gillnets is probably greater than 169. Vessels are typically 10–30ft (3–9m). Commercial landings in 1988 for reef fish, akule and opelu were 120 tonnes, 146 tonnes and 124 tonnes, respectively. Values of these landings were $441,220, $592,964 and $438,845, respectively. Marine mammals reported taken in these fisheries include spinner dolphins and one monk seal. Humpback whales may also be entangled, but there are no confirmed reports of this.

4.15.3 Recommendations

(1) It is **recommended** that fisheries data collection programmes be developed and implemented in those areas where they are currently lacking.

(2) It is **recommended** that the appropriate US agency be urged to assist the Freely Associated States of the Federated States of Micronesia and the republic of the Marshall Islands in developing counterpart legislation similar to the US Marine Mammal Protection Act and Endangered Species Act. Similar assistance should be provided to Palau.

4.16 Japan coastal region

There are many trap net fisheries in Japanese coastal waters. These can be divided into large- and small-scale trap nets for miscellaneous coastal fishes throughout Japan and a large-scale trap net fishery for salmon in Hokkaido and northern Japan. Summaries of information on these fisheries are presented below. The Japanese large-scale driftnet fisheries originated in Japanese coastal waters, but Japan now prohibits the use of large driftnets within its 200 mile zone because of conflicts with other types of gear which were already used before the introduction of this technique (United Nations, 1990). Detailed information on trap net fisheries is given by Tobayama *et al.* (SC/O90/G36).

4.16.1 Japan coastal small-scale trap net fishery

Small-scale trap fisheries for a large variety of fish species are found along much of the Japanese coast. Typically the water depth at the pocket is less than 27m. There were 14,591 such fish traps in 1988 (this number has varied between 14,324 and 16,123 over the past 11 years). The total landings were 191,523 tonnes in 1988 and were worth $424 million. Some of the 14 cetacean species listed in SC/O90/G36 could have been taken, but there are no statistics specifically for bycatch in this fishery.

4.16.2 Northern Japan coastal large-scale trap net fishery for salmon

Salmon are taken in large-scale trap fisheries in Hokkaido. In these traps, water depth at the pocket exceeds 27m. The number of nets has been stable, varying between 674 and 778 over the past 11 years. Most of the traps are 1–2km long and are fished from summer to autumn. The catch was 92,497 tonnes in 1988 and was worth $481 million. Some of the 14 cetacean species listed in SC/O90/G36 could have been taken, but there are no statistics specifically for bycatch in this fishery.

4.16.3 Japan coastal large-scale trap net fishery

Large-scale trap fisheries for a variety of fish species exist along the Japanese coast. This fishery is limited to water depths at the pocket of greater than 27m (with some exceptions in Okinawa and the inland sea). The number of nets has been stable, with fluctuations between 791 and 909 over the past 11 years. Most traps are fished year-round. Total catches were 363,766 tonnes in 1988 and were worth $500 million.

4.16.4 Recommendation

It is **recommended** that collection of statistics on the incidental capture of marine mammals in trap and gillnet fisheries in Japan be improved.

4.17 Korean coastal region
No information was made available to the meeting. A fishery yearbook for 1987 reported that 39,921 tonnes of fish were landed from 'large gillnets', 58,539 tonnes from 'small gillnets', 21,421 tonnes from 'large set nets' and 32,508 tonnes from 'small set nets' (Ministry of Agriculture, Forestry and Fisheries, 1988). There is no information available on incidental catches of cetaceans, but it must be assumed that some does occur and it is **recommended** that the national government begin efforts to collect such information.

4.18 China, Taiwan Insular region
Chen (1990) noted that bottlenose dolphins are taken in gillnets in China, Taiwan but did not specify if these are incidental or directed takes. In 1989, a variety of local (as opposed to far-seas) coastal and offshore fisheries using drift and set nets landed over 55,135 metric tonnes of fish and crustaceans caught in China, Taiwanese or adjacent waters, of nearly 100 species (Taiwan Fisheries Bureau, 1990). Information on bycatches is badly needed and it is **recommended** that the national government establish a programme to collect the information.

4.19 Mainland China region
There are a huge number of coastal and freshwater fisheries in Chinese waters that have the potential to impact cetacean populations. Until recently, and with the exception of the baiji, incidental captures of cetaceans have received little study. Since 1983, however, a total of 74 finless porpoise specimens have been recovered by researchers from passive fishing gear in Jiangsu province. [The highly endangered baiji continues to be threatened by incidental mortality in rolling hook longlines – a type of gear not discussed at this meeting]. The carcasses of other small cetaceans killed in coastal fisheries may be used locally for livestock feed. Chinese fisheries are reviewed by Zhou in SC/O90/G21.

4.19.1 Drift gillnets
These nets are widely used in Chinese coastal waters to take a great variety of target species. Mesh sizes vary from 4–16cm, depending on the target species. Unknown numbers of finless porpoises are taken by these nets in coastal waters and in the Yangtze River. Other species are probably also taken, although there are few records of entanglement. Rough estimates indicate that there may be as many as 10,000 drift gillnet vessels active in Chinese coastal waters.

4.19.2 Set gillnets
At least eighteen varieties of set gillnets are used in Chinese waters, with mesh sizes varying from 5.6–32cm. Although the nets are extensively used in shallow inshore waters, there are no data on cetacean entanglements. Approximately 7,000 set gillnet vessels operate along the Chinese coast.

4.19.3 Stow nets
These fixed traps are important components of the coastal fisheries of the East China Sea, Yellow Sea and Bohai Sea. Fish, shrimp and crabs are transported by nearshore currents into these nets. The nets are divided into six major categories, depending on their structural configuration. Finless porpoises are known to be taken by Chinese stow nets. As many as 20,000 vessels are used in the Chinese stow net fishery.

4.19.4 Fish traps
Three major types of traps (other than stow nets) are used in both fresh and salt water to take a variety of species. Finless porpoises and false killer whales are taken alive by traps in coastal waters and occasionally transported to zoos and aquaria. Baiji are sometimes captured by stake net traps set in the lower Yangtze.

4.19.5 Recommendations
(1) A general system to monitor the levels of marine mammal mortality in gillnet, stow net, trap and longline fisheries off the Chinese coast is urgently needed and it is **strongly recommended** that such a system be established as soon as possible.
(2) The population status of the finless porpoise should be studied urgently. Although data are lacking for the Indo-Pacific hump-backed dolphin, it is believed that this coastal species may also be threatened by incidental catches in fishing gear. It is **recommended** that studies of the two species be initiated.
(3) It is **recommended** that urgent measures be taken to strictly enforce the ban on longline snag fisheries ('rolling hooks') in the Yangtse.

4.20 Eastern North Pacific and Russian Far East region
This region includes the west coast of the USA and Canada and the east coast of the Russian Federation. Several of the more important gillnet and trap fisheries are summarised below. Not included in the summaries is the discontinued joint-venture driftnet fishery for flying squid in Canada. More detailed information is available in Barlow *et al.* (SC/O90/G29) and Burkanov (SC/O90/G10).

4.20.1 California drift gillnet fishery for swordfish and sharks
Nylon mono- and 3-filament nets are used to catch shark and swordfish in the offshore waters of California. Nets are 500–1,000 fathoms long (910–1,820m) and have a 18–24" (45–60cm) mesh. Vessels are approximately 30–75ft (9–23m) in length and carry a crew of 2–6 fishermen. There are 185 permits to participate in this fishery, but only 150 are active. The total effort consisted of approximately 8–10,000 net pulls per year, with a slight decrease in recent years. Nets are suspended 2–5m below the surface and are only allowed to soak at night. Assuming an average length of 750 fathoms (1,370m), total effort is about 10,000KND. Cetaceans taken have included gray, minke, Hubb's and Cuvier's beaked whales, common dolphins, northern right whale dolphins, short-finned pilot whales, Pacific white-sided dolphins, Risso's dolphins and killer whales. Annual mortality rates have been estimated only for California sea lions (150–5,100), harbour seals (0–150) and rorquals (73).

4.20.2 California set gillnet fishery for halibut and angel sharks
Bottom-set gillnets are used to catch halibut in central and southern California and angel sharks in southern California. Vessels range from 15–40ft (4.5–12m) in length and have crews of 1–3 fishermen. Currently there are 200 permits, but only 189 are actively fishing. Nets are made of nylon mono- or multi-filament with a mesh size of approximately 8" (20cm). Nets are 150–200 fathoms (275–365m) long. In 1986/87, about 30,000 sets were made for a

total fishing effort of 8–11,000KND. Effort is decreasing in central California and may be stable or decreasing in southern California, largely due to the impact of gillnet regulations. Annual marine mammal mortality has been estimated for harbour porpoises (50–300), gray whales (<10), California sea lions (2,000–4,000) and harbour seals (1,000–2,000).

4.20.3 Washington bottom-set gillnet fishery for salmon
A small fishery exists for chinook salmon in northern Washington State. This fishery is unique in that it uses bottom-set gillnets rather than the more typically floating gillnets for salmon. The fishery is run by native Americans. Vessels are typically small (16–24ft/5–7.5m). Mono- and multi-filament nylon nets are used, with mesh sizes of 7.75–8.5" (19.5–21.5cm). There are 6–10 vessels fishing a total of about 1,300–2,600 net-days each year. Total effort is thus about 240–480KND. Annual marine mammal catches include harbour porpoises (20–100) and minke whales (0–1).

4.20.4 Alaska and British Columbia driftnet fisheries for salmon
There are many separate areas where drift gillnets are allowed in Alaska and Canada. Although the fisheries may be regulated separately, the methods used are similar and all are combined for this summary. Nylon multifilament nets are used with lengths of 135–550m and mesh sizes of 4.5–8.5" (11.5–21.5cm). Vessels are typically 7–12m in length. The number of vessels is limited by the number of permits. Currently there are 3,230 license holders in Canada and 3,487 in the USA. Fishing effort is fairly stable, but catch varies with the strength of the salmon runs. Landings in 1988 were approximately 100,000 tonnes and were worth approximately $647m. Marine mammal mortality in nets includes mostly harbour porpoises, Dall's porpoises, white whales and harbour seals. Mortality rates have not been estimated for most of this region.

4.20.5 Alaska set gillnet fisheries for salmon
Again, there are many separate areas where set gillnets are allowed for salmon fishing. All such areas are considered together in this review. Set gillnets are used to catch all five Pacific salmon species. Nets are 15–150 fathoms (27–275m) in length and are usually set to float at the surface, perpendicular to the shore. Nets are typically set with small (4–8m) vessels. There are 4,172 permit-holders allowed to fish with set gillnets in Alaska. The total value of landings was in excess of $140m in 1988.

4.20.6 Salmon trap fisheries in the Kamchatka region
In eastern Russia, salmon are caught almost exclusively in trap nets. Gillnet fishing is not allowed, but is carried out illegally by vessels from several countries. Approximately 100 traps (100m x 800m dimension) are in the Kamchatka region. Each is operated by approximately 10–12 fishermen. The traps are typically operated 70–75 days each year. Fishing effort varies with the strength of the salmon run. About 40–60,000 tonnes of salmon are landed each year and total landings are worth 24–36 million rubles. The only historical records of cetacean mortality include one narwhal and one gray whale (which was released). Seals (*Phoca larga*) commonly are found inside and outside the trap and are frequently shot. One stranded North Pacific right whale was found entangled in net fragments.

4.20.7 Bottom long-line fisheries in Kamchatka and Okhotsk Sea
Longlines are used to catch cod in eastern Russia. Vessels are large (500 tonnes) and fish one 51km line per vessel. There are 10 vessels in the fleet, each of which fish 120 days per year. Fishing effort is currently up. There are no known records of marine mammal mortality in this fishery.

4.20.8 Crab trap fisheries in the Kamchatka region
Crab traps are fished by large (300–900 tonne) vessels in eastern Russia. There are 50–80 vessels, each with 18–30 fishermen. Each vessel fishes approximately 450 traps during a 120–180 day fishing season. The fishery is stable. Marine mammal mortality has involved gray whales (only one known case) and seals (*Phoca larga* and probably *Phoca hispida*).

4.20.9 Recommendations
(1) It is **recommended** that baseline data be gathered on levels of marine mammal mortality for all fisheries in the region based on direct observations and other appropriate methodology. Fisheries which are found to have a significant level of marine mammal mortality should be continuously monitored.
(2) The population size of those species most likely to be affected by fishing mortality should be estimated. For most species it is **recommended** that this include determining stock boundaries, abundance and seasonal distribution. When possible, trends in abundance should also be measured.

4.21 Southeastern Pacific region
The mortality of cetaceans is known to be high in some areas within this region, which includes Ecuador (including Galapagos Islands), Peru and Chile (including Easter Island). Information from Ecuador is scarce, but the coastal artisanal and industrial fisheries of Peru and Chile are thoroughly described by Reyes and Oporto (SC/O90/G11). In central Peru small cetaceans are used for human consumption; in Chile, the meat from dolphins and porpoises is often used for bait.

4.21.1 Swordfish driftnet fishery
This fishery operates in Chilean waters from 15 to 200 n.miles from shore. The target species is swordfish, captured in driftnets up to 2.2km in length and 29–45m deep. The mesh size employed in this fishery varies from 45–56cm. Approximately 800 vessels are active in this fishery, which is currently stable or increasing in size. Landings in 1989 reached 5,824 tonnes, with a value of between $12 and $25m. An unknown number of sperm whales, killer whales and southern right whale dolphins are taken in these driftnets. It is interesting to note the similarities between this fishery and the former Italian swordfish driftnet fishery in gear type, operation and the incidental catch of sperm whales.

4.21.2 Chilean bottom set net fishery
Ratfish and sciaenids are taken in demersal set gillnets in southern Chilean coastal waters. The nets are made of 15cm mesh and vary in length, depending on the location, from 200–800m and are from 4–6m deep. The nets are set in water depths of 15–80m and allowed to soak for 10–12 hours. In 1989, 57 Burmeister's porpoises and 51 Chilean dolphins were landed; catches of Peale's dolphins are also occasionally recorded. Approximately 90 small vessels are active in the fishery, but this number is expected to triple in the next few years.

4.21.3 Chilean salmon cage fishery
Peale's dolphins, together with sea lions and fur seals, are occasionally captured in anti-predator nets set around salmon aquaculture operations in Chilean waters. These anti-predator nets are made of 47cm mesh. The numbers of dolphins killed is unknown, but there are about 3,400 active salmon cages operating in this expanding industry.

4.21.4 Ecuadorian gillnet fisheries
This category encompasses a variety of disparate fisheries that operate in both coastal and offshore areas. Cotton and monofilament nets are used, with mesh sizes of 5–20cm and lengths of 70–200m, depending on the target species. The nets are set for a variety of fishes, from sharks and billfish to jacks and catfishes. Bottlenose and pantropical spotted dolphins are taken in these fisheries in relatively small numbers.

4.21.5 Peruvian gillnet fisheries
A diverse group of artisanal gillnet fisheries exists in Peruvian waters. These fisheries target a variety of species, ranging from bonito and blue sharks to demersal rays. The mesh size varies with target species from 3–44cm. The nets are constructed from multifilament and are from 70–270m in length and from 2–27m deep and may be operated as both bottom set and surface driftnets. Approximately 2,600 artisanal vessels are active in this growing fishery. The minimum count at one port in central Peru was 868 Burmeister's porpoises, 5,115 dusky dolphins, 476 common dolphins, 132 bottlenose dolphins and smaller numbers of 11 other odontocete species landed between 1985 and 1989. In addition, at least one humpback whale was entangled but released alive.

Gillnet fisheries in Peru blur the traditional distinction between directed and incidental take, because all small cetaceans are used for human consumption. Thus, captures of dolphins and porpoises are welcomed by fishermen as additional sources of income. In several cases, such as the offshore driftnet fishery, dusky dolphins and other odontocetes have themselves become the target species. It is likely that the utilisation of cetacean bycatches in this manner developed after the crash of the industrial anchoveta fishery in 1972.

4.21.6 Recommendations
(1) It is **recommended** that national fisheries agencies in the region should collect and report fishery statistics separately for gillnets and for other types of gear.
(2) It is **recommended** that information be obtained on cetacean entanglement in the swordfish and set net fisheries of Chile.
(3) It is **recommended** that all three nations collect more comprehensive statistics on cetacean catches and in number rather than weight.
(4) Alternative fishing methods should be sought to reduce marine mammal mortality without affecting fishery yields. It is **recommended** that technological programmes to this end be established.
(5) The crab fishery in Chilean and Argentine waters needs further study and an alternative to wildlife meat as crab bait needs to be found; it is **recommended** that a regional effort to do this be initiated.
(6) It is **recommended** that regional cooperative educational programmes be developed to highlight the problem of cetacean mortality in fishing operations.
(7) It is **recommended** that the impacts of marine farming on cetacean populations in Chile receive urgent attention.

4.22 North Pacific Basin (large-scale pelagic driftnet fisheries)
Driftnet fisheries are conducted in the North Pacific basin by Japan, South Korea and China, Taiwan. Detailed information is given by Jones *et al.* (SC/O90/G43), Nagao (SC/O90/G55) Northridge (SC/O90/G35), Watanabe (SC/O90/G52) and Yatsu (SC/O90/G8),

4.22.1 Japanese salmon drift gillnet fishery
Surface driftnets are set for Pacific salmonids (pink, sockeye, chum, coho and chinook) by mothership and landbased fleets in the western North Pacific and the Bering Sea. Nets are nylon monofilament of 11–13cm stretched mesh. Regulations require vessels to set no more than 15km of net, which is usually deployed in three sections. Vessels in each fishery are mostly less than 30m in length. The mothership fleet included 43 catcherboats in 1989 and operated from June 1 to early July. Vessels averaged 30 fishing days. Effort was approximately 19,350KND. Landings totalled about 1,150 tonnes of salmon. The landbased fleet operates from late May through June and totalled 108 vessels in 1989. Vessels also average 30 fishing days. Effort was approximately 48,600KND. Total landings were about 2,040 tonnes. There is a definite downward trend in this fishery. The predominate cetacean bycatch is of Dall's porpoises. US observers were placed in the mothership fleet inside the US EEZ from 1981 to 1987. Annual point estimates of the take ranged from 741 to 4,187 Dall's porpoises, the latter number occurring in 1982. A few harbour porpoises were also taken. Northern fur seals are incidentally taken.

4.22.2 Drift squid gillnet fishery
Japan, the Republic of Korea (ROK) and China, Taiwan operate fleets in the North Pacific targeting on neon flying squid (*Ommastrephes bartrami*). In 1989, a joint Japan-Canada-USA programme placed observers on 32 vessels. This programme has been expanded to 74 vessels in 1990. Joint programmes were arranged between the USA and China, Taiwan and the USA and ROK in 1989 as well, placing observers at sea in 1990. Information on the Japanese fishery is more complete and will be discussed separately.

The Japanese squid driftnet fleet includes 457 vessels and approximately 8,000 fishermen in 1990. The area of operation is the North Central Pacific, from 20°N-46°N (mostly north of 38°) and 170°E-145°W. The season is June-December, peaking in July-August. Vessels are 25–60m in length. The gear is nylon monofilament surface gillnet, usually 11–12cm stretch mesh. Data collected in 1989 indicated that an average of approximately 50km/vessel/day was set. There were 33,646 days fished in 1989, with 1,719,311km of net fished. The value of the 157,773 tonnes of squid landed in 1988 was $300m. The number of vessels in the fishery appears to be stable. Data from the 1989 pilot observer programme yielded the following catch-rates (per 50km of net): northern right-whale dolphin = 0.32; Pacific white-sided dolphin = 0.18; Dall's porpoise = 0.10; common dolphin = 0.01; others/unknown = 0.04. The catch rate for all cetaceans was 0.64 per 50km of net. Scientists from Canada, Japan and the USA will be

analysing the data to estimate the catch for the entire fishery in the near future. Statistically reliable catch rates will be obtained from the 1990 observer programme.

China, Taiwanese and ROK squid driftnet fleets operate in the North Pacific between early March and late December. Fishing peaks in July-August. The area of operation is similar to that of the Japanese fleet, although both nations fish west of 170° East. Vessels range in size from 29–70m. There are approximately 150 Korean and 27 China, Taiwanese vessels with about 3,500 to 4,600 crew total. Vessels deploy surface gillnets of 7.5–13cm stretch mesh. Nets are usually 10–11m deep and up to 60 km or more in length. They are set out in 3 to 6 discrete sections. There is a trend towards fewer vessels, although the amount of gear deployed per vessel has increased. Effort data will be available after observers return from sea. The cetacean bycatch is undocumented, although the species taken will likely be similar to those of the Japanese fleet. Cetacean incidental take rates may differ from those in the Japanese fleets because smaller mesh sizes are used and different areas are fished.

4.22.3 Japanese large mesh drift gillnet fishery

Japanese vessels targeting on albacore and skipjack tuna, swordfish and marlin use nylon multifilament 170–210mm stretch mesh. The area of operation is north of 10°N, south of the squid fishing area, from approximately 145°W to Japan. This includes both coastal and high seas vessels, totalling 459 in 1988 (there will be less than 200 vessels in the high seas in the 1990/91 season). Coastal vessels set approximately 12km of net and high seas vessels set approximately 20–50km. The fishery is valued at $70m, with 25,000 to 40,000 tonnes landed including 7,000–15,000 tonnes of albacore. There appears to be a stable or downward trend in fishing effort. Cetacean catch rates on high seas vessels will be obtained during the 1990 joint observer programme. Reports from a research cruise indicate the species taken includes Northern right whale, common, Pacific white-sided, striped, bottlenose, Risso's and spotted dolphins, pygmy killer whales, pygmy sperm whales and ziphiids.

4.22.4 China, Taiwanese large mesh drift gillnet fishery

China, Taiwanese vessels of 29–70m length operate in the North Pacific targeting on albacore and skipjack tuna, swordfish and marlin. Little is known of these fleets, although USA and China, Taiwanese observers will monitor fishing activities on about 20 of 123 vessels in the 1990 season. Fishing is mostly between May and November, north of 20°N and south of the squid fishing area. There are probably 2,000–3,000 fishermen of several different nations, including China, Taiwan, the Philippines, Thailand and South Africa. Limited information indicates nets are nylon multifilament, 18–21cm stretch mesh and from 6.5 to 21m deep. Normal net depth is 10–11m. Cetacean bycatch is unknown but probably includes many of the same species seen in the squid driftnet fishery. Several warmer-water species may be taken as well.

4.22.5 Recommendations

(1) Japan, Canada, Korea, the USA and China, Taiwan are to be commended for the establishment of an international programme to collect data on incidental catches in the North Pacific. It is **recommended** that, should these fisheries continue, the observer programme continue to collect statistically adequate data.

(2) It is **recommended** that the data collected on mammals taken in the squid driftnet and large mesh driftnet fisheries be analysed as soon as possible.

4.23 South Pacific Basin (large-scale pelagic driftnet fisheries)

This area has experienced extensive driftnet activity in recent years. Vessels from Japan, ROK and China, Taiwan have been active, although recent conservation measures have greatly affected the composition of the fishery. Northridge (SC/O90/G35) provides a review of this fishing activity. Additional information is provided by Hagler (1990), Coffey and Grace (1990), Murray (1990), Watanabe (1990) and Sharples *et al.* (1989).

4.23.1 Large-mesh driftnet fishery

Albacore and other large pelagic species are captured in driftnets between 20 and 55 km long, 10–15m deep and with mesh sizes of 16–20cm. The fishery operates in the Tasman Sea and in the waters east of New Zealand. Large-mesh driftnetting in this area was started in 1983 by Japanese vessels. By the 1988–89 season the fishery included 64 Japanese vessels, between 60 and 130 China, Taiwanese vessels and a single Korean fishery survey vessel. In 1988, catches by the Japanese fleet alone had reached 4,801 tonnes. These driftnets are known to have taken a variety of cetaceans, including common, striped and Risso's dolphins, short-finned pilot whales and southern bottlenose whales. Estimates of entanglement rates for common dolphins have varied between 56 and 70 individuals per 1,000km.

Concern over conservation of both tuna and non-target species gave rise to the Tarawa Declaration, adopted by the South Pacific Forum in 1989. The Declaration resolved to prevent and discourage the practice of driftnetting in the region. The Japanese fleet has since withdrawn from the area and China, Taiwan has indicated that it will also cease driftnetting activity in the South Pacific. There are currently no Korean vessels active in the region.

4.24 Indian Ocean Basin (large-scale pelagic driftnet fisheries)

The only large scale driftnet fishery that exists in this region is the China, Taiwanese high seas large-mesh driftnet fishery. Information was provided by Northridge (SC/O90/G35) and Cockcroft (SC/O90/G20).

4.24.1 Large-mesh driftnet fishery

There is little published information on this China, Taiwanese fishery. Albacore is the primary target species, but a variety of large pelagic fish are also captured. The gear used is similar to that used in other high seas driftnet fisheries: mesh sizes of 20–22cm, total net lengths of 37–47km and net depth of 2–24m. There are no data on actual fishing effort, but most fishing activity is concentrated in either the Arabian Sea or southern Indian Ocean. The fishery was started in 1985 and by 1989 included 139 vessels, with evidence of continued expansion. Catch estimates for 1989 were 19,523 tonnes. No data on cetacean entanglements are available, although incidental catches are likely to be substantial. Additional information is given in Indian Ocean Fishery Commission (1990).

4.25 North Atlantic Basin (large-scale pelagic driftnet fisheries)

The only documented large-scale driftnet fishery in the North Atlantic is the new and rapidly growing French

albacore fishery (SC/O90/G35,G53). The fishery has also been entered recently by Ireland on an experimental basis. There is circumstantial evidence that a China, Taiwanese driftnet fleet may also be operating in the North Atlantic (SC/O90/G35).

4.25.1 French albacore driftnet fishery

This fishery began as an experimental fishery in 1986. The primary target species is albacore, but bluefin tuna and swordfish are also taken. The area fished includes the offshore Bay of Biscay and waters extending from near the Azores to south of Ireland. The net mesh size ranges from 8–12cm; individual net panels are 50m long and 20–36m deep, with a hanging ratio of 0.6. Total net length ranges from 2,500 to 7,000m and varies with vessel size; a 20km net was reported observed by Greenpeace. The 37 vessels in the fleet in 1989 were all less than 25m long. The fishery has grown rapidly since its inception and is still expanding. The fishing season is approximately 3.5 months long, yielding a rough estimate of several hundred thousand KND per year. The catch in 1988 was 750 tonnes. Cetaceans known to be taken incidentally include striped, common and bottlenose dolphins. Other species are probably also taken. The incidental catches have been estimated at 131 dolphins in 1989 and 420–460 in 1990, at a rate of 0.03 to 0.08 per km of net (Antoine, 1990). There is no information on the bycatches in an Irish experimental fishery in the same region.

4.25.2 China, Taiwanese tuna/squid driftnet fishery

China, Taiwanese driftnet vessels have been seen in Port of Spain Harbour, Trinidad with driftnets stacked on their rear decks. The China, Taiwanese Government has stated that the nets are for flying squid rather than for tuna. Possible areas of fishing include off the mouth of the Amazon, in the region of the Azores and off West Africa. Nothing is known of landings or incidental catches.

4.26 South Atlantic Basin (large-scale pelagic driftnet fisheries)

An unacknowledged China, Taiwanese driftnet fishery for tuna exists in the South Atlantic (SC/O90/G4, G20, G35).

4.26.1 China, Taiwanese albacore driftnet fishery

A fleet of perhaps several hundred China, Taiwanese driftnet vessels is known to fish in the vicinity of the South Atlantic islands of Tristan da Cunha and Gough and farther to the east. One vessel that went aground in South African waters carried 145km of driftnetting. There is no information available on landings. Increased discharges and transshipments of frozen tuna in Cape Town indicate that the fishery has been rapidly expanding. Based on reports for one month on the fishing grounds and a total of 500 vessel months, 7,500–10,000 dolphins and 1,000–1,500 small whales may be killed annually; the species make-up of this bycatch is unknown.

5. IMPACTS ON SPECIES AND POPULATIONS

DeMaster chaired the sub-group established to evaluate the impact of passive nets and trap fisheries on species and populations of cetaceans. Hohn and Heyning served as rapporteurs and compiled the initial versions of this section of the report, with the assistance of Brownell, Perrin and Forney.

The terms of reference given by the IWC Scientific Committee were to estimate the mortality of cetaceans in passive nets and trap fisheries and assess the impact of that mortality on cetacean populations. The agenda included examination of what might constitute sustainable kill levels; identifying fisheries with kills clearly not sustainable, possibly not sustainable and sustainable; summarising the age and sex composition of the kill, summarising information on population trends, providing preliminary estimates of net replacement rates for populations under sustainable exploitation, and discussing problems of stock identity and their implications. It was agreed to accomplish this by constructing a table that listed, by species and stock or geographic region: (1) the annual level of kill in passive nets and traps; (2) the approximate annual level of mortality from other sources, including directed fisheries, incidental mortality in non-passive gear and accidental mortality such as boat collisions; (3) population size; and (4) the impact of the kill in passive nets and traps. Other relevant information is given below as notes to the table.

The impact of mortality in passive nets and traps on populations was calculated from estimated kills and population size, where possible. In addition, the impact was categorised as to the severity of the mortality to the population. For those few populations for which the level of mortality, population size and replacement rates were known or could be reasonably estimated, this task was relatively easy. For most populations, however, this evaluation was made on the basis of very scanty information, reflecting knowledge of the fisheries and very rough estimates of possible or probable levels of mortality in passive fishing nets and traps.

5.1 Definitions

The various broad levels of impact used in the table are defined below.

(1) *Not sustainable.* Kill and population data indicate that the mortality rate exceeds the expected replacement rate of the population.

(2) *Possibly not sustainable.* Kill and population data indicate that the mortality rate is close to the expected replacement rate of the population, giving reason to believe that the population may decline.

(3) *Potential.* Adequate data on kill, population size or both are lacking. The available data suggest that the kills may not be sustainable. More data need to be collected. For cases where adequate data were not available but information from similar situations/areas/species was available and indicated that the kill was not sustainable, it was considered likely that the population in question probably cannot sustain the kill.

(4) *Minimal.* Data suggest some impact on the population although mortality rates do not exceed the level that should cause an immediate decline in the population.

(5) *Not significant.* Mortality in passive gear is known to occur, but data suggest that the levels are low relative to population size.

(6) *Unknown.* Used when sufficient data for even the crudest evaluation were unavailable.

The members of the sub-group were assigned species/regional reviews and asked to complete a form that was drafted to help members compile the information in a consistent manner. These data were tabulated and re-examined by the sub-group for consistency, as possible.

Table 1

A summary of information on the number of cetaceans killed annually by passive gear and impacts of these mortalities on the populations. Stocks are not listed if the workshop received no data or was not aware of any data confirming kills in such fisheries. Population estimates were obtained from the literature or from workshop participants. Species are presented by known stock or geographic regions where data were available. Stocks/areas with unsustainable catches are highlighted in bold text. *This Table must be used in conjunction with the extensive annotations given in the text of Section 5.*

Terms, abbreviations and symbols used in the table:

No. killed p.a. - refers to annual kills in passive gear and traps only; '>' or '<' beside the number indicates that the figure represents a minimum or maximum, respectively. A minimum estimate might be available because the sampling effort was low relative to likely fishing effort, e.g., only a small number of fishing ports were observed. A maximum may be given if the mean mortality is less than a whole number and the estimate is rounded up, generally done when fewer than one animal was recorded killed per year or if the number places a likely upper bound on the kill.

Additional killed p.a. - refers to annual kills caused by other forms of non-natural mortality, such as kills in non-passive gear, directed kills and accidental kills such as boat collisions. '>' or '<' has the same meaning as above.

Population size - abundance was unknown for most populations. For some populations/regions, an abundance estimate was not available but the population was suspected to be small '(small?)'. When the population size given is thought to be a minimum or maximum, the estimate is preceded by '>' or '<', respectively.

Impact of passive kill - when data were available, the percentage of the population killed annually in passive nets and traps is given. In addition, five qualitative levels of impact are used: not sustainable; maybe not sustainable; potential; minimal; and not significant. A '*' beside the designation 'potential' indicates that although the population size is unknown, it is thought to be low relative to the magnitude of kill in passive gear.

Species and stock/area	*No. killed p.a.*	*Additional killed p.a.*	*Population size*	*Impact of passive kill (% of popn)*
		Family Balaenidae		
Eubalaena australis, southern right whale				
S. Africa	< 1	unknown	1200	<0.2: minimal
New Zealand	< 1	unknown	unknown	unknown
Eubalaena glacialis, northern right whale				
Western N. Atlantic	< 1	some	> 350	< 0.3: maybe not sustainable
N. Pacific	< 1	0	50	< 2: maybe not sustainable
Caperea marginata, pygmy right whale				
Coast of S. Africa	< 1	none	unknown	unknown
		Family Eschrichtiidae		
Eschrichtius robustus, gray whale				
N. Pacific - eastern stock	low tens	> 179	21,000	< 0.5: not significant
		Family Balaenopteridae		
Balaenoptera spp., unidentified rorqual				
Caribbean	some	unknown	unknown	unknown
B. acutorostrata, minke whale				
Mediterranean	< 4	unknown	rare	minimal
Western N. Atlantic	10-20	some	unknown	unknown
Eastern N. Atlantic	some	some	unknown	unknown
Southern Hemisphere	some	300	750,000	not significant
Western N. Pacific	< 10	0	unknown	unknown
Eastern N. Pacific	low tens	some	unknown	unknown
B. edeni, Bryde's whale				
Coastal Brazil	< 1	unknown	unknown	unknown
B. physalus, fin whale				
Mediterranean	< 1	some	< 1,000	0.1: minimal
Eastern Canadian coast	< 1	unknown	low 1,000's	< 0.1: not significant
Northern Indian Ocean	< 1	some	unknown	unknown
Megaptera novaeangliae, humpback whale				
Western N. Atlantic	5-20	< 3	5,500	< 0.4: minimal
Indian Ocean	some	0	small?	unknown
Western N. Pacific	some	0	small?	potential
Hawaii - Alaska	< 2	0	> 1,000	< 0.2: minimal
Mexico - California	some	0	250	potential
Coastal Peru	< 1	0	low 100s?	minimal
		Family Platanistidae		
Platanista gangetica, Ganges susu	some	some	unknown	unknown
		Family Iniidae		
***Lipotes vexillifer*, baiji**	**some**	**some**	**300**	**not sustainable**
Pontoporia blainvillei, franciscana				
Southern Brazil	90	unknown	unknown	potential
Uruguay and northern Argentina	> 230	some	unknown	unknown
Inia geoffrensis, boto	some	some	unknown	unknown

Table 1 continued

Species and stock/area	*No. killed p.a.*	*Additional killed p.a.*	*Population size*	*Impact of passive kill (% of popn)*
		Family Monodontidae		
Delphinapterus leucas, white whale				
Bristol Bay	< 30	19	1,000-1,500	< 2-3: maybe not sustainable
Cook Inlet	some	10	300-450	unknown
		Family Phocoenidae		
Australophocaena dioptrica, spectacled porpoise	unknown	unknown	unknown	unknown
Neophocaena phocaenoides, finless porpoise				
Thailand/Pakistan/India	some	some	unknown	unknown
Yangtze River	10-20	unknown	1,500	0.7-1.3: minimal
Yellow Sea	50	unknown	unknown	unknown
Coastal Japan	some	some	2,500	unknown
Phocoena phocoena, harbour porpoise				
Baltic	some	0	unknown	potential
Kattegat and Belt Seas	200	none	8,000	2.5: maybe not sustainable
North Sea area, incl. Faroe Is.	100-700	some	82,000	0.1-0.9: sustainable
Northern Norway, Barents Sea	100	several	11,000	0.9: sustainable
France, Portugal	some	unknown	unknown	unknown
Western Greenland	800	unknown	unknown	potential
Newfoundland to western Greenland	3,000-4,000	unknown	unknown	potential
Gulf of St. Lawrence and Nova Scotia	600-2,000	unknown	unknown	potential
NE coast USA, Bay of Fundy, SW Nova Scotia	**300-800**	**unknown**	**> 8,000**	**4-10: not sustainable.**
West Africa	> 30	unknown	small?	potential
Coastal Japan	some	0	unknown	potential
Central N. Pacific/Bering Sea/Alaska	0-2	some	unknown	unknown
Prince William Sound/Copper River Delta	low tens	some	unknown	unknown
British Columbia	some	unknown	unknown	potential
Northern Washington State	20-100	0	< 1,000	> 3-15: maybe not sustainable
Central California	50-300	unknown	3,000	1.7-13: maybe not sustainable
***P. sinus*, vaquita**	**30-40**	**7**	**few hundred**	**not sustainable**
P. spinipinnis, Burmeister's porpoise				
Coastal Uruguay	some	some	unknown	unknown
Coastal Argentina	> 12	some	unknown	unknown
Eastern S. Pacific - Peru and Chile	> 450	unknown	unknown	potential
Phocoenoides dalli, Dall's porpoise				
Sea of Japan/Okhotsk Sea	some	unknown	> 47,000	unknown
Truei-type	some	30,000	> 58,000	unknown
Western N. Pacific	741-4,187	unknown	unknown	unknown
Central N. Pacific	> 7,000	unknown	741,000	> 0.9: sustainable
Bering Sea	245-908	unknown	212,000	0.1-0.4: not significant
Eastern N. Pacific	some	some	unknown	unknown
		Family Delphinidae		
Cephalorhynchus eutropia, Chilean dolphin	some	some	unknown	unknown
C. heavisidii, Heaviside's dolphin	some	some	unknown	potential
C. hectori, Hector's dolphin	27-95	0	3,400	0.8-2.8: maybe not sustainable
C. commersonii, Commerson's dolphin				
Coast of southern Argentina	some	some	unknown	unknown
Chile	some	some	unknown	unknown
Delphinus delphis, common dolphin				
Mediterranean	400	some	unknown	unknown
Eastern N. Atlantic	some	unknown	unknown	unknown
Western N. Atlantic	211-422	< 20	31,000	0.7-1.4: sustainable
Brazil region	some	unknown	unknown	unknown
Coastal Argentina	> 8	50-100	unknown	unknown
Coastal West Africa	some	some	unknown	unknown
Eastern S. Atlantic basin	some	unknown	unknown	unknown
Southwestern Indian Ocean basin	> 1,000	some	unknown	unknown
Indian Ocean, coast of S. Africa	33	unknown	15,000	0.23: not significant
Northern Indian Ocean	some	unknown	unknown	potential
Tasman Sea	thousands	unknown	unknown	unknown
Coastal Japan	some	unknown	unknown	unknown
Central N. Pacific	500	unknown	unknown	unknown
Coastal California and Baja California	> 50	unknown	unknown	potential
Coastal Peru (Pucusana and Cerro Azul)	> 50	> 100	unknown	potential
Feresa attenuata, pygmy killer whale				
Coastal Sri Lanka	> 170	unknown	unknown	unknown
Central N. Pacific	some	unknown	unknown	unknown
Coastal Peru	some	unknown	unknown	unknown

Table 1 continued

Species and stock/area	*No. killed p.a.*	*Additional killed p.a.*	*Population size*	*Impact of passive kill (% of popn)*
Globicephala sp., species unidentified				
Western N. Atlantic	54-108	40-50	11,000	0.5-1.0:maybe not sustainable
Globicephala melas, long-finned pilot whale				
Mediterranean	50-100	some	unknown	potential
Atlantic coast of France	some	unknown	unknown	unknown
G. macrorhynchus, short-finned pilot whale				
Caribbean	some	some	unknown	unknown
Northern Indian Ocean	> 100	some	unknown	unknown
Japanese southern form	10	300-700	24,000	< 0.1: not significant
Japanese northern form	some	50	4,200	minimal
Coastal California	some	some	< 100	unknown
Coastal Peru	< 10	unknown	unknown	minimal
Grampus griseus, Risso's dolphin				
Mediterranean	30-100	some	> 3,000	1.7-3.3: maybe not sustainable
Eastern N. Atlantic	some	unknown	unknown	unknown
Western N. Atlantic, coast of USA	76-152	< 5	12,000	0.6-1.2: sustainable
Caribbean (off Columbia)	1	unknown	unknown	minimal
Coastal Sri Lanka	> 1,300	some	unknown	potential
Coastal Japan	some	some	105,000	not significant
Central N. Pacific	some	unknown	unknown	unknown
Pacific coast of USA	some	some	unknown	not significant
Coastal Peru	1	unknown	unknown	minimal
Lagenodelphis hosei, Fraser's dolphin				
Coastal Sri Lanka	> 10	unknown	unknown	potential
Philippines	some	unknown	unknown	unknown
Coastal Japan	some	some	unknown	unknown
Lagenorhynchus acutus, Atlantic white-sided dolphin				
Western N. Atlantic, coast of USA	< 5	< 5	36,000	not significant
L. albirostris, white-beaked dolphin				
Western N. Atlantic	some	unknown	unknown	unknown
L. australis, Peale's dolphin				
Coastal S. America	low tens	some	unknown	unknown
L. obliquidens, Pacific white-sided dolphin				
Coastal Japan	some	some	> 85,000	not significant
Offshore N. Pacific	11,000	0	unknown	potential
Eastern N. Pacific	some	> 100	> 50,000	unknown
L. obscurus, dusky dolphin				
Coastal Argentina	some	some	unknown	unknown
Coastal S. Africa	some	some	unknown	unknown
New Zealand	20-50	unknown	unknown	not significant
Coastal Peru	> 1800	some	unknown	potential
Lissodelphis borealis, northern right whale dolphin				
Central N. Pacific	19,000	unknown	unknown	potential
Pacific coast of N. America	some	unknown	> 45,000	unknown
L. peronii, southern right whale dolphin				
Pacific coast of S. America	> 5	some	unknown	unknown
Orcaella brevirostris, Irrawaddy dolphin	some	some	unknown	unknown
Orcinus orca, killer whale				
Mediterranean	< 1	unknown	rare	minimal
N. Atlantic	some	60-80	unknown	potential
Coastal Argentina	some	0	unknown	unknown
Coastal Sri Lanka	< 1	0	unknown	unknown
Indonesia	some	unknown	unknown	unknown
Central N. Pacific/Bering Sea	< 2	some	unknown	unknown
Eastern N. Pacific	< 1	some	unknown	unknown
Peponocephala electra, melon-headed whale				
Northern Indian Ocean	< 10	some	unknown	unknown
Pseudorca crassidens, false killer whale				
Brazil region	some	unknown	unknown	unknown
Coastal Sri Lanka	> 125	unknown	unknown	unknown
Australasia	> 11	some	unknown	unknown
Coastal China	some	unknown	unknown	unknown
Coastal Japan	some	0-500	16,000	unknown
Coastal Peru	1	unknown	unknown	unknown
Sotalia fluviatilis, tucuxi	>90	some	unknown	unknown

Table 1 continued

Species and stock/area	*No. killed p.a.*	*Additional killed p.a.*	*Population size*	*Impact of passive kill (% of popn)*
Sousa chinensis, Indo-Pacific hump-backed dolphin				
Indian Ocean coast of S. Africa	**7.5**	**unknown**	**< 200**[1]	**4%: not sustainable**
Coastal Sri Lanka	100	some	unknown	potential
Other N. Indian Ocean	some	unknown	unknown	unknown
Australasia	> 100	unknown	unknown	potential
Sousa teuszii, Atlantic hump-backed dolphin				
West coast of Africa	some	unknown	small?	unknown
Stenella attenuata, pantropical spotted dolphin				
Northern Indian Ocean	> 1,500	some	unknown	potential
Australasia	> 130	unknown	unknown	unknown
Philippines	some	unknown	unknown	unknown
Western N. Pacific	some	< 1,000	800,000	unknown
Coastal Peru and Ecuador	some	some	36,000	not significant
S. clymene, clymene dolphin				
Caribbean	1	unknown	unknown	unknown
S. coeruleoalba, striped dolphin				
Mediterranean	**5,000-10,000**	**some**	**> 100,000**	**5: not sustainable**
Eastern N. Atlantic	some	unknown	unknown	unknown
Western N. Atlantic	22-44	unknown	20,000	0.1-0.2: sustainable
Coastal Sri Lanka	> 700	unknown	unknown	potential
Coastal Japan and western N. Pacific	some	2,000-5,000	380,000	potential
S. frontalis, Atlantic spotted dolphin				
Western N. Atlantic	13-26	unknown	unknown	0.1-0.2: not significant
Caribbean	1	unknown	unknown	unknown
Brazil region	some	unknown	unknown	unknown
S. longirostris, spinner dolphin				
Caribbean (off Venezuela)	1	unknown	unknown	unknown
Coastal Sri Lanka	> 4,000	some	unknown	potential
Thailand (dwarf form)	some	some	unknown	unknown
Other northern Indian Ocean	some	unknown	unknown	unknown
Australasia	> 1,000	unknown	unknown	unknown
Philippines	some	unknown	unknown	unknown
Hawaii	some	unknown	unknown	unknown
Steno bredanensis, rough-toothed dolphin				
Mediterranean	some	unknown	rare	unknown
Brazil region	some	unknown	unknown	unknown
Coastal Sri Lanka	> 50	unknown	unknown	unknown
Coastal Japan	some	0-500	unknown	unknown
Tursiops truncatus, bottlenose dolphin				
Mediterranean	110-455	some	> 10,000	1-< 5: maybe not sustainable
Western N. Atlantic (offshore)	81-162	<10	8,000	1-2: maybe not sustainable
Western N. Atlantic (coastal)	15	unknown	1,000	1.5: maybe not sustainable
Gulf of Mexico	some	30	40,000	unknown
Caribbean	some	unknown	unknown	unknown
Brazil and Uruguay	some	unknown	unknown	unknown
Coastal West Africa	< 10	unknown	unknown	unknown
Indian Ocean coast of S. Africa, s. of Natal	**20-23**	**0**	**250**[1]	**8: not sustainable**
Indian Ocean coast of S. Africa, n. of Natal	**11-14**	**0**	**< 1,000**	**>3.7: not sustainable**
Coastal Sri Lanka	> 500	some	unknown	potential
Northern Indian Ocean	some	some	unknown	potential
Australasia	> 1700	unknown	unknown	potential
Western N. Pacific and coastal Japan	some	500-2000	> 35,000	unknown
Coastal California and Gulf of California	some	unknown	unknown	unknown
Pacific coast of S. America	> 30	some	unknown	potential
		Family Ziphiidae		
Ziphiids, species unidentified	some	unknown	unknown	unknown
Berardius arnuxii, Arnoux's beaked whale	some	unknown	unknown	unknown
B. bairdii, Baird's beaked whale	some	57	4,000	unknown
Hyperoodon ampullatus, northern bottlenose whale	some	unknown	unknown	unknown
H. planifrons, southern bottlenose whale	some	unknown	unknown	unknown
Mesoplodon sp., species unidentified				
Western N. Atlantic	120-240	unknown	unknown	potential
Coastal Sri Lanka	> 80	unknown	unknown	unknown

[1] This estimate makes no allowance for the proportion of schools missed, and so may be an underestimate.

Table 1 continued

Species and stock/area	*No. killed p.a.*	*Additional killed p.a.*	*Population size*	*Impact of passive kill (% of popn)*
M. carlhubbsi, Hubbs' beaked whale				
Eastern N. Pacific	low tens	unknown	unknown	unknown
M. densirostris, Blainville's beaked whale				
Coastal Sri Lanka	some	unknown	unknown	unknown
M. peruvianus, pygmy beaked whale	some	unknown	unknown	unknown
Ziphius cavirostris, Cuvier's beaked whale				
Mediterranean	<10	unknown	unknown	unknown
Coastal Sri Lanka	< 1	unknown	unknown	unknown
Western N. Pacific	some	unknown	unknown	unknown
Eastern N. Pacific	low tens	unknown	unknown	unknown
Family Physeteridae				
Physeter macrocephalus, sperm whale				
Mediterranean	20-30	some	< 1	potential
Coastal Sri Lanka	< 5	12-50	unknown	unknown
Eastern N. Pacific	< 2	0	unknown	unknown
Kogia sp., species unidentified				
Central N. Pacific	some	unknown	unknown	unknown
Kogia breviceps, pygmy sperm whale				
Caribbean coast of Colombia	< 1	unknown	unknown	unknown
Coastal Brazil	some	unknown	unknown	unknown
Coastal Sri Lanka	> 80	unknown	unknown	unknown
N. Pacific	some	unknown	unknown	unknown
K. simus, dwarf sperm whale				
Coastal Brazil	some	unknown	unknown	unknown
Coastal Sri Lanka	> 230	unknown	unknown	potential
Coastal Peru (Pucusana)	1	unknown	unknown	unknown

5.2 Populations experiencing levels of mortality that are not sustainable

For seven of the 54 species/populations/regions for which abundance estimates and data on incidental mortality in passive gear were available, the level of mortality in passive gear and traps was determined to be not sustainable.

Two of these species, the baiji and the vaquita, have such low abundance that even relatively low levels of mortality in passive gear and nets are devastating. Two more populations, the Indo-Pacific hump-backed dolphin off the Natal Coast of South Africa and the bottlenose dolphin off the South Natal coast of South Africa have suffered relatively high levels of mortality in anti-shark nets.

The sixth 'population' currently suffering unsustainable levels of incidental mortality in passive gear is that of the harbour porpoise in the western North Atlantic. The population is relatively large, but the level of incidental mortality in gillnets has also been very high and has occurred for many years. The population has been affected in both summer and winter in different parts of its range by various fisheries.

The seventh population identified as experiencing levels of mortality in passive gear and traps that are not sustainable is the striped dolphin in the Mediterranean. The now-banned swordfish driftnet fishery[1] was primarily responsible for the highest levels of incidental mortality of striped dolphins. This fishery operated for only a few years, but the estimated levels of annual kill were extremely high, over 5,000 animals.

[1] Editor's note: The fishery has since been legally re-instituted.

5.3 Explanation of Table 1 summarising impacts on species and populations

The data used in Table 1 were compiled from published sources, documents available at the symposium and workshop, and unpublished information, such as recent survey results, provided by participants during the workshop. Table 1 comprises an overall survey of what is known and unknown about the impact of passive gear on populations of cetaceans. It must be stressed that the estimates of impact are not definitive; they are based for the most part on fragmentary information and are meant only to point out dangerous or potentially dangerous situations that may require urgent management action or investigation. They also, of course, highlight the fact that most impacts are 'unknown'. For roughly 60% of the known cases of interactions between marine mammals and fisheries, not even tentative conclusions could be drawn, because no data were available on population size or on the size of the incidental catch. Stocks/regions were not included in Table 1 if no known kill in passive nets or traps occurred or if the participants in the workshop were unaware of such a kill. Species or populations, e.g., the Indus susu, subjected to other forms of non-natural mortality than in passive gear or nets were not included, even if such effects were non-sustainable.

Because of the limitations of the table, the levels of mortality and impact on the populations may be underestimated. In situations in which the observed mortality represented only a small portion of the likely mortality, e.g., when only one or a few fish markets were observed, and a reliable estimate of effort was not available, the observed mortality was listed without an

attempt to extrapolate in the absence of accurate and precise data on effort or representativeness of a set of data for a region. In many of these cases, the numbers of animals killed is likely to be significantly higher than reported. This situation occurred, for example, for the northeast Indian Ocean and the Pacific coast of South America.

5.4 Annotations to Table 1

The first section of the annotations contains general notes that pertain to a region or fishery that may affect more than one species or stock. Those in the second are relevant to specific species/stocks in a geographic region and are listed in the same order as in Table 1.

5.4.1 Regional or fishery-specific general notes

MEDITERRANEAN

Notarbartolo di Sciara reported that data for estimates of incidental catch and population size for populations of cetaceans in the Mediterranean have not been systematically collected. Minimum estimates were derived from extensive contacts with the fishing communities and from 20 months of dedicated cruises in the past five years. Extrapolations to the entire Mediterranean were made on the basis of these results. He noted, however, that these estimates have not yet been published or peer-reviewed. A marked increase in incidental catch rates was observed throughout the past 20 years. The estimates given are for the past five years (1986–1990). No reliable information exists for earlier years.

WEST AFRICA

Only a small portion of the coast has been surveyed for incidental mortality of cetaceans in passive gear. The numbers of animals killed is likely to be significantly higher than reported. Mid-water trawls and tuna purse-seines catch common dolphins, bottlenose dolphins and oceanic dolphins of the genus *Stenella* in offshore waters. This catch is thought to be large.

SRI LANKA AND THE COASTAL NORTHEAST INDIAN OCEAN

Very large catches of cetaceans have been reported in the waters around Sri Lanka. Leatherwood supplied estimates of catches updated from Leatherwood and Reeves (1989); details of the revised methodology are given in Annex D. As noted in that Annex, it must be emphasised that all these estimates are biased downward to an unknown extent by cetaceans which are killed but not landed or landed but not tallied and most are further biased downward by the use of the number of registered vessels rather than the number of vessels actually fishing.

Because of the disparity in knowledge of levels of mortality between Sri Lanka and the other countries, for the table the data for Sri Lanka have been listed separately from those of the other countries along the coasts of the northern Indian Ocean.

CENTRAL NORTH PACIFIC HIGH SEAS DRIFTNET FISHERIES FOR SALMON AND SQUID AND LARGE-MESH DRIFTNET FISHERY

Estimates of annual mortality in the central North Pacific squid driftnet fishery were made on the basis of 1989 catch rates and 3 x 10^4 km of netting set (SC/O90/G35).

COASTAL PERU AND CHILE

Direct and incidental mortality of several species of dolphins and porpoises occurs in set nets. In addition, there is a direct catch by means of harpoons. The data on levels of kill are available from only a few fishing ports. The kill levels reported in the table are from animals counted in the fish markets in those restricted ports. No attempt has been made to extrapolate over the entire coastline, as fishing effort and cetacean densities are unknown. However, cetaceans are known to be killed in these fisheries throughout the coastal waters. The actual numbers of animals killed are almost certainly significantly higher than those reported.

5.4.2 Species/population/region-specific notes

FAMILY BALAENIDAE

Eubalaena australis (southern right whale)

Levels of kill in passive gear for *South Africa* and *New Zealand* were reported by Cockcroft and Cawthorn, respectively. The population estimate is from IWC (1986).

Eubalaena glacialis (northern right whale)

In the *western North Atlantic,* five animals are known to have been killed in collisions with ships. Of 118 right whales photo-identified, 57% showed scars typical of entanglement (Kraus, 1990). The population estimate is from IWC (1986).

In the *North Pacific*, some gillnet mortality in known to occur (SC/O90/G31). The size of the population is not known precisely, but it is very small (IWC, 1986).

Caperea marginata (pygmy right whale)

Mortality in passive gear has been reported along the *coast of South Africa* by Ross *et al.* (1975).

FAMILY ESCHRICHTIIDAE

Eschrichtius robustus (gray whale)

For the *North Pacific (eastern stock),* the majority of animals entangled off southern California are sexually immature, and 67% entangle on the northern migration (Heyning and Lewis, 1990). Of stranded animals examined along the west coast of North America, 8.7–25.8% died due to entanglement. In addition, collisions with ships kill an unknown number of animals annually (SC/O90/G2). The 1990 IWC catch limit is 179. The population estimate is from IWC (1993).

FAMILY BALAENOPTERIDAE

Balaenoptera sp. (unidentified balaenopterid)

Vidal reported a kill of a unidentified balaenopterid whale in the *Caribbean* off the coast of Venezuela.

B. acutorostrata (minke whale)

The incidence of kill in passive gear in the *Mediterranean* was reported in SC/O90/G31. Levels of kill and estimates of relative abundance were reported by Notarbartolo di Sciara.

In the *western North Atlantic* region, which includes coastal US and coastal Canadian waters, although the minke whales probably constitute a single stock, the actual stock structure is unknown. A minimum of 320 minke whales have been estimated to occur in US waters (Winn, 1982), although this estimate is thought to be very low. Few whales, probably less than 1 per year, are killed in coastal US waters (Kraus *et al.*, 1990; SC/O90/G6), while 10–20 are known killed in Canadian waters (SC/O90/G6).

For the *Southern Hemisphere*, Cockcroft reported the estimated level of kill in passive gear and traps off South Africa. Directed kills occurred in past years under IWC regulations. More recently, a small directed kill of about

300 animals occurred under scientific permits issued by Japan (e.g. IWC, 1990a). The current 'best' abundance estimate is about 760,000 (IWC, 1991b).

For the *western North Pacific*, mortality figures include animals from the West Pacific/Okhotsk Sea stock and East China Sea/Sea of Japan stock. Data for these two stocks have been combined due to lack of information on incidental takes (SC/O90/G36). The last commercial catch occurred in 1987.

For the *eastern North Pacific*, the limited observer data do not always identify baleen whales to species (Heyning and Lewis, 1990). Heyning reported that some animals are killed by collisions with ships.

B. edeni (Bryde's whale)
Information from *coastal Brazil* is reported in SC/O90/G26.

B. physalus (fin whale)
The incidence of mortality in the *Mediterranean* was reported in SC/O90/G34. Levels of kill in gillnets and estimate of relative abundance were reported by Notarbartolo di Sciara.

For *eastern Canada*, levels of mortality and population estimates are given by several authors (Mitchell, 1974; Winn, 1982; Mizroch *et al.*, 1984; Lien *et al.*, 1985; SC/O90/G6).

Information on the *northern Indian Ocean* is reported in Leatherwood and Reeves (1989).

Megaptera novaeangliae (humpback whale)
In the *western North Atlantic*, the animals found off coastal Canada, the USA and Greenland and that winter in the Caribbean constitute a single stock, which is reflected in the abundance estimate (Katona and Beard, 1990). Mortality in passive gear has occurred at a level of 5–17 per year during the past 12 years in Canadian waters (Lien *et al.*, 1985; 1988b; SC/O90/G6). Kraus *et al.* (1990) reported mortality of less than five per year in coastal US waters. Few are known killed in the Caribbean (SC/O90/G7). A catch limit of three humpbacks per year is currently in force for subsistence whalers of St Vincent & The Grenadines. In recent years, usually only 1–2 have been killed annually. During a 5-week period beginning in November 1987, 14 humpback whales died in Cape Cod Bay and Nantucket Sound after eating Atlantic mackerel containing a dinoflagellate neurotoxin (Geraci *et al.*, 1989). Other animals may have died and remained at sea.

Leatherwood and Reeves (1989) provide information for the *Indian Ocean*.

The *western North Pacific* 'population' is the smallest of the North Pacific groupings. To date, 164 individuals have been identified through photo-identification (Kaufman *et al.*, 1989; K. Mori, pers. comm. to T. Kasuya, 1990).

In the *eastern North Pacific* (Hawaii/Alaska and Mexico/California) all of the entanglements documented have occurred in southeast Alaska, British Columbia and California. Two animals were caught in the offshore driftnet fishery off Southern California (Heyning and Lewis, 1990). Additional information is provided by several authors (e.g. Baker and Herman, 1987; Baker *et al.*, 1990; Calambokidis *et al.*, 1990; Straley and Baker, 1990).

Majluf and Reyes (1989) provide information from *coastal Peru*.

FAMILY PLATANISTIDAE
Platanista gangetica (Ganges susu)
Both direct (harpoon) and incidental kills occur along the Brahmaputra River. Incidental catches occur during the dry season. Incidental mortality increased with the introduction of synthetic nets and the number of nets has been increasing (Mohan, 1989).

FAMILY INIIDAE
Lipotes vexillifer (baiji)
Most are entangled by bottom snaglines ('rolling-hook'). Some are caught in traps (Zhou, 1982; 1986; Lin *et al.*, 1985; Zhou and Li, 1989; SC/O90/G21).

Pontoporia blainvillei (franciscana)
In addition to the kill in passive gear, bottom trawls catch and kill *Pontoporia* at Samboraubon Bay, Argentina, although the catch is considered negligible. In Brazil and Argentina, most of the animals killed are juveniles (SC/O90/G3). Sex and age structure of the kill is available. Other information is given by several authors (e.g. Brownell, 1975; Kasuya and Brownell, 1979; Pinedo, 1982; Pérez Macri and Crespo, 1989; Praderi *et al.*, 1989; Corcuera *et al.*, 1994; SC/O90/G1).

Inia geoffrensis (boto)
Of a sample of 35 dolphins, approximately 70% died in lampara seine nets and 30% in gillnets. Two of the 35 were harpooned, possibly because of their interference with fishing operations (Best and da Silva, 1989; Perrin and Brownell, 1989)

FAMILY MONODONTIDAE
Delphinapterus leucas (white whale)
For *Bristol Bay*, the estimate of incidental catch is based on a small sample of years. There is an aboriginal harvest (Hazard, 1988). Hazard (1988) also provides data for *Cook Inlet*.

FAMILY PHOCOENIDAE
Australophocaena dioptrica (spectacled porpoise)
This species is the second most frequently killed cetacean in passive gear in Tierra del Fuego (Goodall *et al.*, 1990; 1994) although the number killed is unknown. A direct fishery exists for use as crab bait. Several others papers provide information (e.g. Goodall and Cameron, 1980; Goodall *et al.*, 1988a; Lichter and Goodall, 1988)

Neophocaena phocaenoides (finless porpoise)
Data for *Thailand/Pakistan/India* are reported in SC/O90/G12, G22 and G30.

Levels of mortality in passive gear in the *Yangtze River* and *Yellow Sea* were given in SC/O90/G21. Unpublished estimates of abundance were reported by Zhou.

For *coastal Japan*, the population estimate is the preliminary sighting estimate for the population in the Inland Sea only. Mortality in passive gear occurs in other areas around Japan as well. Finless porpoises migrate into the Inland Sea for calving in Spring. Their distribution suggests that Japanese trap net operations may have a significant effect on their survival (Kasuya and Kureha, 1979).

Phocoena phocoena (harbour porpoise)
The *Baltic* region includes information from Sweden's east coast, Finland, Russian Federation, Luithuania, Latvia, Estonia, Poland and Germany's Baltic coast (Kremer and Schulze, 1990; SC/O90/G25).

Several papers include information for the *Kattegat and Belt Seas* (e.g. Danielsen *et al.*, 1989; Lindstedt and Lindstedt, 1989; Lindstedt, 1990; SC/O90/G57).

For the *North Sea* area (including the Faroe Islands), estimates of levels of incidental mortality in passive gear from three separate papers are widely disparate, ranging from 100 animals per year (Bjørge and Øien, 1990) to 700 animals per year for the Skagerrak (Kinze, 1994). Clausen and Andersen (1988) reported that up to 3,000 animals are killed per year, but the numbers are unsubstantiated. The estimate of abundance from the North Sea area has a CV of 0.24 (Bjørge and Øien, 1990).

Levels of mortality for *Northern Norway/Barents Sea* were given in Bjørge and Øien (1990). The estimate of abundance from northern Norway has a CV of 0.44 (Danielsen *et al.*, 1989)

Duguy and Hussenot (1982) report mortality in nets along the coast of *France*.

In *Western Greenland* and the area from *Newfoundland to western Greenland*, both incidental and directed catches are large (Gaskin, 1984; Lien *et al.*, 1988b; Kinze, 1994). Insufficient data exist to allow determination of the impact of this long-term fishery on the population, but, given the high levels of mortality, there is reason to be concerned.

For the *Gulf of St. Lawrence and Nova Scotia* region, a sample of fishermen reported taking over 600 porpoises in 1988, but total mortality is unknown (Fontaine *et al.*, 1994). Most of this mortality occurred in groundfish gillnets and some of the carcasses are kept for human consumption. This fishery has existed for some time (Laurin, 1976).

The population grouping of the *northeast coast of the USA, the Bay of Fundy and southwestern Nova Scotia* may also include southwestern Nova Scotia. Estimates of fishery mortality range from 280 (Polacheck, 1989) to almost 1,000 (Kraus *et al.*, 1983; 1990). The estimates are not based on systematic sampling of the entire range of the groundfish gillnet fishery. Other takes are known to occur, but their magnitude is unknown. The estimate excludes an occasional and probably small kill in gillnet fisheries to the south of the Gulf of Maine. Best available estimates of abundance range between to 8,000 and 15,300 (Kraus *et al.*, 1983), with the lower number thought to be biased downward (SC/O90/G44). An even lower estimate of 3,500 (Winn, 1982) may be unreliable. Current research is attempting to refine estimates of both abundance and mortality (Read and Gaskin, 1988), but there are already indications that the population is in decline (Read and Gaskin, 1990).

Information on *West Africa* is given in Gaskin (1984) and SC/O90/G5.

For *coastal Japan*, some data are given in SC/O90/G36. Kasuya reported that the impact of passive gear is potentially significant because of the large number of trap nets off Hokkaido (950 large-scale and 4,000 small-scale trap nets along less than 3,000km of coastline).

In the *central North Pacific/Bering Sea* area, the high seas driftnet fishery for salmon kills 0–2 harbour porpoises annually (SC/O90/G35).

Observations of fisheries in the *coastal waters of Alaska* suggest that the Prince William Sound/Copper River Delta area probably has the highest level of mortality of harbour porpoise in Alaskan waters (K. Wynne, pers. comm.; SC/O90/G28).

Along the *Pacific coast of the USA and Canada*, the stock structure of *Phocoena* is unknown. For the USA, limited evidence exists to support the hypothesis that separate populations exist in Washington, Oregon and California (Calambokidis, 1986). Mortality estimates have been further stratified to reflect regions where known levels of mortality occur. The potentially large impacts given for northern Washington (Gearin *et al.*, 1994) and central California represent gillnet mortality in very specific areas (Brownell, 1964; Hanan *et al.*, 1987) and assume that the porpoises in those subareas comprise separate populations within the overall populations within the states. Because of the uncertain stock status of the subareas, the regional impacts have been designated as 'maybe not sustainable' rather than 'not sustainable'. The population in central California has been subjected to long-term losses due to interactions with fishing gear (Szczepaniak and Webber, 1985). It is currently estimated to be at 30–97% of original population size (Barlow and Hanan, 1994). Mortality in passive gear has declined during the last two years because of restrictions on the use of set gillnets. The take in gillnets has been biased towards juveniles (Hohn and Brownell, 1994). The number of harbour porpoises in British Columbia appears to be declining, possibly due to gillnet mortality (Cowan, 1988; Stacey *et al.*, 1994).

P. sinus (vaquita)

The incidental kill in passive gear is known to have been at least 32–33 per year in 1985 and 1990 based on direct counts (Turk Boyer and Silber, 1990). At least seven vaquitas have been caught in shrimp trawls since 1985. The population size is unknown but could be as low as several hundred (Vidal, 1994). The vaquita has the smallest geographic range of any marine cetacean.

P. spinipinnis (Burmeister's porpoise)

The *western South Atlantic* region includes Uruguay and Argentina. Burmeister's porpoises are killed in gillnets set for fish and sharks (Corcuera *et al.*, 1994). In the 1970s, at least some were taken in centolla (crab) tangle nets in Tierra del Fuego (Goodall and Cameron, 1980). The estimated kill for one port in Argentina, Necochea/Claromecó was 12 animals/year (SC/O90/G2). Along the rest of the coast, no estimates are available. In Uruguay, the estimated take is less than one year, although all organised shark fisheries along the Uruguayan coast are thought to kill this species (SC/O90/G1).

In the *eastern South Pacific*, this species is taken in a variety of coastal fisheries from northern Peru to southern Chile (SC/O90/G11; SC/O90/G54). Counts of animals killed have been reported for specimens landed at the fish markets at Pucusana, Peru, while additional animals are known to be killed in the sciaenid fishery in southern Chile. The total kill probably numbers in the low thousands (Brownell and Praderi, 1982; Read *et al.*, 1988) and is increasing in some areas (Van Waerebeek and Reyes, 1990a; b). More males than females are caught in the Peruvian fishery.

Phocoenoides dalli (Dall's porpoise)

Stocks in the *coastal and offshore Japan* region can be incidentally taken by Japanese large-mesh driftnets and Korean squid gillnets, but the details are unknown. In coastal waters they are killed in trap nets. In addition, there is a direct kill, totalling 30,000 animals in 1989, in the Sea of Japan and Okhotsk Sea (SC/O90/G36). The kill is of both the *dalli* and *truei* types, although the proportion of the kill of each type is unknown (SC/O90/G8).

In the *western and central North Pacific*, two putative stocks inhabit the range from 155°-172°E (IWC, 1990b).

Incidental kill is by the Japanese high seas salmon fisheries and Korean, Taiwanese and Japanese high seas driftnet fisheries for squid. The estimate of kill was made on the basis of observations on Japanese squid driftnet vessels and extrapolated to all nations fishing the region (SC/O90/G8). For the salmon fishery, the mean kill rate from 1981–87 in the US Fisheries Conservation Zone (FCZ) collected by US and Japanese scientific observers was used with the relevant fishing effort data for each fishery. Kill rates outside the US FCZ may be somewhat lower than the rate used. Although the number of observations from Japan is high, the observations do not cover the entire fishing season and may not be representative of the areal distribution of the fishing effort. In addition, Korean and Taiwanese vessels were not observed; they used different mesh sizes and operated in different areas and time periods. The kill estimate is therefore preliminary. Information is available on life history.

For the *Bering Sea*, population estimates are based on the US Platform of Opportunity Programme (NMFS, unpubl. data). Sightings data are collected during surveys by trained observers and analysed using line transect methodology. Jones reported that these estimates were used in US official determinations of status of the populations. Kill estimates are based on the mean kill rate over the period 1981–87. Data were collected by Japanese and US scientific observers on salmon catcherboats. Fishing effort and area are currently decreasing. Additional mortality may be incurred in the extensive trawl fisheries in the Bering Sea (SC/O90/G35). Data are available on life history.

In the *eastern North Pacific*, mortality occurs in the Alaska trawl fishery (SC/O90/G28) and in nets off the coast of British Columbia (Stacey *et al.*, 1994).

FAMILY DELPHINIDAE

Cephalorhynchus eutropia (Chilean dolphin)

This species is killed incidentally in passive gear in southern Chile. There is also incidental kill in purse-seines and a harpoon fishery where the animals are taken for crab bait (Goodall *et al.*, 1988b).

C. heavisidii (Heaviside's dolphin)

Mortality occurs in near-shore set nets and in trawls and purse-seines along the southern African coast. Some animals are also taken illegally with hand harpoons (Best, 1984).

C. hectori (Hector's dolphin)

Mortality figures are from 1984–88 from Pegasus Bay/ Canterbury Bight only. Entanglement rates are probably highest in this area, but additional entanglements undoubtedly occur elsewhere (Dawson and Slooten, 1988; Slooten and Dawson, 1988). The Banks Peninsula Marine Mammal Sanctuary was established in 1989 to reduce incidental mortality of this species (Dawson, 1991).

C. commersonii (Commerson's dolphin)

Kill occurs in gillnets in southern Patagonia, on the northeast coast of Tierra del Fuego and in Chile (Goodall *et al.*, 1988a; Leatherwood *et al.*, 1988; Lichter and Goodall, 1988). Bottom and mid-water trawlers kill an additional unknown number in northern Patagonia. In Tierra del Fuego, this species is intentionally killed by harpoon and gunshot for use as crab bait. No systematic monitoring of mortality or collection of carcasses has occurred but the number killed is thought to be high. Abundance has decreased to low levels in the Magellan Straits (Goodall *et al.*, 1988a; Lichter and Goodall, 1988).

Delphinus delphis (common dolphin)

In many ocean basins, there are two reported morphological forms of common dolphins, a long-beaked and a short-beaked form. In the eastern North Pacific the long-beaked form has been described as *D. bairdii* or *D. delphis bairdii*. Off South Africa it has been called *D. capensis* and in the northern Indian Ocean *D. tropicalis*. The short-beaked form has been referred to as *D. delphis*. It has not been fully resolved whether these two forms represent two species of common dolphins or two distinct ecological races[2]. In either case they need to be managed as separate populations. Most reports only list the kill as common dolphins, making the impact of such kills impossible to ascertain, but potentially a problem.

The incidence of mortality for the *Mediterranean* was given in SC/O90/G34.

In the *eastern North Atlantic*, common dolphins are killed in French and Irish driftnet fisheries (Duguy and Hussenot, 1982; SC/O90/G35).

In the *western North Atlantic*, a recently expanded driftnet fishery for swordfish and tuna has developed along the continental shelf edge of the northeastern United States and is currently being monitored. During August-November 1989, 19 common dolphins were caught on 12 trips (SC/O90/G6). The number of common dolphins killed annually has been estimated on the basis of 5–10% of fishing trips observed. Common dolphins are also killed in the squid trawl fisheries in the shelf and shelf-edge region of the northeast US (Waring *et al.*, 1990). Abundance estimates from aerial surveys are given in Winn (1982).

Estimates for the *Brazil region* are given in SC/O90/G26.

In *coastal Argentina*, mortality in gillnets was estimated to be eight animals/fishing season for one port (Claromecó). Additional mortality occurs in bottom trawls and purse-seines. The annual level of mortality in purse-seines is estimated to be 50–100. This total also includes kills of dusky dolphins, likely the predominant species (Corcuera *et al.*, 1994; SC/O90/G2).

In *coastal West Africa*, numerous fisheries probably kill common dolphins in passive gear. Other kills occur in tuna purse-seines (SC/O90/G5).

In the *eastern South Atlantic Ocean* basin, kills occur in high seas driftnets and around islands (SC/O90/G20).

In the *southwestern Indian Ocean* basin, dolphins are taken in high seas driftnets and around islands (Cockcroft and Peddemors, 1990; SC/O90/G20).

For the *Indian Ocean coast of South Africa*, estimates are reported in Cockcroft (1990) and Cockcroft and Peddemors (1990).

In the *northern Indian Ocean*, mortality in passive gear has been reported from the Arabian Sea (Papastavrou, 1990), India (SC/O90/G12; SC/O90/G22), Sri Lanka (Alling, 1983; Leatherwood and Reeves, 1989) and Pakistan (SC/O90/G30).

Over a two-year period in the *Tasman Sea*, 4,600 dolphins, mostly *Delphinus delphis* were killed in driftnets (SC/O90/G35).

[2] Editor's note: The IWC Scientific Committee accepted the species *Delphinus capensis*, the long-beaked common dolphin, at its 1994 meeting (IWC, 1995, in press) based on Heyning and Perrin (1994).

In *coastal Japan*, this species has been taken by drive fisheries in the past. Currently data are being collected by means of an observer programme (SC/O90/G36).

In the *central North Pacific*, data are currently being collected in observer programmes in the high seas squid driftnet programme and large-mesh driftnet programme (SC/O90/G35, SC/O90/G52).

In *coastal California and Baja California* common dolphins are caught in set and drift gillnets along central and southern California (SC/O90/G24) and may be caught in high number in the Gulf of California (SC/O90/G7). The majority of common dolphins killed off California are of the long-beaked form (Evans, 1982; Perrin *et al.*, 1985).

For *coastal Peru*, Heyning, Reyes and Van Waerebeek reported that mortality is of the long-beaked form. The estimate of mortality is for the ports of Pucusana and Cerro Azul only (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a; SC/O90/G54). Van Waerebeek reported that the mortality off northern Peru is thought to be much higher.

Feresa attenuata (pygmy killer whale)

For *coastal Sri Lanka*, estimates are reported by Leatherwood and Reeves (1989).

In the *central North Pacific*, data on the mortality of this species in the large mesh driftnet fishery in the central North Pacific are being collected (SC/O90/G52).

For *coastal Peru*, one specimen is known to have been taken (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a).

Globicephala sp. (unidentified pilot whale)

In the *western North Atlantic*, pilot whales are killed incidentally in the drift gillnet fishery and distant-water fleet mackerel and squid trawl fisheries. The mortality has not been recorded by species; the fishery operates well beyond the known range of the short-finned pilot whale. Seven animals were observed killed on 12 trips in the swordfish driftnet fishery during 1989. It is estimated that 5–10% of the fishing trips were observed. From 1977–1990, a minimum of 409 specimens have been observed killed in the mackerel and squid fisheries, with an annual average of 46 observed killed from 1984–88. The estimate of population size (Winn, 1982) given in the table pertains to both species over the range of the survey and does not cover the known range of the short-finned pilot whale in the North Atlantic. When extrapolated over total fishing effort, the total mortality in the foreign squid and mackerel trawl fishing gear is 2.0–2.7% of the estimated population size (Waring *et al.*, 1990). This rate may not be sustainable. From 1948–1971, the Newfoundland drive fishery killed an average of 2,260 each year (Mercer, 1975).

Globicephala melas (long-finned pilot whale)

For the *Mediterranean*, Notarbartolo di Sciara reported that other sources of man-induced mortality include entanglement in longlines and direct kill by gunshot. This species is distributed mainly in the western basin.

In *France*, some kill occurs in gillnets (Duguy and Hussenot, 1982).

G. macrorhynchus (short-finned pilot whale)

Some kill occurs in the *Caribbean* in passive gear (SC/O90/G7). A directed fishery for pilot whales occurred in the waters around St. Vincent (Caldwell and Caldwell, 1975).

For the *northern Indian Ocean*, Leatherwood reported that incidental mortality probably occurs in the China, Taiwanese (abbreviated as 'Taiwanese' in the remainder of this section) driftnet fishery. Pilot whales are killed in the coastal fisheries around Sri Lanka (Leatherwood and Reeves, 1989) and in the waters of Pakistan (SC/O90/G30).

Pilot whales of the *Japanese southern form* are killed in trap nets and in the drive fisheries and small-type whaling (SC/O90/G36; Kasuya and Miyashita, 1989; Miyashita, 1993). Data are being collected from whaling operations.

Some individuals of the *Japanese northern form* are killed in Japanese and Korean gillnets. The other fishery mortality is from small-type whaling (SC/O90/G36; Miyashita, 1993). Data are being collected from whaling operations.

In *coastal California*, prior to the early 1980s, a migratory group of pilot whales entered the Southern California Bight in winter to feed on spawning squid. The developing squid fishery resulted in the deaths of an unknown number of whales by entanglement in nets and by gunshot (Miller, 1983). Since 1983, a year with a major El Niño Southern Oscillation event concomitant with the years of highest incidental mortality, few pilot whales have been seen nearshore. Pilot whales are currently killed in drift gillnets (SC/O90/G28).

In *coastal Peru*, counts of pilot whales in the fish market at Pucusana gave one whale each in 1985 and 1986, years of relatively low observer coverage, three whales in 1987 with 298 days of coverage and five whale in each 1988 and 19899 with 492 days of monitoring. As only one fishing market was sampled, these estimates are undoubtedly low (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a; b; SC/O90/G54).

Grampus griseus (Risso's dolphin)

In the *Mediterranean*, Risso's dolphins are killed in several gillnet fisheries (SC/O90/G34). Notarbartolo di Sciara reported that, in addition to mortality in driftnets, kills include those resulting from harpoons, gunshot and entanglement in longlines. Risso's dolphins are distributed mainly in the western basin. For the *eastern North Atlantic*, some kills were reported by Duguy and Hussenot (1982).

Along the *western North Atlantic coast of the USA*, mortality has occurred in the swordfish driftnet fishery and the foreign trawl fisheries for mackerel and squid (Waring *et al.*, 1990; SC/O90/G6). During August-November 1989, three *Grampus* were caught in the driftnet fishery on 12 observed trips, representing an estimated coverage of 5–10%. The estimate of population size (Winn, 1982; Kenney, 1990) was based on a survey that may not have covered the entire range of Risso's dolphin in the western North Atlantic.

Caribbean data are provided in SC/O90/G7.

In *coastal Sri Lanka*, a harpoon fishery exists in addition to the incidental kills in coastal gillnets and in the Taiwanese driftnet fishery (Leatherwood and Reeves, 1989).

In *coastal Japan*, incidental mortality occurs in trap nets and possibly in the large-mesh driftnet fishery. Kasuya reported that the impact of kills in trap nets is thought to be not significant. Risso's dolphin was previously taken in the drive fishery at Iki Island (SC/O90/G36; Miyashita, 1993).

In the *central North Pacific*, mortality results from the high seas driftnet fishery and the large-mesh net fishery. Data are being collected by means of an observer programme (SC/O90/G52).

Along the *Pacific coast of the USA*, some animals are thought to be killed in gillnets. The squid purse-seine fishery is responsible for additional mortality (SC/O90/G24).

In *coastal Peru*, only one Risso's dolphin was observed in the fish market in Pucusana, Peru in 1987, when there were 298 days of monitoring (Van Waerebeek and Reyes, 1990b). Another specimen was landed in Pucusana in 1988–89 during 492 days of monitoring (SC/O90/G54).

Lagenodelphis hosei (Fraser's dolphin)
Mortality in *coastal Sri Lanka* has been reported by Leatherwood and Reeves (1989).

In the *Philippines*, mortality occurs in driftnets, as bycatch in purse-seines and by harpoon (SC/O90/G29).

In *coastal Japan*, the documented take is by Japanese trap nets. This stock may also be taken by large-mesh gillnets in higher numbers (SC/O90/G36). Data are being collected by means of an observer programme (SC/O90/G52). This species is also killed in drive fisheries.

Lagenorhynchus acutus (Atlantic white-sided dolphin)
Along the *western North Atlantic coast of the USA*, Gilbert and Wynne (1987) reported the incidental take of several of this species in the winter surface-gillnet fishery for mackerel in Cape Cod Bay. A small number of white-sided dolphins have been reported killed in the foreign trawl fisheries for mackerel (Waring *et al.*, 1990). The estimate of abundance was given by Kenney (1990).

L. albirostris (white-beaked dolphin)
For the *western North Atlantic*, reports of mortality in passive gear were given in Alling and Whitehead (1987).

L. australis (Peale's dolphin)
In *coastal South America*, incidental kill in passive gear occurs in gillnets in the south of Patagonia and in Tierra del Fuego. Two specimens were observed caught in bottom and mid-water trawls at Puerto Deseado (SC/O90/G2). A direct fishery kills some animals for use as crab bait. In 1978, 23 dolphins were known killed (Goodall and Cameron, 1980).

L. obliquidens (Pacific white-sided dolphin)
In *coastal Japan*, incidental mortality occurs in trap nets. Partial observations showed an average of 7.8 dolphins killed annually (SC/O90/G36). Population estimates are for the East China Sea – Sea of Japan (Miyashita, 1986).

In the *central North Pacific*, most of the kill in passive gear is in the high seas driftnet fishery (SC/O90/G8; SC/O90/G35; SC/O90/G42). The total mortality of this species in high seas squid driftnets has been extrapolated from the observed Japanese take rate. Japanese salmon driftnets have killed 0–2 animals annually from 1978–87 (SC/O90/G35). One animal was reported killed in a research operation using large-mesh gillnets.

In the *eastern North Pacific*, two stocks may occur, with the northern temperate and southern temperate forms meeting in the Southern California Bight (Leatherwood *et al.*, 1984; Walker *et al.*, 1986). Incidental mortality occurs in the California and British Columbia driftnet fisheries (Stacey *et al.*, 1994; SC/O90/G28). Some animals stranded along the California coast were thought to have been killed in gillnets (SC/O90/G24). Some mortality occurred during the experimental fishery for squid but that fishery did not develop. Additional sources of mortality are Alaskan trawls (SC/O90/G28).

L. obscurus (dusky dolphin)
For *coastal Argentina*, mortality in gillnets was estimated to be 1.4 animals/fishing season for one port (Necochea/Claromecó). The catches were considered sporadic. Additional mortality occurs in bottom trawls in northern Patagonia and purse-seines in Necochea/Claromecó. In 8–10 months, eight dolphins were recovered from one bottom trawl vessel (Corcuera *et al.*, 1994; SC/O90/G2). The annual level of mortality in purse-seines is estimated to be 50–100, a total which also includes kills of common dolphins, although the majority of the kill is suspected to be of dusky dolphins (Corcuera *et al.*, 1994; SC/O90/G2).

In *coastal South Africa*, mortality in mullet and elephant fish gillnets occurs but at an unknown and probably minimal level. Additional mortality occurs in purse-seines and there is also some removal for transfer to oceanaria (SC/O90/G20; Best and Ross, 1977).

Cawthorn reported that in *New Zealand* mortality occurs in deep-set gillnets.

For *coastal Peru*, the reported kill of >1,800 includes landings at the port of Pucusana only. Mortality is incidental as well as directed using drift gillnets, with a few specimens taken by harpoon (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a; b). Some counts from other ports are available but the representativeness of the counts throughout a single year and across years and ports is unknown. All age classes are taken and the sex ratio is about 1:1.

Lissodelphis borealis (northern right whale dolphin)
In the *central North Pacific*, right whale dolphins are killed incidentally in the squid driftnet area (SC/O90/G8, G35, G52). In 1989, 455 were observed killed in Japanese squid gillnets. This number represented partial coverage only. When extrapolated over the Japanese, Taiwanese and Korean fleets, the total estimated kill is 19,000 (SC/O90/G35). Some (0–4 per year) also are killed in Japanese salmon driftnets (SC/O90/G35). In research cruises using large-mesh gillnets, 22 right whale dolphins were killed (SC/O90/G52).

Along the *Pacific coast of North America*, two mortalities are known to have occurred in drift gillnets in US waters, while in four years 13 were known to have been killed in Canadian waters (SC/O90/G28). A population size for *Lissodelphis* in the Northeast Pacific is available for limited regions along the coast of California through a series of aerial surveys (Leatherwood and Walker, 1979). However, stock structure and total distribution is unknown.

L. peronii (southern right whale dolphin)
Along the *Pacific coast of South America*, three were reported killed in gillnets in Peru from 1985–90. In Chile, several were found near fish terminals and landings sites after having been killed in swordfish driftnets. The number reported accelerated rapidly in 1989–90, which is cause for concern. A few are also harpooned by artisanal fishermen in Chile in the swordfish harpoon fishery (SC/O90/G11). Van Waerebeek reported that the animals landed in Peru have been adults.

Orcaella brevirostris (Irrawaddy dolphin)
In most areas where this species occurs, data on incidental kills are limited. Some kill is known from India and the northern Indian Ocean coast (SC/O90/G12; SC/O90/G22). In the Queensland, Australia area from 1967–1989, a total of 522 dolphins was killed in shark nets (Harwood *et al.*, 1984; Harwood and Hembree, 1987; Paterson, 1990). Four species of dolphins were involved: *Tursiops truncatus*, *Delphinus delphis*, *Orcaella brevirostris* and *Sousa chinensis*. The number of each species killed is not known

because mortality counts were not stratified by species. The fishery subsequently moved into the waters of Papua New Guinea and Indonesia (Liu, 1989), probably eliminating that fishery as a source of additional mortality in coastal waters of Australia but inflicting mortality on animals in nearby waters that probably constitute the same population. In some areas, this species is killed for local consumption and some live capture occurs (Marsh *et al.*, 1989).

Orcinus orca (killer whale)

The incidence of mortality in the *Mediterranean* was given in SC/O90/G34. Notarbartolo di Sciara reported estimated mortality rates and relative abundance.

The abundance of killer whales in the entire *North Atlantic* is unknown. Killer whales are reported to become entangled occasionally in inshore herring nets off Norway (Lien *et al.*, 1988a). Changes in killer whale migrations, caused by changes in herring migration, may explain the increase in abundance of killer whales in Norwegian coastal and inshore waters since the early 1980s (Christensen, 1988) and subsequent entanglements. Directed fisheries for killer whales that take an average of less than 10 animals per year occur in Greenland (Heide-Jørgensen, 1988). Approximately 700 killer whales (average 58 per year) were killed in the North Atlantic by Norwegian vessels between 1970–1981 (Øien, 1988). From 1976–1988, 59 killer whales were caught off Iceland for public display (Sigurjónsson and Leatherwood, 1988).

Some kill has been reported in the Caribbean off Trinidad and Tobago (SC/O90/G7).

In *coastal Argentina*, one kill is known to have occurred in the Necochea gillnet fishery in October 1990 (Corcuera *et al.*, 1994).

In *Sri Lanka*, an average of <1 animal per year is killed (Leatherwood and Reeves, 1989; Leatherwood *et al.*, 1991).

Information for *Indonesia* is given in Hembree (1980).

In the *central North Pacific/Bering Sea* region, some kill has been reported in Japanese salmon gillnets (SC/O90/G35). Squid gillnets and large-mesh gillnets may also take this species. Some additional kill by US salmon boats in the Bering Sea has been documented (Dahlheim, 1988).

In the *eastern North Pacific*, a low level of kill has been reported from gillnets (SC/O90/G24). In the period 1986–88, two animals were known killed in the Alaska trawl fishery for pollock (SC/O90/G28).

Peponocephala electra (melon-headed whale)

For the *northern Indian Ocean* area, a small kill has been documented for Sri Lanka (Leatherwood *et al.*, 1991). In addition, there is a small live-capture removal of this species. Leatherwood reported that this species is likely taken in coastal and high seas gillnet operations throughout the temperate and tropical Indian Ocean.

Pseudorca crassidens (false killer whale)

In the *Brazil* region, some mortality in passive gear occurs (SC/O90/G26).

This species is killed in the coastal net fisheries of *Sri Lanka* (Leatherwood and Reeves, 1989; Leatherwood *et al.*, 1991).

In *Australasia*, this species is one of several killed in Taiwanese drift gillnets off the coast of northeast and northwest Australia (Harwood *et al.*, 1984; Harwood and Hembree, 1987). From 1981–1985, an annual mortality of 11 animals was estimated on the basis of an observer programme. Significant declines in cetacean catch rate with both time and increasing cumulative effort occurred from 1981–83. Similar analyses for 1984–85 were not done because of changes in observer coverage, fishing methods and area of operation. The fishery subsequently moved into the waters of Papua New Guinea and Indonesia (Liu, 1989), probably eliminating the fishery as a source of additional mortality in coastal waters of Australia but inflicting mortality on animals in nearby waters that probably constitute the same population. One kill in longline gear offshore has been recorded. Two animals were removed by live capture in 1989. Some seasonal movement is known.

In *coastal China*, mortality in passive gear has been reported by several authors (Wang, 1979; Zhou *et al.*, 1982; Shi and Wang, 1983; SC/O90/G21).

In *coastal Japan*, incidental mortality occurs in Japanese trap nets (SC/O90/G36). Additional kills occur in the drive fishery and in culls (Tamura *et al.*, 1986). The population estimate is 2,700 in the East China Sea and 13,000 off the Pacific coast (Miyashita, 1993). Several stocks may be included. Biological information suggests a low reproductive rate.

Mortality has been reported for *coastal Peru* in SC/O90/G11.

Sotalia fluviatilis (tucuxi)

Two stocks are recognised, a marine and a freshwater form (Borobia and Sergeant, 1989). Both stocks are killed in passive fishing gear (SC/O90/G7; SC/O90/G26). Artisanal net fisheries in Brazil kill at least some of the marine form (Simões-Lopes and Ximenez, 1990).

Sousa chinensis (Indo-Pacific hump-backed dolphin)

Hump-backed dolphins are killed in anti-shark nets off Natal, South Africa. Available information suggests that the level of mortality may lead to the depletion of local groups (SC/O90/G20; Ross, 1984; Ross *et al.*, 1989).

Kills for *coastal Sri Lanka* were reported by Leatherwood and Reeves (1989).

In the *northern Indian Ocean*, incidental mortality is known to occur in Sri Lanka, India, Pakistan and Thailand (Bhatia *et al.*, 1989; SC/O90/G22, SC/O90/G30) and probably occurs in other countries as well.

In *Australasia*, this species is one of several killed in Taiwanese drift gillnets off the coast of northeast and northwest Australia (Harwood *et al.*, 1984; Harwood and Hembree, 1987). From 1981–1985, an annual mortality of 11 animals was estimated on the basis of an observer programme. Significant declines in cetacean catch rate with both time and increasing cumulative effort occurred from 1981–83. Similar analyses for 1984–85 were not done because of changes in observer coverage, fishing methods and area of operation. This fishery has since moved into waters of Papua New Guinea and Indonesia (Liu, 1989), probably eliminating the fishery as a source of additional mortality in coastal waters of Australia but inflicting mortality on animals in nearby waters that probably constitute the same population. Other incidental catches include observed catches of up to an average of 25 dolphins/year in shark nets (that estimate includes four species of dolphins) (Paterson, 1990). Anderson reported that inshore set nets kill about 80 per year, although this number is probably an underestimate, and that some may

be killed in the shark/tuna/mackerel driftnets in the Northwest Territory. Estimates of total incidental take are probably low.

S. teuszii (Atlantic hump-backed dolphin)
Mortality along the *West coast of Africa* was reported by Cadenat and Paraiso (1957).

Stenella attenuata (pantropical spotted dolphin)
For the *northern Indian Ocean*, incidental kill has been reported from coastal Sri Lanka and Pakistan (Leatherwood and Reeves, 1989; SC/O90/G30) and it probably occurs in other regions.

In *Australasia*, this species is one of several killed in Taiwanese drift gillnets off the coast of northeast and northwest Australia (Harwood *et al.*, 1984; Harwood and Hembree, 1987). In the period 1981–1985, an annual mortality of 126 animals was estimated on the basis of an observer programme. Significant declines in cetacean catch rate with both time and increasing cumulative effort occurred 1981–83. Similar analyses for 1984–85 were not done because of changes in observer coverage, fishing methods and area of operation. This fishery has since moved into waters of Papua New Guinea and Indonesia (Liu, 1989), probably eliminating the fishery as a source of additional mortality in coastal waters of Australia but inflicting mortality on animals in nearby waters that probably constitute the same population. Estimates of total incidental take are probably low.

In the *Philippines*, these dolphins are taken by purse-seines, harpoons and driftnets (SC/O90/G29).

In the *western North Pacific*, research operations with large-mesh gillnets incurred some incidental kill (SC/O90/G52). A drive fishery is still active but at lower levels than in the past. The estimate of population size may include more than one stock (Kasuya and Miyashita, 1989).

Some animals are known to be caught in gillnets off central *Peru* (Read *et al.*, 1988). This stock is of the coastal subspecies of the spotted dolphin that ranges from Mexico to Peru and is killed in the tuna purse-seine fishery in small numbers (Perrin *et al.*, 1985). The abundance was estimated as 36,000 in 1989 (Gerrodette and Wade, 1991).

S. clymene (clymene dolphin)
For the *Caribbean*, Vidal reported an animal killed off Venezuela.

S. coeruleoalba (striped dolphin)
Notarbartolo di Sciara reported that in the *Mediterranean*, large numbers were killed in the recently-banned driftnet fishery. Other sources of mortality include purse-seines, longlines, trawls, harpoons and gunshot (SC/O90/G34) and a recent mass die-off due to unknown causes.

For the *eastern North Atlantic*, mortality was reported by Duguy and Hussenot (1982) and in SC/O90/G35.

In the *western North Atlantic*, four striped dolphins were observed killed during 1989 in the swordfish driftnet fishery conducted in northeast US shelf-edge waters (SC/O90/G6). The annual kill has been estimated on the basis of 5–10% of trips observed. The estimate of abundance was reported in Kenney (1990).

In addition to the incidental kill in *coastal Sri Lanka*, there may be a small directed harpoon fishery (Leatherwood and Reeves, 1989). Leatherwood reported that there are probably additional takes in the large-mesh gillnet and Taiwanese driftnet fisheries in the Indian Ocean.

In *coastal Japan* and the *western North Pacific*, incidental mortality occurs in the gillnet fishery (SC/O90/G8) and possibly in the large-mesh gillnet fishery (SC/O90/G52). Until the 1960s, the drive fishery killed 15–30,000 each year. The level has gradually declined to 2–5,000 (Kasuya and Miyashita, 1989).

S. frontalis (Atlantic spotted dolphin)
In the *western North Atlantic*, this species is killed in the swordfish driftnet fishery in US shelf-edge waters (SC/O90/G6). The annual kill has been estimated on the basis of 5–10% of trips observed.

For the *Caribbean*, some mortality has been reported off Venezuela (SC/O90/G7).

Mortality in the *Brazil region* was reported in SC/O90/G26.

S. longirostris (spinner dolphin)
For the *Caribbean*, Vidal reported an animal killed in passive gear off Venezuela. A directed fishery occurred in the past (Caldwell and Caldwell, 1975) that may still be active.

This species is killed in large numbers in *Sri Lanka* (Leatherwood and Reeves, 1989). Observations of fisheries in Sri Lanka suggest that even larger numbers may be killed in gillnets when all regions of the northern Indian Ocean are considered. A small harpoon fishery also exists. Mortality in Taiwanese driftnets is likely. This dolphin may be the most common species in the northern Indian Ocean, but the cumulative impact of the various fisheries may be dangerously high.

A dwarf form of spinner dolphin is killed in waters of *Thailand* (Perrin *et al.*, 1989).

In *other northern Indian Ocean* areas, this species is killed in Bangladesh, India and Oman, but the levels of mortality are unknown (SC/O90/G12; SC/O90/G22; SC/O90/G30).

In *Australasia*, this species is one of several killed in Taiwanese drift gillnets off the coast of northeast and northwest Australia (Harwood *et al.*, 1984; Harwood and Hembree, 1987). From 1981–1985, an annual mortality of about 1,000 animals was estimated on the basis of an observer programme. Significant declines in cetacean catch rate with both time and increasing cumulative effort occurred from 1981–83. Similar analyses for 1984–85 were not done because of changes in observer coverage, fishing methods and area of operation. This fishery has since moved into waters of Papua New Guinea and Indonesia (Liu, 1989), probably eliminating the fishery as a source of additional mortality in coastal waters of Australia but inflicting mortality on animals in nearby waters that probably constitute the same population. Estimates of total incidental take are probably low.

Mortality in the *Philippines* is reported in SC/O90/G29.

Steno bredanensis (rough-toothed dolphin)
The occurrence of incidental mortality in the *Mediterranean* is reported in SC/O90/G34. Notarbartolo di Sciara reported that this species is an occasional visitor to the Mediterranean.

Incidental mortality for the *Brazil region* is reported in SC/O90/G26.

Low numbers are killed in gillnets in *coastal Sri Lanka* (Leatherwood and Reeves, 1989).

In *coastal Japan*, some dolphins are killed in Japanese trap nets (SC/O90/G36). They are occasionally killed in Japanese drive fisheries.

Tursiops truncatus (bottlenose dolphin)

For the *Mediterranean*, Notobartolo di Sciara reported that mortality occurs in drift gillnets, longlines and trawls and by harpoon and gunshot. The abundance estimate was based on a series of research cruises. See the explanation of the abundance estimate in annotation section I (above).

In the *offshore western North Atlantic*, mortality has occurred in the swordfish driftnet fishery operating at the shelf-edge of the northeast US (SC/O90/G6). During August-November 1989, 10 offshore bottlenose dolphins were observed killed. The estimated kill represents an adjusted number for a maximum of the 5–10% of the trips observed, as reported by Waring and Payne. Abundance estimates are reported in Kenney (1990).

In the *coastal areas of the western North Atlantic*, a die-off of bottlenose dolphins occurred along the US Atlantic coastline during 1987–88 (Scott *et al.*, 1988). From June 1987 through June 1988, over 700 dolphins stranded from New Jersey south to Florida. Scott *et al.* (1988) suggested that the coastal form was reduced by as much as 53% and, assuming a constant rate of mortality equal to pre-epidemic estimates, the average expected recovery time for this population while sustaining human-induced mortality is greater than 100 years.

Few direct reports are available for the incidental kill in the *Gulf of Mexico*. Interviews with fishermen and examination of stranded animals suggested that in some areas up to 1% of local populations may be taken each year (Reynolds, 1985; Burn and Scott, 1988). Bottlenose dolphins in this region are also removed by live capture. Burn and Scott (1988) summarised stranding data for the southeastern USA and found that human-related mortality may range as high as 7% of all observed mortality in the region.

Mortality in the *Caribbean* is reported in SC/O90/G7.

In *Uruguay*, bottlenose dolphins are killed incidentally in the catfish fishery but reportedly 'cooperate' with mullet fishermen (Simões-Lopes, 1991). Mortality in Uruguay is reported in SC/O90/G1.

Mortality for *coastal West Africa* is reported in SC/O90/G5.

The population along the south coast of Natal, South Africa, may be unable to sustain the level of incidental take in shark nets and may be declining. Most of the kill comprises lactating females and their calves (Cockcroft, 1990; Cockcroft and Ross, 1991). The population along the north coast of Natal may also be adversely affected by the level of shark-net catches, and (as for the south coast) most of the kill comprises lactating females and their calves (Cockcroft, 1990; Cockcroft and Ross, 1991). In addition, studies have shown that the population may be suffering further impact from the high levels of pollutants (Cockcroft *et al.*, 1990).

Mortality in *Sri Lanka* alone is estimated to be over 500 annually (Leatherwood and Reeves, 1989). Observations of fisheries in Sri Lanka suggest that large numbers of this species may be killed in gillnets when all regions of the northern Indian Ocean are considered.

In the *northern and western Indian Ocean*, incidental mortality of coastal forms also occurs in gill nets along the east coast of Africa (Mozambique, Madagascar) and the northern Indian Ocean (e.g. Thailand, Pakistan). Information is given in Leatherwood and Reeves (1989) and SC/O90/G12, G20, G22, G26 and G30. Local populations may have become depleted in many of these areas.

In *Australasia*, this species is one of several killed in Taiwanese drift gillnets off the coast of northeast and northwest Australia (Harwood *et al.*, 1984; Harwood and Hembree, 1987). From 1981–1985, an annual mortality of about 1,700 animals was estimated on the basis of an observer programme. Significant declines in cetacean catch rate with both time and increasing cumulative effort occurred from 1981–83. Similar analyses for 1984–85 were not done because of changes in observer coverage, fishing methods and area of operation. This fishery has since moved into waters of Papua New Guinea and Indonesia (Liu, 1989), probably eliminating the fishery as a source of additional mortality in coastal waters of Australia but inflicting mortality on animals in nearby waters that probably constitute the same population. Estimates of total incidental take are probably low. Other incidental catches include observed annual catches of up to an average of 25 from shark nets around Australia (that estimate includes four species of dolphins – Paterson, 1990). Anderson reported that inshore set nets probably kill a few per year and that some (<10) may be killed in the shark/tuna/mackerel driftnet in the Northwest Territory. The inshore population is probably vulnerable in some areas.

In the *western North Pacific and coastal Japan*, incidental kill occurs in trap nets (SC/O90/G36) and in research operations using large-mesh gillnets (SC/O90/G52). A direct kill occurs by Japanese harpoon and drive fisheries (Kasuya and Miyashita, 1989). The estimate of population size is only for the East China Sea-Sea of Japan area (Miyashita, 1986).

In *coastal California and the Gulf of California*, two stocks are currently recognized (Walker, 1981). The stock structure of the incidental kill is unknown, however, making it difficult to assess the impact of local mortality. Abundance in California was estimated by Hansen (1990). Sources and levels of mortality are discussed in SC/O90/G7, G24 and G28.

Inshore and offshore stocks exist along the *Pacific coast of South America*. Incidental mortality occurs in the artisanal drift gillnet fishery which takes animals mainly from the offshore stock. The estimates of kill are based on observations made in the port of Pucusana only (Read *et al.*, 1988; SC/O90/G54).

FAMILY ZIPHIIDAE

Ziphiids (unidentified beaked whales)

The 19 nominal species in this family are often difficult to identify in the field, especially for untrained observers. This difficulty is compounded by the fact that, due to their size, entangled animals are usually cut adrift from nets rather than hauled aboard. This lack of species identification is a problem in determining the impact of fisheries.

Berardius arnuxii (Arnoux's beaked whale)

Information is given in SC/O90/G52.

B. bairdii (Baird's beaked whale)

This species is taken in a direct fishery off Japan. The number taken is controlled by a Japanese quota that has ranged from 40 to 57 animals annually. Ohsumi (1975)

documented the kill of Baird's beaked whale in Japanese high seas salmon drift gillnets. Miyashita (1990) estimated population size.

Hyperoodon ampullatus (northern bottlenose whale)
Although there are few documented cases of entangled bottlenose whales, this species was subjected to heavy exploitation in a direct fishery. The species was provisionally listed as a Protected Stock by the IWC in 1977.

H. planifrons (southern bottlenose whale)
Although no absolute abundance estimates are available, this species seems to be the most abundant beaked whale species in sub-Antarctic and Antarctic waters (Kasamatsu *et al.*, 1988).

Pygmy beaked whale (unidentified mesoplodont)
This group of 13 species is extremely difficult to identify in the field. In two regions, the westen North Atlantic and coastal Sri Lanka, kills of pygmy beaked whale are potentially high. In addition, the Sri Lankan data probably underestimate the kill of all ziphiids as the catch must be brought ashore in small boats to be counted in the fish markets. Only calves or small juvenile animals are represented in the estimates. Without identification, the most conservative approach would be to assume that all the kills in each region are from only one species.

In the *western North Atlantic*, 12 mesoplodonts of unknown species were observed killed during 1989 in the swordfish drift gillnet fishery conducted in northeast US shelf-edge waters. The total kill presented in the Table has been estimated on the basis of 5–10% of fishing trips observed during 1989.

Information for *coastal Sri Lanka* is reported in Leatherwood and Reeves (1989).

M. carlhubbsi (Hubbs' beaked whale)
Information for the *eastern North Pacific* is reported in SC/O90/G24 and G28.

M. densirostris (Blainville's beaked whale)
Information for *coastal Sri Lanka* is reported in Leatherwood and Reeves (1989).

M. peruvianus (lesser beaked whale)
This new species of beaked whale was described from specimens killed in gillnets along the coast of Peru (Reyes *et al.*, 1991).

Ziphius cavirostris (Cuvier's beaked whale)
Notarbartolo di Sciara reported that this species is taken in gillnets in the *Mediterranean*.

Information for *coastal Sri Lanka* is reported in Leatherwood and Reeves (1989).

In the *western North Pacific*, Kasuya and Miyashita reported that carcasses of this species were sighted during the Japanese sighting cruises. Miyashita also confirmed a carcass entangled in a monofilament gillnet.

Information for the *eastern North Pacific* is reported in SC/O90/G24.

FAMILY PHYSETERIDAE
Physeter macrocephalus (sperm whale)
Notarbartolo di Sciara reported that the stock structure in the *Mediterranean* is unknown. If this population represents a separate stock from the North Atlantic, then the kills of sperm whales may not be sustainable. However, it is likely that the small numbers of sperm whales in the Mediterranean represents part of some larger North Atlantic stock that migrates in and out of this sea. If the latter scenario is correct, then the kills in swordfish driftnets represent a smaller impact to this population of sperm whales.

Information for *coastal Sri Lanka* is reported in Leatherwood and Reeves (1989).

Information for the *eastern North Pacific* is reported in SC/O90/G11, Perrin (1990) and Darling (1988).

Kogia sp. (unidentified kogiid)
These two closely related species are difficult to identify in the field (Ross, 1984). Because of this, incidental kills are sometimes only identified to genus.

In the *central North Pacific*, an unidentified kogiid was reported killed in the Japanese driftnet fishery by Omura *et al.* (1984).

Kogia breviceps (pygmy sperm whale)
Information for the *Caribbean coast of Colombia* is reported in SC/O90/G7.

Information for *coastal Brazil* is reported in Caldwell and Caldwell (1989) and SC/O90/G26.

Information for *coastal Sri Lanka* is reported in Leatherwood and Reeves (1989).

Kasuya reported that this species has been taken in Japanese squid gillnets in the *North Pacific*

Kogia simus (dwarf sperm whale)
Information for *coastal Brazil* is reported in Caldwell and Caldwell (1989) and SC/O90/G26.

Information for *coastal Sri Lanka* is reported in Leatherwood and Reeves (1989).

Information for *coastal Peru* is reported in Van Waerebeek and Reyes (1990a).

6. CAUSES AND SOLUTIONS

Lien chaired the sub-group reviewing causes of entanglement and possible solutions. Donovan acted as rapporteur with assistance from Lien. The sub-group agreed to review the following topics:

(1) behaviour and sensory abilities;
(2) modifications to existing fishing gear; and
(3) alternative technology and management;
making use of the meeting documents and information furnished directly by the participants and from the published literature.

6.1 Sensory abilities – thresholds and detection

The sub-group agreed that under this section of its report it would concentrate on the physiological thresholds and sensory capabilities of cetaceans. The relevance of this information to possible solutions to the fishing gear entanglement problem is discussed further under Item 6.6, although inevitably some aspects are discussed here also.

6.1.1 Acoustics
The acoustic capabilities of cetaceans have probably been better studied than other sensory capabilities they have (e.g. see review in Watkins and Wartzok, 1985). Details are not presented here. Several papers were available that provided information on the detection on nets by odontocetes using echolocations (SC/O90/G9, G15; Au,

1990; Au and Jones, 1991) and on echolocation in general (SC/O90/G13, G16, G17). Table 2 shows, for some species, the theoretical echolocation detection ranges for monofilament gillnet used in the North Pacific salmon mothership fishery and for polyester rope/metallic bead chain. Bubbles created by high sea states (see Item 4.2.6) will decrease these detection ranges. Table 2 and field observations (SC/O90/G9) indicate that dolphins are able to detect the monofilament section of gillnets at sufficient ranges to avoid entanglement. Gillnets modified by added gear such as rope and metallic bead chain should be detected at considerably greater distances than unmodified gillnet. However, experiments with such modification added to increase sonar detection have not been successful in reducing entanglements (e.g. SC/O90/G13, G15, see also Annex E). Possible reasons why dolphins are still being entangled in modified and unmodified nets despite their acoustic capabilities are summarised below. They are discussed in more detail under the indicated report items.

Table 2

Theoretical 90% probability of detection ranges as a function of biosonar source level, based on bottlenose dolphin biosonar performance data, for sea states 0-3 (Au, pers. comm.)

Peak-to-peak source level (dB re 1μPa)	Monofilament gillnet[1]	Polyrope[2]	Metallic bead chain[3]
150	2.2m	8.9m	7.3m
160	4.0m	15.9m	13.0m
170	7.1m	28.2m	23.0m
180	12.6m	50.1m	41.0m
190	22.4m	89.1m	72.9m
200	39.8m	158.5m	129.6m

[1] 0.49mm diameter nylon monofilament, 10cm mesh size; [2]0.635cm twisted polyester rope; [3]household light switch chain.

(1) Dolphins may not echolocate all the time. Some species such as Hector's dolphin often do not echolocate when navigating in a familiar environment (Dawson, 1988) and may echolocate only when foraging for food (SC/O90/G16). However, Norris reported that there is a school phenomenon with some pelagic dolphins whereby a number of individuals in a school are always echolocating.
(2) Dolphins may detect a gillnet but may not perceive the net as a barrier. Barriers may be totally alien to pelagic dolphins accustomed to roaming freely in the ocean and they may not have evolved behaviour patterns to deal with them (see Item 6.2.2). The diffuse echoes from nets (SC/O90/G15) may resemble a penetrable volume such as the deep scattering layer or kelp and other seaweed.
(3) Dolphins may be foraging for food in the vicinity of nets and be oblivious to nets and other obstacles while focusing their attention on prey (see Items 6.1.2 and 6.2.1). Attention to social activity such as play or competitive behaviour may also distract them (see Item 6.3).
(4) There are indications that dolphins are attracted to nets either by the presence of entangled fish or the presence of prey congregated near the nets (see Item 6.2.1). Some dolphins may be caught through 'carelessness' or inattention when around nets (see Item 6.3.2). Dolphins, especially young and inexperienced ones, may be attracted to nets as novel objects to explore and play with.
(5) Sleep, especially at night when most dolphin entanglement seems to occur, may be a factor in the non-detection of nets (see Item 6.2.2). However, as noted above in some schools of pelagic dolphins it seems that a number are always awake.

It should be also be noted that fishing gear emits noise that might be detected by cetaceans (see Item 6.5.2). The 'self noise' generated by water movement through a set net or by wave action pulling at surface float lines may be very loud, louder than the returning echoes produced from the dolphins, echolocating signals (Lien *et al.*, 1990). The acoustic energy is low frequency and large cetaceans with good low frequency hearing may be better able to take advantage of gear noise than small cetaceans that do not typically have good low frequency hearing. Detection and localisation of nets by passive hearing (i.e. when the animals are not echolocating) will be less precise than by echolocation.

The sub-group agreed to the following recommendations for future research:

(1) determine the sonar detection capabilities of some of the smaller odontocetes such as Dall's porpoise, harbour porpoise, Commerson's dolphin and Hector's dolphin;
(2) perform research to understand the acoustic and behavioural dynamics involved with dolphin-gillnet interaction and with fish-gillnet interaction, to determine why and how dolphins get entangled and the proportion of a pod or school of dolphins that typically gets entangled;
(3) determine the amount of self-noise in nets for different sea states for surface nets and current conditions for bottom set nets, and compare fish and dolphin entanglement with sea state conditions (see Item 6.2.6).

6.1.2 Prey size/ target strength

SC/O90/G16 examined the acoustic behaviour of a wild bottlenose dolphin during foraging. Slowest sonar click rates corresponded to maximum search range and may be related to the detection of preferred prey size and effort to capture. The dolphin was insensitive to secondary echoes from ranges beyond those defined by the click rate. Sonar click rate also varied inversely with the dolphin-prey closure range, becoming higher as the closure range decreased.

6.1.3 Vision

In addition to echolocation and hearing, vision is important to many cetaceans. Cetaceans have excellent underwater vision (e.g. Dawson, 1980; Watkins and Wartzok, 1985). It is important to understand the characteristics of cetacean eyes in order to assess the visual problems they may face in dealing with nets. One tends to think of dolphins as echolocating animals, forgetting that they may sometimes carry out much of their behaviour wholly without phonation, especially in times of danger. Baleen whales are not known to orient by echoes, although the possibility of such a capability should not be discounted (Lien, 1987). They can orient in very murky water and over considerable distances in conditions when vision would not seem to serve them well (Lien, 1980). Listening to the sounds produced by objects themselves may be the basis for detection (Lien *et al.*, 1990) but the possible use of vision cannot be eliminated.

Vision is important to cetacean orientation and it appears to mediate some aspects of the schooling of dolphins; manoeuvring may be related to pattern marks and their movement across the visual field of adjacent animals. Such patterns are best developed in clear water cetaceans and are reduced to whole-body flash signalling in murky water animals (Madsen and Herman, 1980; Norris and Dohl, 1980; Norris *et al.*, 1985). In the dark, bioluminescence is certain to be important, especially in the visualisation of moving nets. Cetacean eyes are especially adapted for low light levels (e.g. Herman *et al.*, 1975). They are amongst the few mammalian species in which the optic cup is fully tapetalised over its entire area (Dawson *et al.*, 1987a; 1987b). Their eyes are also able to deal with the extremely difficult visual environment of the surface sea, where the flicker effect may reverse intensities many times a minute, sometimes reaching peaks at several times the intensity of direct sunlight.

Most evidence suggests an almost or total lack of colour vision in cetaceans, although the highest sensitivity of the retina in coastal species is centred in the blue to yellow green, while that of open sea species emphasises the blue (Madsen and Herman, 1980).

For these reasons the visibility of nets may provide important orientation signals during both night and day and even in rather murky water. The question of diurnal variation is discussed under Item 6.2.2.

As in the case of acoustic perception of nets, there are many behavioural observations indicating that cetacean species *can* perceive nets using sight (e.g. bottlenose and hump-backed dolphins off Natal: Cockcroft, 1990; Dall's porpoises in the high sea: SC/O90/G9; humpback whales off Newfoundland: Lien, 1980). The potential reasons why entanglement still occurs are similar to those listed above in Item 6.1.1.

6.1.4 Other

The sub-group agreed that acoustics (hearing/echolocation) and vision were the most important sensory capabilities of cetaceans with respect to the entanglement problem. However, the other senses may also play some role and they are reviewed briefly below. It should be noted that little direct evidence of their role is available.

MECHANICAL

Mechanical senses include touch, pressure, position, acceleration and vibration sensing. The anatomy of many of these receptors is reviewed in SC/O90/G18. The author concludes that in general cetaceans appear well-equipped to sense the mechanical aspects of their surroundings and that this may include an ability to follow currents in the water. This is of some interest in the light of a review of environmental factors and entanglement of bottlenose and hump-backed dolphins off the Natal coast of South Africa by Cockroft (1990). He found that current direction on the day of capture was often different from the normally prevailing direction. No correlation between entanglement and fullness of stomach was found, suggesting that it is not simply a function of dolphins following prey species that may be influenced by the currents.

Clearly, mechanical senses will detect the gear itself only when the animals come into contact with it, by which time entanglement may have already occurred. However, since nets may be set either with or across currents, analysis of entanglements with respect to orientation of the nets and current direction may be useful.

THERMAL

The anatomy and physiology of thermal control are reviewed in SC/O90/G18. The ranges and/or seasonal distribution of many cetacean species can be described with reference to surface isotherms or to the temperature characteristics of particular water masses. The range of temperatures at which most cold-blooded prey species can live tends to be narrow, in comparison with the ranges which cetacean species can tolerate. Water surface temperature and temperatures at specific depths are sometimes used to locate fishery target species (e.g. SC/O90/G14 – swordfish fishery; SC/O90/G8 – flying squid fishery).

All cetaceans have the means to sense environmental temperature and at least some fishing gear is set in relation to water temperature. If cetaceans follow temperature gradients as a travel cue or as a guide to prey, they could be brought into collision with nets set across the travel path. This possibility requires investigation.

CHEMORECEPTORS

The anatomy of chemoreceptors and the experimental investigation of chemoreception is reviewed in SC/O90/G18. Chemoreception may provide social information (e.g. reproductive state, alarm), directional information (e.g. following salinity gradients) or foraging information (e.g. detecting the excreta of prey). Evidence for this is at present anecdotal and further research is needed to establish the true role of chemoreception in the life of cetaceans.

Natural history literature often refers to the presence of blood in the water as an 'alarm' substance. Italian fishermen reportedly throw back carcasses of incidentally killed dolphins, believing that this will deter other animals. Lien (1980) reported that fresh humpback blood did not prevent another humpback whale getting caught in a set net off Newfoundland. Hawaiian fishermen were unsuccessful in discouraging bait stealing by dolphins (including bottlenose and rough-toothed dolphins and pygmy and false killer whales) by lacing the bait with quinine. However, bottlenose dolphins readily eat fish containing quinine in captivity so perhaps this is not surprising (Schallenburger, 1979).

Myrick (1988) reported that spotted dolphins chased and set upon by purse-seiners are hypocalcaemic, a common stress reaction in other mammals. A further characteristic of stress in mammals is the presence of chemicals in the urine that may constitute an 'alarm' substance. Kleinenberg *et al.* (1964) report an incident of an unmolested group of white whales fleeing when they reached an area where an earlier group had fled due to the presence of hunters. This could be indicative of an alarm substance.

Fishing gear has its own chemical characteristics, as do target and non-target species caught in that gear. Lien reported that older Newfoundland fishermen relate that there were fewer collisions by animals with cotton and hemp nets that were dipped in oily tar; they believed that animals such as whales and seals could smell them. Chemoreception may play some role in entanglements either due to stimulants provided by gear, prey species or conspecifics, but considerable research is needed to determine this and investigate the possibility of developing effective chemical 'deterrents'.

MAGNETIC AND ELECTRICAL

SC/O90/G18 reviews magnetic and electrical detection by cetaceans. Behavioural evidence suggests that cetaceans may be able to sense the flux density of the earth's magnetic field as a travel guide, generally swimming parallel to the contours (i.e. in areas with low field gradient). Beaches where strandings and drive fisheries for long-finned pilot whales have taken place tend to have perpendicular magnetic contours. Travelling (but not feeding) fin whales have been shown to use magnetic contours as a travel guide, based on data from the UK, Ireland and USA east coast. There is also some evidence for a 'travel clock' re-set by geomagnetic information and used in monitoring position and progress (Kirschvink, 1990; Klinowska, 1990).

While it seems unlikely that gear itself would provide any magnetic information, it is not inconceivable that cetaceans following magnetic contours could be brought into collision with gear deployed across these contours. In such situations gear could be re-oriented to align with cetacean movement.

6.2 Environmental/ecological correlates

6.2.1 Food

Entanglements may occur where: the target species are prey or potential prey for cetaceans; the fish caught are not prey species but cetaceans are attracted to the nets because other potential prey are associated with the net; the target and incidental species are seeking similar prey; or the cetaceans and fisheries occur in the same vicinity for reasons related to physiography and biological productivity.

(1) SITUATIONS IN WHICH MARINE MAMMALS ATTEMPT TO REMOVE PREY FROM NETS

There is evidence from some fisheries that marine mammals attempt to remove prey from nets. This includes harbour porpoises in the North Atlantic (e.g. SC/O90/G46; SC/O90/G8; Read and Gaskin, 1988). Lien (1994) reported that in Newfoundland, long-finned pilot whales intentionally frequent traps to remove the target species of squid (*Illex illecebrosus*). There are no reports of such behaviour in baleen whales. Many pinniped species are known to actively and efficiently remove prey from nets and traps (e.g. see Beddington *et al.*, 1985).

(2) SITUATIONS IN WHICH MARINE MAMMALS ARE NEAR NETS, BUT DO NOT REMOVE PREY FROM THE NETS

Nets may serve as attractants which lure fish and other animals to the area of the net; nets are known to have a 'calling area'. The use of fish attracting devices (FADS) is a technique whereby objects are installed which serve as the focus for the establishment of a marine community. Prado reported that FADS are known to draw in fish from distances of 4–5 n.miles. Cetaceans may be attracted to nets in a similar manner, or may respond to prey species which react in this way.

Marine mammals may also be attracted to scavengers feeding on fish in the nets.

Another possibility is that target and non-target species have similar prey items or are linked in some way through the food web. This is probably common in many situations e.g. *Tursiops* in South African shark nets (Cockcroft, 1990; SC/O90/G20), Dall's porpoises in salmon driftnets reported by Jones), harbour porpoises in the halibut fishery and vaquitas in the totoaba fishery.

In some cases marine mammals, for example humpback whales in Newfoundland, use nets as a backdrop to corral fish (Lien, 1980). Minke whales may be attracted to nets by the scrapefish discarded by fishermen as they clean their gear (Lien, 1994).

In many cases nets are set in areas of high biological productivity and as a result both target species and mammals are present.

6.2.2 Physical conditions

DIURNAL CYCLES

Diurnal behaviour patterns may be considered with regard to the timing of net sets, the soak time and the behaviour of both target and non-target species.

Like most organisms, cetaceans have specific diurnal patterns and cycles (e.g. Klinowska, 1980). These cycles may contribute to the likelihood of entanglement. Some species may travel considerable distances on a daily basis. Diurnal travel patterns may increase the likelihood of encountering nets, and travel may be associated with food sources, migration or other factors such as tides and currents (Klinowska, 1980).

Many diurnal cycles are linked closely to prey behaviour. One of the most obvious is the daily vertical migration of the deep scattering layer (DSL). Linkage to the DSL is probably strong in most oceanic species, notably *Stenella longirostris* (Norris *et al.*, 1985).

Some cetaceans descend to rest, sleep or reduce their activity during parts of the day. This behaviour may increase the chances of entanglement due to decreased awareness of surroundings, but it also reduces travel and the probability of encountering a net. Some species have a general tendency toward increasing group size later in the day (Norris and Dohl, 1980; Scott *et al.*, 1990) and large groups may have a greater ability to detect threats such as nets. Some cetaceans are active at dawn and dusk, when low or changing light levels may decrease the likelihood of net detection, although as noted under Item 6.1.3, cetacean vision is good in low light.

The diurnal behaviour patterns of target and incidental species are probably closely linked. However, in fisheries where this is not the case it may be possible to reduce entanglement rates while concurrently maintaining catch levels by adjusting the timing of gear setting and soak durations.

TURBIDITY

This is potentially an important factor if vision is the major sense used by the cetacean to detect fishing gear. There is little direct information of the effect of turbidity on entanglement rates of cetaceans. The only attempt at a quantitative study is that described by Cockroft and Ross (1991) for dolphins caught in shark nets off the Natal coast of South Africa. Nets are examined daily and so turbidity on the day of capture is known but turbidity at the precise time of capture is not.

Cockroft found that animals were caught at all levels of turbidity, although at one location near a river mouth where the water visibility was <1m, hump-backed but not bottlenose dolphins were caught. This is thought to reflect the fact that bottlenose dolphins tend to avoid turbid water off that coast while hump-backed dolphins are often associated with riverine conditions (e.g. Ross, 1977; Norris *et al.*, 1985). Turbidity may also be a factor in the seasonal changes in distribution of bottlenose dolphins off the coast (Cockcroft, 1990).

Visual characteristics of fishing gear, including brightness, colour and size, were found to be less important than turbidity in determining distances at which gear could be visually detected (Lien, 1980).

AMBIENT NOISE

Ambient noise could be an important factor as it has the potential for making gear less acoustically detectable. Again, almost no quantitative information exists on entanglement rates at different levels of ambient noise. In the Cockroft (1990) study off Natal, no direct measure of ambient noise was available. However, the author looked at swell height and depth of net as some indication of likely ambient noise and found no significant correlation with entanglement rate, although he noted the paucity of data. Lien *et al.* (1990) suggest that high risk areas for entrapments of humpback whales may be characterised by high levels of ambient noise.

Ambient noise may be a factor in entanglements for certain fisheries and species. However, this cannot be determined without carefully designed experiments. Until these are completed it will be impossible to consider ambient noise when trying to develop possible modifications to fishing practice or gear which may help to reduce entanglement problems.

TIDES AND CURRENTS

Tides and currents are known to affect the distribution of some cetacean species in certain areas (e.g. Würsig and Würsig, 1979), probably by influencing the distribution of prey species. Again there is almost no direct information on the influence of either tide or currents on entanglement rates of cetaceans. In the Cockroft (1990) study off Natal, however, there was a significant correlation between current direction and entanglement rate, with most captures occurring when the current direction was northerly. The reason for this is unclear.

Tides and currents may be a factor in entanglements for certain fisheries and species. However, as for the other factors discussed, without carefully designed experiments it will be impossible to try to develop possible modifications to fishing practice or gear which may help to reduce entanglement problems. This is discussed further under Items 6.1.4 and 6.3.3.

DEPTH

This is clearly an important factor in some entanglement situations. Different cetacean species spend differing amounts of time at different depths depending on their feeding strategy and whether they are travelling, etc. The depths at which fishermen set their nets depends on the target species and the type of gear. The potential for deploying nets at depths less likely to cause potential contact with cetaceans is high for some fisheries. Experiments along those lines have already been carried out with some degree of success (SC/O90/G58; Harwood and Hembree, 1987). These are discussed further under Item 6.2.2.

SEA STATE AND BUBBLES

The surface sea is often turbulent and waves can drive plumes of bubbles into the water for several meters. Such bubble plumes will probably be largely opaque to echolocating cetaceans. The bubbles can be divided into three categories: (1) tiny bubbles that quickly dissolve; (2) mid-range bubbles that may develop films over their surfaces that can cause them to persist for long periods; and (3) larger bubbles whose greater hydrostatic lift causes them to rise quickly to the surface.

The mid-sized bubbles can be very persistent, remaining in the upper sea water column for a matter of hours. They are also of a range of diameters that form excellent echolocation reflectors (*ca* 60 microns and above) and may appear as much as seven times their actual size to an echolocating animal. This means that the surface sea, especially during times of rough weather, can completely obscure the echolocation trains of dolphins. Translated to the driftnet problem this could mean that in the upper few meters of the sea, bubbles might completely blot out echo returns from nets in the area.

If cetaceans typically swim through such acoustically-opaque water, they could be especially vulnerable to entanglement. Since there are no true obstacles at sea except for occasional floating debris, dolphins may deliberately swim 'blind' through such water, making them especially prone to entanglement. Differential entanglement during various sea states should be examined as part of a preliminary assessment of this question (see Item 6.1.1).

6.3 Behaviour

While we understand some cetacean behaviour, there is much more to know. In particular the behaviour of cetaceans near nets is little studied and poorly understood; there is little systematic knowledge of many behavioural processes which may dispose them to entrapment risk near fishing gear.

6.3.1 Curiosity, exploration

There are few published accounts which describe exploration behaviour of cetaceans (SC/O90/G49) and it is not possible from these studies to infer how cetaceans might react when first encountering fishing gear or what changes these initial encounters may produce in subsequent activities near nets.

Entrapments frequently involve disproportionate numbers of young cetaceans, which may be due to the animals lack of experience with fishing gear. This lack of familiarity may encourage curiosity, exploration or play which could result in entrapment (Cockcroft, 1990; SC/O90/G51). Age-dependent mortality resulting from risky exploration and play activities has been observed in terrestrial animals. Studies of social and play activities have found that they commonly have high costs in terms of injury or predation in young animals (Fagen, 1981). The observed age or sex skew in frequency of entrapments of young cetaceans in some fisheries may be a result of age or sexual segregation in certain species and some increased probability that these groups encounter fishing gear (Cockcroft, 1990).

For small cetaceans in particular, many close encounters with nets result in mortality (Table 3, Item 6.4), with consequently no opportunity for an individual's initial curiosity about nets to change. Observational learning is well documented in odontocetes; entrapment events could result in changes in the behaviour of other animals in a group. Cetaceans may learn to associate nets with negative events. They may also habituate to the novelty of nets as they more frequently encounter them. While this may produce fewer approaches for exploration, close approaches because of lack of attention may occur.

In baleen whales, it is also younger animals that appear to be those most commonly caught in fishing gear. In Newfoundland, entrapments typically involve small

humpbacks (Lien, 1980; Lien, 1994). Humpback collisions with fishing gear appear to result from their failure to detect it; the higher probability of accidents by young animals would appear to reflect 'recklessness' or inexperience.

There is an urgent need for studies to examine the exploratory behaviour of young cetaceans and the role this behaviour may have in producing entrapments in fishing gear.

6.3.2 Attention and perception

Although in some populations the frequency of incidental entrapments by cetaceans is quite high, it is likely that the animals usually detect nets and avoid entrapment (Awbrey *et al.*, 1979; Cockcroft *et al.*, 1990; Hatakeyama, 1986). Generally, it has been assumed that detection of nets is accomplished by their acoustical properties (see Item 6.1.1).

While nets appear to be within dolphins' acoustical detection thresholds (SC/O90/G15; Au, 1990; Au and Jones, 1991), there may be reduced attention to acoustic cues or selective processing of information that is simultaneously being presented while feeding, travelling or resting. Animals may attend to particular stimuli over others both because the ability to process information is limited and through more 'voluntary' control over their attentional capacity (SC/O90/G48).

It is known that dolphins and porpoises may spend large amounts of time during which they produce no echolocation signals. Dawson (1990) found that Hector's dolphin did not echolocate regularly while navigating in a familiar environment. SC/O90/G16 reported that a wild bottlenose dolphin echolocated only when foraging for food. During periods while not echolocating, dolphins may be less capable of detecting nets.

Humpback whales have been observed feeding near fishing nets at night and to avoid becoming entrapped, without vocalising. (Lien, 1980). Collisions with fishing gear by this species in Newfoundland most frequently occur on the first day the gear is placed in the water; probability of a collision with a particular net decreases as soak time increases (Lien, 1988). It appears the animals are 'surprised' by the presence of new fishing gear but, following an encounter, learn its location. Similarly, accidents are most common on the first day whales move into an area where fishing gear has previously been installed; accidents decrease over time (Lien *et al.*, 1990).

Many observations indicate that dolphins are aware of the presence of nets as judged by their swimming behaviour around the gear (e.g. Silber *et al.*, 1994). In some cases the dolphin may perceive the net as a barrier. Tests of terrestrial species that have evolved in circumstances without barriers typically find that these animals have great difficulties learning to solve barrier problems (Maier and Maier, 1970). Fishermen setting on swordfish in the northwest Atlantic leave gaps between nets in a fleet to allow marine mammals to escape; Smolowitz reported that if there are no gaps fishermen feel that animals encountering the net are more likely to get caught.

6.3.3 Orientation

Orientation cues used by an animal can affect the likelihood of entrapment in fishing gear. If travelling, the navigational strategy used by an animal may modify the probability of encountering and detecting fishing gear (see Item 6.1).

According to Keeton (1974), animals generally have redundant navigation systems which are used in a hierarchical order. Little is known of cetacean navigation strategies; the satellite technology which may provide this information is still developing.

Proximate orientation by an animal while near nets may also be a factor in entrapments. If a dolphin echolocates on a fish target near nets, it may have difficulty detecting the net behind it (SC/O90/G17). Depth of field in the echolocation abilities of dolphins is poorly understood (Penner, 1988).

6.3.4 Escape patterns

There are few studies which provide information on escape efforts of small cetaceans when they collide with fishing gear or once they are entrapped in nets (SC/O90/G51; Hatakeyama *et al.*, 1988). The percentage of animals that encounter nets and successfully escape is not known; it is believed that this varies among species (Table 3, Item 6.4). Smaller cetaceans may not escape as often as the larger whales and the nature of the fishing gear and the depth of set may also be important factors.

Anecdotal accounts of observed escapes from fishing gear entrapments vary. Systematic disentanglement of dead animals from nets may provide information on their escape efforts (J. Coe, pers. comm.; Barham *et al.*, 1977). Lien reported that in Newfoundland, monitoring by side scanning sonar and underwater video cameras of fishing gear installed at locations where collisions are frequent may provide information on collisions and escape efforts of humpback whales.

6.3.5 Social patterns

There are important differences in social organisation among species of cetaceans; these differences may result in species being differently vulnerable to entrapment. They will also determine, in part, the effectiveness of efforts to minimise bycatch.

A body of theory (Norris and Dohl, 1980) proposes that schools, such as those of open-ocean dolphins, are sensory integration systems which mediate the behaviour of individual animals in the presence of danger in the three dimensional world of the open sea. Understanding how such cetacean schools communicate and process information may facilitate analysis of behaviour observed during encounters with nets. Norris reported that open ocean dolphins seem to have much difficulty if required to swim in smaller groups, or to pass through escape gates or spaces between nets smaller than will allow the school to pass. In dealing with these species, schools rather than individuals may be the appropriate unit for analysis with respect to the entanglement question. Cetaceans living in more restricted, nearshore habitats tend to travel in smaller groups.

In some cetaceans, the tendency for reciprocal or kin altruism acts (Caldwell and Caldwell, 1966; Conner and Norris, 1982) may contribute to entrapments. Many have reported mothers and young which are captured together in nets (Cockcroft, 1990); in some cases entrapped young have tooth marks on the body which appear to be the result of adult attempts to remove them from the net (Dawson, 1990).

6.3.6 Feeding behaviour

As noted under Item 6.2.1, feeding behaviour by cetaceans may be a significant contributing factor in many entanglements. Animals may be chasing prey species that

are either the target species of the fishery, or others that occur in the same area as the target fishery. In some cases, animals may actually be taking prey species from the net (SC/O90/G2), or they may simply be attracted by entangled fish. Harbour porpoises in the Bay of Fundy feed on hagfish (*Myxine glutinosa*) that are feeding on fish captured in the nets (SC/O90/G6).

There is evidence that the smaller odontocetes are capable of acoustically and visually locating nets and observational data suggesting that free-ranging animals avoid capture in nets (Dawson, 1990; Hatakeyama, 1986; SC/O90/G9, G13, G15 and G20). This information implies that the entanglement problem may be less one of detection capabilities than one of alertness and attention (see Item 5.2). Observations of feeding porpoise and dolphins indicates that high speed chases culminating in prey capture is common in several species. If prey fish attempt to escape by swimming into or through a nearby net, a dolphin predator maybe so focused upon the target of the pursuit that the less salient visual and acoustic signals of a net fail to alert the animal (SC/O90/G17; SC/O90/G48).

For the more gregarious species, an additional confounding feature of feeding behaviour may be the feeding 'frenzy' that occurs in several species of small cetaceans when a school of fish is encountered. Highly active behaviour of a large group of feeding dolphins may reduce visibility or mask cues that would normally alert animals to the presence of nets and may distract normally wary animals in the excitement. Further, large schools of prey species may obscure visual or acoustic cues that would alert cetaceans to the presence of nets.

In the mysticetes, the levels of entanglement involving humpback and right whales in the North Atlantic, gray whales along the Pacific coast of North America and minke whales in the several areas of the Northern Hemisphere suggest that the animals have difficulty detecting the presence of gear, at least under certain conditions, or that they fail to attend properly to the gear while they are feeding or engaged in other activities. Mysticetes are not known to echolocate but from environmental constraints it seems likely that they detect the presence of gear using acoustical cues. Humpbacks in Newfoundland feed on capelin (*Mallosus villosus*) at night in turbid water next to cod traps in complete silence but their behaviour indicates that they can locate fishing gear and avoid it (SC/O90/G51; Lien, 1994).

The feeding lunges of humpback and minke whales and the bubble clouds used by humpbacks in feeding activities may make these animals susceptible to entanglement. In Newfoundland, capelin collect and school densely next to the leaders of cod traps; most collisions by humpbacks are observed to occur with leaders during these times (Lien *et al.*, 1988b). Entrapment of humpback whales is frequently by a net and rope bridle through the mouth, indicating it has been feeding when the collision occurred (Lien, 1980). Right whales may be vulnerable to entanglement while feeding because they engage in long skimming transits with their mouths open; in the northwest Atlantic about 50% exhibit scars in the corners of their mouths which are believed to be the result of fishing gear (Kraus *et al.*, 1984; Kraus, 1990).

6.4 Morphology: anatomy of entrapment

Cetacean entanglement in fishing gear probably occurs in a variety of ways, but there are almost no quantitative data on this. Where detailed reports exist, it appears that the head, mouth, flippers, dorsal fins and flukes are involved (SC/O90/G1,G2,G8,G25 and G26; Heyning and Lewis, 1990; Lien *et al.*, 1990). In a four year study of 10,259 Dall's porpoise entanglements in the North Pacific salmon driftnet fishery, Snow (1987) found that 27% were caught by the flukes, 10% by the pectoral flippers, 9.5% by the mouth and 24% in a 'complex' fashion. In anecdotal reports, the evidence indicates that the animals strike the net with their rostrum first, then roll themselves up into the net, presumably in the panic following the initial strike. There is one record of a Dall's porpoise breaking and swimming through a drift gillnet in the North Pacific (SC/O90/G9). In the case of many of the larger whales, particularly the mysticetes, lines or nets are caught in the mouth and may end up being carried around for several years (e.g. Kraus, 1990). Animals trailing such gear appear to be at a higher risk for subsequent entanglements (Lien, 1980) and may have a lower survivorship. The barnacles and callosities of humpback, gray and right whales may render these species more susceptible to entanglement (Lien, 1994).

The level of mortality associated with observed entanglements appears to be related to the size of the animal, although other factors such as gear type, mesh size and proximity to the surface, may also affect mortality rates. Small cetaceans suffer extremely high mortality from gillnets, but lesser mortality from encounters with weirs or seines (unless, as in the eastern tropical Pacific, deliberately captured in the purse seines). Larger animals tend to escape from most gillnets, probably because the gear is not strong enough to contain them, but in fisheries with heavier gear (e.g. cod traps or weirs), larger whales usually require assistance to escape.

Information on entanglement/mortality rates has two significant gaps: (1) animals may be entangled but escape carrying gear and/or injuries, thus lowering their probability of survival and (2) animals may strike the fishing gear and 'bounce' off without becoming entangled. Both possibilities will lead to undercounting cetacean/fishing gear encounters. Scarring indicating prior entanglement events and animals carrying gear have been reported in right whales (Kraus, 1990) and humpbacks (Lien, pers. comm.). About 4 to 5 times as many holes (presumably made by whales) as whales have been reported in nets by fishermen in Newfoundland and California (Lien, 1980, reported by Lagrange).

If animals escape entanglements but are carrying gear that subsequently affects survival, then the lethal effects of entanglements will be underestimated. Alternatively, if animals are bouncing off gear without any adverse effects, then the degree of mortality from net encounters will be overestimated. Given these caveats, data on survivorship from observed entanglements are presented in Table 3.

6.5 Types of gillnet and marine mammal bycatch risk

It is important that in the description of gillnet fisheries (as for any other) and in reports on research and experiments, the specifications of the gillnet or other gear used are complete and unambiguous. The lack of such information will preclude understanding of the true situation and comparison among experiments. Annex F presents guidelines for the correct description of gillnets.

Different types of gillnet are involved with entanglement of different cetacean species under different conditions. Entanglement problems should be considered case by case,

Table 3

Mortality in observed entanglements of cetaceans. These data do not include records of animals that struck gear but did not become entangled or those that became entangled and then escaped.

Species	Location	Year	Type of gear used	n	Mortality	Source
Harbour porpoise	Gulf of Maine	1975-89	Gillnet, bottom or midwater	71	99%	SC/O90/G6
Harbour porpoise	Baltic Sea	1988-89	Gillnet, bottom or midwater	70	100%	SC/O90/G25
Harbour porpoise	Newfoundland	1989	Gillnet, bottom or midwater	39	95%	SC/O90/G51
Harbour porpoise	Bay of Fundy	1979	Weirs	27	39%	Read & Gaskin, 1988
Harbour porpoise	Southern California	1983-86	Gillnet, bottom or midwater			
Small cetaceans	Peru		Gillnet, bottom or midwater		100%	SC/O90/G11
Franciscana	Uruguay	1974-89	Gillnet, bottom or midwater	3,008	100%	SC/O90/G1
Franciscana & Burmeister's porpoise	Argentina	1988-89	Gillnet, bottom or midwater		100%	SC/O90/G2
Small cetaceans [1]	Northwest Pacific	1988-89	Surface drift nets	1,167	96%	SC/O90/G8
Sperm whale	Italy	1988-89	Surface drift nets	9	0% [2]	SC/O90/G34
Humpback whale	Newfoundland	1979-90	Cod traps, gillnets	576	16% [2]	Lien, this volume
Right whale	North Atlantic		Cod traps, lobster gear	20	12% [2]	Kraus, 1990
Minke whale	Gulf of Maine	1975-89	Gillnets, lobster gear, weirs	28	64%	Kraus, pers. comm.
Minke whale	Newfoundland		Gillnet, bottom or midwater		70%	Lien, 1988

[1] Mainly Dall's porpoise, northern right whale dolphin, Pacific white-sided dolphin
[2] Numbers affected by disentanglement efforts by researchers and fishermen

considering the characteristics of the particular fishery, as well as the characteristics and behaviour of the susceptible cetacean species.

6.5.1 Bottom gillnets

Gillnets set on the bottom in coastal waters from nearshore areas to depths of around 200m are commonly used to catch demersal fish. Although they have been shown to entangle several cetacean species, the most critical problem area currently appears to involve coastal bottom-feeding small cetacean species such as the harbour porpoise. These species may be more susceptible to mortality in gillnets than larger cetaceans because they are less able to escape by breaking the gear. Other factors which may be involved in coastal bottom gillnet entanglements include:

(i) turbid water;
(ii) shared prey species (herring, mackerel, etc.);
(iii) depth of net relative to depth of water (in very shallow places);
(iv) long net soak time, in some cases;
(v) proximity to shore;
(vi) acoustically complex environment;
(vii) strong construction.

Relevant characteristics of the small cetacean species involved include their general tendency to stay in relatively small groups and use echolocation more than the open ocean species.

6.5.2 Bottom driftnets

The use of coastal bottom driftnets, particularly for shrimp, has increased tremendously during the past ten years. This technology sometimes gives artisanal fishermen access to a valuable resource. Although a small scale fishing method, the aggregate quantity of gear in the water in a given area may be substantial. Reliable information from such fisheries is not available but cetacean mortality may not occur at a high rate, possibly due to the following factors:

(i) the relatively short soak times (commonly 15–120 minutes);
(ii) continuous monitoring of the condition of the gear;
(iii) the acoustically 'noisy' character of nets drifting on the bottom;
(iv) the relatively small mesh size of shrimp driftnets (65–80mm stretched);
(v) the depth of the net relative to depth of water in shallow places.

6.5.3 Coastal drifting midwater or surface gillnets

Coastal drifting midwater or surface gillnets are used to catch salmon, mackerel, sardine, herring, etc. They are also known to take cetaceans, and relevant factors may include:

(i) the depth of net relative to the depth of water (in very shallow places);
(ii) the target fish species also being the cetaceans' prey species;
(iii) the nets often being aimed at dense schools of fish, rather than dispersed populations – a foraging strategy known for many cetacean species.

6.5.4 Large-mesh pelagic driftnets

Large-mesh pelagic (also often used within 200 n.miles) driftnets of the type used for swordfish, sharks and other large pelagic fish are known to entangle cetaceans.

Swordfish and shark driftnets are often made of relatively strong multifilament twine with diameter over 2mm, which is more visible than the monofilament often used on smaller mesh nets. Stretched mesh size often exceeds 200mm and often ranges up to 560mm. These nets are either surface or midwater set. Smaller cetaceans appear to be more susceptible to mortality. Relatively large mesh driftnets (>100mm mesh size) are also used to catch several species of tuna.

6.5.5 High seas monofilament driftnets

High seas monofilament driftnets are set at or near the surface stretch up to 60km or more in length and are known to entangle several species of open-ocean cetaceans (SC/O90/G4, G8, G9, G43). Some species of small cetacean such as Dall's porpoise appear to be particularly vulnerable. The low visibility of monofilament and the flexibility associated with its drifting condition may be factors which increase its tendency to take mammals.

6.5.6 Traps and weirs

Fish traps and weirs comprise another type of passive fishing gear which takes cetaceans. This type is not intended to entangle fish, but rather to guide fish into some type of 'pen' from which escape is difficult. Both large and small cetaceans are caught in these traps. It appears that mortality for small cetaceans in this gear is relatively low, and in some areas both large and small cetaceans are routinely released alive. Several studies have documented tendencies for cetacean entanglement in such gear and recorded relevant information regarding deterrence, learning and particularly high entrapment rates at specific sites (Lien *et al.*, 1988b; 1990).

6.6 Technical aspects of modifying gillnets

Cetacean entanglement has been documented from many different types of gillnets. Attempts to alleviate this problem have sometimes involved modifications of the fishing gear and methods, and this continues to be a very important area of study and development.

A gillnet is a combination of several components. The characteristics of each component should be considered, as well as the ways the components are assembled. A great many technical options are available. Different types of modifications are likely to be appropriate for different types of fisheries, different environments and different cetacean species. Research and development should be planned accordingly.

There are a number of problems with designing and evaluating experiments on gear modification. These include:

(a) the fact that experiments must be carried out on a sufficient scale and over a long period of time for statistically significant results to be obtained;
(b) the lack of baseline data;
(c) the fact that results from one area under one set of conditions may not be valid for another area.

Annex E lists papers describing gear modification experiments.

6.6.1 Types of modifications

MODIFICATIONS TO INCREASE THE TARGET STRENCTH OF GILLNETS

Japanese researchers have experimented with two types of passive modifications to gillnets (SC/O90/G9, G13) to reduce entanglement of Dall's porpoise in the North Pacific driftnet fishery for salmon. In the first, three hollow air-tube threads were intertwined into the central band of an otherwise standard gillnet. The air-tube threads had a target strength only marginally higher (3–4dB) than standard monofilament. Mean catches of cetaceans in these modified nets were about 21% lower than those for standard nets, although the reduction was not statistically significant in two of the six seasons tested. Practical difficulties were encountered in handling the modified nets.

The second modification consisted of intertwining three multifilament threads into the central band of an otherwise standard gillnet. These threads had a target strength about 10dB higher than standard monofilament. Overall, these nets had marginally lower catch rates than the air-tube nets (above), but the reduction was not significant in either season tested (1986, 1987). Data comparing only adjacent sets showed a significant difference in June 1987, but not July. Paradoxically, the distribution of entanglements within the nets showed that significantly more porpoises were caught in the central (modified) band of multifilament nets than in the corresponding band of the air-tube nets.

The strongest test yet of the effect of passive acoustic modifications to gillnets was conducted by Harwood and Hembree (1987). The target strength of the nets was raised by over 20dB by weaving 4mm bead chain into the driftnets used for sharks in northern Australian waters (SC/O90/G15). No significant difference in the catch rate of cetaceans (predominantly bottlenose and spinner dolphins) was found. Hembree and Harwood (1987) also tested 8mm air-filled plastic tubing, but found it operationally unusable (for practical constraints see SC/O90/G13).

There are designs for acoustic reflectors that would have much higher target strengths than any of the materials tested so far (SC/O90/G17) and these warrant further research. Such reflectors may have the additional advantage of allowing fishermen to find lost gear. However, it should be noted that while such designs are much more promising for acoustical reasons, the effectiveness of all types of acoustic reflectors is subject to the constraints outlined in section 6.1.1 above and in several papers (SC/O90/G13, G15, G16 and G17).

ACTIVE SOUND EMITTERS

The benefit of adding sound emitters to gillnets to reduce entanglement of small cetaceans appears equivocal. When sound emitters were added to Japanese air-tube nets, there was no significant decrease in catch rates in any of the years tested (data from Ogiwara, 1986; Hatakeyama, 1988; Snow *et al.*, 1988). Neither did the addition of sound emitters significantly effect the horizontal distribution of entanglements (SC/O90/G13).

Even if sound emitters reduced catches of dolphins and porpoises it is extremely unlikely that it would be practical in the foreseeable future to place them in all gillnets. Current devices are large, heavy (Hatakeyama, 1986), reasonably expensive (Ogiwara, 1986) and need to be regularly recharged (Hatakeyama, 1988). It is possible that many small sound emitters that are designed to have short ranges would be more effective at alerting cetaceans to the presence of nets than are the current large, long-range emitters.

There are also a number of problems which may occur in efforts to reduce entanglement of cetaceans by adding sound emitters to nets (SC/O90/G13):

(a) any sound sufficiently aversive to scare cetaceans away may also decrease fish catches;
(b) sounds might attract the attention of nearby cetaceans and encourage them to investigate the source of the danger;
(c) cetaceans must associate the sound with the danger of entanglement, which, in the absence of sophisticated communication between individuals, will only be learned by animals that experience both the danger and the warning sound and survive to associate the two – the proportion of small cetaceans that experience entanglement and survive is unknown but presumably small (see Item 6.3 above);
(d) habituation to the sounds is a general problem – randomising the sounds used (e.g. Hatakeyama, 1986) might prevent habituation, but it would also prevent association of any particular sound with the danger of gillnets;
(e) there are cases in which marine mammals appear to feed directly on fish caught in gillnets, or on fish

associated with nets (SC/O90/G6) – attaching sound emitters to nets could have the effect of 'ringing the dinner bell'.

These problems apply chiefly to small cetaceans. Large cetaceans, because they have higher survival rates in interactions with gear, have a far greater potential to be conditioned to avoid fishing gear (or at least fish traps, SC/O90/G51). Early tests (Lien *et al.*, 1994) show some promise.

SUB-SURFACE GILLNETTING

Hembree and Harwood (1987) examined the effect of setting driftnets lower in the water column. They compared nets set 4.5m below the surface with nets set at the surface. The sub-surface nets had significantly lower (50%) catches of cetaceans, but also significantly lower (25%) catches of target fish. SC/O90/G58 presents preliminary results of Japanese research examining the effect of sub-surface setting in both the North and South Pacific. Encouragingly, the sub-surface nets took very few cetaceans, while catch rates of target species were about the same, but the small sample sizes make statistical comparison with nets set at the surface difficult. The economic viability of sub-surface driftnetting in these fisheries is not yet clear, as the nets are more expensive and have longer handling times than normal driftnets set at the surface. SC/O90/G45 reported on the commercial use of subsurface nets in the California swordfish gillnet fishery.

6.6.2 Summary and conclusions

Reductions so far achieved in entanglement rates of small cetaceans via modifications to gillnets have been equivocal and of a marginal nature. However, there are many aspects of the acoustical interaction between cetaceans and gillnets that warrant further study. Current knowledge suggests that it is unlikely that acoustic modifications will provide a total solution in the foreseeable future. Acoustic modification may be useful in reducing entanglement in species where impacts on populations are not immediately threatening. In addition, acoustic modifications could be used in concert with other management actions (e.g. gear or area restrictions) to achieve necessary reductions in catch. For seriously reduced (or rare) species or populations of cetaceans it will be necessary to implement other means of reducing entanglement rates.

In view of the promising results obtained from the subsurface gillnet experiments, it is recommended that further experiments be carried out to address the following:

(1) the statistical validity of the results;
(2) seasonal or geographical effects;
(3) applicability of the technique to other gillnet fisheries.

6.7 Alternative technologies

When a new technology becomes available there is a group of fishermen, sometimes referred to as early innovators and who are usually local industry leaders, who utilise it in solving problems they have before them. There is a second group of people within the industry who will then apply the technology when it has proved its value. A third group often exists that will oppose the technology ('the Luddite Tendency').

Properly defining a problem is half its solution. What is necessary in the case of cetacean capture in fixed gear is to help the fishermen understand that this is a problem that they have to face and that will affect their livelihood (possibly by draconian regulatory methods if a solution is not found) and encourage them to solve it. Incidental catch of cetaceans in fishing gear is, first of all, a fisherman's problem. The Workshop believes that the approach most likely to succeed is to identify and talk to these early innovators in the relevant fisheries, help them to define the problem and give them the equipment and assistance (in expertise and personnel, particularly with respect to cetaceans) they need to find a solution.

A less desirable way to let fishermen know they have a problem is to place a financial disincentive on the taking of cetaceans (SC/O90/G40). This has the advantage of not defining the solution. It presumes the problem is 'the taking of cetaceans'.

If governments define solutions *vis a vis* regulations (e.g. banning gillnets, modifying gear characteristics, fishing methods and strategy etc.) it risks perverting innovation and causing inefficiencies in the fishery and may result in unforeseen and undesirable consequences (e.g. increasing takes of other non-target species).

It must also be recognised that the problems and their severity vary from species to species and area to area. In certain cases immediate action may be required to save a cetacean species from local extinction (see also Item 11).

6.7.1 Industry involvement

Experience has shown that fishermen must be involved from the earliest opportunity in solving fisheries' problems. For many years, various organisations in diverse situations have worked to improve fishing technology and introduce new methods. Both the improvement of existing fishing technology and the introduction of new technology have the best chance of success if the fishermen themselves are directly involved in the process. Many fishermen have a great deal of knowledge and expertise with local technology, species, fishing conditions and ecology. They are also familiar with the economic and social conditions in their fishery. Their involvement throughout the project enhances the potential of obtaining the best solution and the fastest application.

In some areas, fishermen have demonstrated concern for mammal entanglement problems and have expressed an interest in collaborating with scientists and authorities to help solve the problems.

6.7.2 Understanding why a fishery uses gillnets

When alternative fishing technologies are considered, many characteristics of the envisioned alternatives should be compared with the characteristics of gillnets. Effects on resources, technical feasibility, economic feasibility and social acceptability should be considered. The first step would be to examine alternative gears in use in the specific fishery in question or used in similar fisheries in other areas for the same target species.

An essential pre-requisite to assisting fishermen changing from gillnets is to understand why particular fishermen are using them. Gillnetting often:

(i) has been traditionally used;
(ii) matches the vessels and technology locally available;
(iii) involves lower operational costs;
(iv) results in greater profits;
(v) is used for species that do not take bait or hooks;
(vi) is used where the bottom is too rough for trawling;
(vii) results in a lower fish bycatch problem (size and species);

(viii) is used where there are neither the means nor incentive to develop alternatives

In considering alternative gear and methods, a large number of factors should be considered, including the following:

(i) effectiveness for taking the target species and likely catch levels;
(ii) effects on target and incidentally caught resources;
(iii) fish market considerations and opportunities;
(iv) capital costs of fishing and economic feasibility under local conditions;
(v) foreign exchange inputs required;
(vi) energy costs of fishing;
(vii) appropriateness for economic and educational levels of fishermen;
(viii) safety factors for fishermen.

Several possible scenarios emerge if one considers proposals to ban gillnetting in an area.

(1) The fishermen may stop fishing entirely and find alternative employment and/or suffer economically.
(2) Larger gillnet boats may be able to convert to trawling. However, most coastal gillnet vessels lack the size and power to trawl effectively. Trawling in general is more capital intensive, consumes more fuel and often involves more serious problems with fish bycatch, as illustrated by a comparison of shrimp trawl fisheries and shrimp gillnet fisheries.
(3) A few vessels may be able to convert to purse-seining, which is practised on both large and small scale in different areas. Effects on resources, as well as technical and economic feasibility, would have to be evaluated.
(4) Some coastal gillnetters may convert to longlining, which can be done effectively in many areas from relatively small boats, without great capital investment and with relatively low fuel consumption. There are many different types of longlining, coastal and open ocean, and each must be evaluated individually. In many conditions, economic longlining takes up more bottom area than gillnetting, possibly leading to increased conflicts with other gear types. Longlining in many areas can be less selective for fish species and size and more dangerous for fishermen.
(5) Some gillnetters, particularly those in areas with significant pelagic resources, may convert to trolling. Although this method is used effectively in some areas, its disadvantages must be considered. It is effective for a limited number of species, many of which are highly seasonal. Fuel consumption and time required for finding fish may be high. Productivity per line is often low and it is generally only commercially feasible only for relatively high-priced species. It is practised primarily by small-to-medium sized vessels and may be an auxiliary method practised in combination with others.
(6) Fishing with vertical lines and hooks may be considered as an alternative in some areas. Handlines, automated reels and jigging machines are all in use in different areas. The productivity of handlines may be relatively low and the technology for automated systems may be appropriate only in certain fisheries at this time.

Many other fishing methods are practised commercially in different areas and their potential for a given area should be considered. It should be noted that many organisations have devoted substantial resources to the development and introduction of improved fishing methods. The problems encountered are often substantial and in many cases the success rate has not been very encouraging.

6.8 Disentanglement technology and resources

It is frequently possible to disentangle large whales from fishing gear if appropriate methods are used (Lien, 1988). Large whale entanglements can be classified into those where animals are anchored or fixed in place (such as an entanglement in a codtrap) and those where animals are free-swimming (such as an animal with gillnetting through the mouth or around the tail which has broken away from the anchors). All disentanglement procedures with cetaceans entail an element of risk to the rescuers and should be undertaken with caution. However, these efforts are important, particularly for endangered species.

For entangled cetaceans that are well anchored, current procedures use vessels of various sizes and lift the animals tail to the surface where it is accessible from the vessel. Cutting of the gear away from the whale is done from the vessel until the animal is free. Cooperation with the fishermen, who have a good working knowledge of where different lines are attached and/or anchored, is important to minimise both the time the disentanglement takes and the damage to the gear (Lien, 1988; Lien *et al.*, 1990). Divers are never placed in the water, because of the risk involved with large amounts of fishing gear.

For free-swimming animals, two approaches have been employed. Both require catching and clipping ropes onto the fishing gear trailing from the swimming animal. Lien (pers. comm.) favours anchoring the whale immediately at this point and working the animal as described above. Mayo (pers. comm.) has used inflatables to attach (with carabineers) buoys and sea-anchors to slow the whale down. When the whale becomes tired, Mayo uses the inflatable as the working platform to slide up to the tail area along the entangled gear and cuts away the gear as it is accessible. Di Natale (pers. comm.) has attached a large vessel to free-swimming entangled sperm whales, then used divers to cut away netting from the tethered animal. However, several large diameter ropes have been broken during some of these disentanglement operations by the thrashing of the animal.

Generally, larger vessel disentanglement efforts pose the least risk to researchers and fishermen; any operation which places divers in the water is the most dangerous. A list of some institutions which have disentangled whales regularly and may serve as information and/or rescue centres is given below.

Memorial University of Newfoundland, 230 Mt Slio Road, St. John's, Newfoundland, Canada, A1B 3X9.
Center for Coastal Studies, PO Box 1036, Provincetown, MA 02657, USA.
New England Aquarium, Central Wharf, Boston, MA 02110, USA.
Natural History Museum of Los Angeles County, 900 Exposition Blvd, Los Angeles, CA 90007, USA.
Tethys, Istituto per lo studio e la Intela dell'Ambiento Marino, piazza Duca D'Aosta 4, 20124 Milano, Italy.

6.9 Management

The Workshop had been asked to address the management options for controlling, reducing or eliminating the cetacean bycatch. It recognised the importance of determining management objectives and methods implementation as primary elements in the alleviation of marine mammal bycatch in specific fisheries. However, it

also recognised that, in addition to its areas of interest, fruitful discussion of functional management would range across subjects outside its expertise, including legal authority, jurisdictions, economics, social and cultural considerations and enforcement resources and technology. Throughout the report the group's recommendations and priorities are made or set in full recognition that non-scientific constraints on the management process may affect their utility.

Notwithstanding the above, the group noted the following general points with respect to management and the incidental take of cetaceans.

(1) Bycatch is the collection of non-target species caught but not retained in any fishery. Bycatch may be unharmed, injured or dead when discarded. It includes both commercial and non-commercial fish and shellfish, marine mammals, birds, turtles and invertebrates. Bycatch is a fact of life for most fisheries. It typically becomes a management issue when a second or third party attaches some value to the discarded animals. The higher the value, the more likely some authority will be created or invoked to justify management actions to control, reallocate or eliminate the bycatch.

(2) Marine mammals usually have almost no commercial value to passive gear fishermen. As bycatch they are cumbersome, aggravating and occasionally dangerous. However, many people attach considerable value to marine mammals and wish to protect them from harm in fisheries through statute and regulation. By establishing an economic consequence to the taking of marine mammals in the act of fishing, some control may be exercised over that taking. This type of 'artificial' valuation of marine mammals may be necessary if their bycatch in passive fishing gears is to be reduced or eliminated. It implies the creation of authority permitting governmental agencies to apply appropriate measures. This type of authority varies widely around the world, as does the value people and cultures attribute to marine mammals.

Recognising these limitations on management capabilities, some examples of management methods that may be employed to help control the bycatch of marine mammals and other species are discussed below. Almost all will reduce the economic productivity of the target fisheries and it might be expected that fishermen will try to avoid being included e.g. by changing country of registration or vessel class.

6.9.1 Time and area restrictions

Recent developments in satellite transmitter technology have made it possible to track and record the movements of vessels far from shore, thereby making the application of time and area restrictions feasible in medium to large scale fisheries. The success of such restrictions in reducing bycatches depends on the degree to which the target and non-target species separate. This information is lacking for most passive fisheries.

6.9.2 Bycatch quotas

This method limits the number/weight of the bycatch of one or more species. Its implementation presumes some means to track the take of controlled species in a near-real time frame. Obvious problems with this approach lie in deciding which species or species group will be limited and how the limitation (closure, relocation, gear change, etc.) may affect other bycatch species.

6.9.3 Effort and access limitations

This could achieve a broad target limitation on combined bycatches. For example, if bycatch levels are known for certain fishing zones and acceptable aggregate targets or limits for the bycatch exist, a simple limitation on effort by zone could achieve the desired result. It is a less stringent hybrid of the time/area and bycatch quota methods.

6.9.4 Bans on practices and technologies

This approach has always been a tool for the management of living resources in specific situations. Examples include bans on the use of explosives for fishing, on sundown sets by US tuna seiners and on import of fisheries products not taken in conformity with domestic regulation. It is under consideration as a solution to the high seas driftnet bycatch problem.

6.9.5 Individual or fleet performance criteria

With enough information concerning the bycatch performance of a specific fishing technology, it is possible to establish performance targets that allow fishermen some influence over their regulation. Setting a take-per-unit-effort limit per vessel or fleet that is monitored and reported on a regular schedule may engage the ingenuity of individual fishermen to find ways to keep the rate below the limit, thus extending their access to the fishery. Typically, this approach is used in conjunction with direct or implied quotas and effort limitations. For example, when the current take rate exceeds the specified limit it triggers closure or relocation of the fishery or mandates the use of alternate technology (e.g. from gillnets to longlines).

6.9.6 Retention of all catch – the 'no bycatch' option

This is not being used as a management method at this time but its impact on fishery profitability could motivate current high bycatch fishery participants to seriously explore bycatch reducing measures or alternate gears. This is an artificial manipulation of the economics of the fishery that is difficult to enforce and has unknown practical and market consequences.

6.9.7 Limitations on non-marine mammal bycatch levels

In cases where authority exists to limit takes of species other than marine mammals, this authority might be exercised to control marine mammal bycatch indirectly. For example, both halibut and harbour porpoises are taken as bycatch in certain coastal gillnet fisheries. Controlling the fishery to limit the bycatch of halibut and protect another commercial fishery might also reduce the take of harbour porpoises. This approach can take advantage of existing fishery management laws and implied property rights of conflicting fisheries to reduce bycatch of many other species.

6.9.8 Stipulations on gear and procedures

Gear and procedures that are effective and economical are likely to be implemented with little difficulty since less bycatch means more efficient fishing operations. Gear and procedures which are expensive or reduce vessel efficiency will meet significant resistance, requiring solid justification and potent authority. This is the approach whereby techno-behavioural solutions can be implemented.

6.9.9 Economic assistance and subsidies

If the above methods do not work or cannot be implemented, then it is conceivable that the implied property rights of fishermen can be purchased. By

measuring what tangible losses must be inflicted to achieve a bycatch goal, society/government/managers, etc. may make a first approximation of its cost. Governments have devised myriad ways to transfer value to industry ranging from direct payments, to subsidies for construction, insurance and price support, to protection from both foreign and domestic competition. Under this heading it should be recognised that market manipulation can be used both to support and coerce industry.

6.9.10 Conclusions

Each management situation will be in some ways unique. As an initial step in evaluating management latitude and options for controlling marine mammal bycatch, the Workshop **recommends** that the following questions be addressed:

(1) What is/are the specific management objective(s), including full definitions of the terms used?
(2) Who is being managed?
(3) Under what authority(s) is this objective legitimate?
(4) Under what/whose jurisdiction(s) does the problem reside?
(5) What other management objectives interact with this, and how?
(6) What entity(s) is responsible for attaining the objective(s)?
(7) What resources are available for management and enforcement?
(8) What management methods are applicable?
(9) What alternatives are available to those being managed?

In answering these questions, the ease or difficulty of achieving a specific objective will become obvious. Also, a number of further, more detailed questions will arise, giving insight into needed work plans and strategies to build the information (including technical and scientific) and authority foundation for meeting the objective. In cases where authority and jurisdiction are limited or absent, this process may be lengthy and political.

7. CONCLUSIONS AND RECOMMENDATIONS

In a plenary session on the last day of the Workshop, the group reviewed and adopted the conclusions and recommendations put forward by the three sub-groups.

7.1 Global review of fisheries

7.1.1 General

(1) Throughout all regions there is a general lack of adequate statistics on gillnet and trap usage and on marine mammal entrapment.

It is **strongly recommended** that:

(a) fishery agencies and regional bodies (including those of the FAO) ensure that statistically valid data on gillnet and trap effort and cetacean catches are collected and promptly analysed and reported;
(b) adequate statistics on marine mammal entanglement be obtained through independent observer programmes, following scientifically established designs.

(2) Fleets from China, Taiwan and some other distant-water driftnet fleets continue to operate without documentation in the Atlantic and with inadequate data for operations in the Indian and Pacific Oceans. This is a matter of grave concern, not only for nations adjacent to the fishing areas but also with respect to the status of marine mammals taken in these fisheries.

It is **recommended** that, while such activities continue, data on all distant-water fleets must be collected by the flag nations and nations servicing these fleets and independent observers placed on board vessels. The bycatches must be reported and evaluated and appropriate management actions taken before further fishing is authorised.

(3) The Workshop **recommends** that the development of any new fisheries, or expansion of existing fisheries, should only be countenanced after a rigorous multidisciplinary environmental impact assessment that includes the potential effects on target and non-target species, including cetaceans. To this end, aid and development agencies, including UN, national and non-governmental organisations, should be advised of the potentially detrimental effects of these fisheries.
(4) It is **recommended** that national and international organisations address the education of fishermen, officials and scientists as well as the general public concerning the problem of cetacean interactions with gillnet and traps. Specific recommendations for the nations most critically involved are listed in the regional reviews.
(5) Japan and the USA are conducting research to assess the possible impact of lost and discarded fishing gear ('ghost nets'). The Workshop **recommends** that similar research programmes be initiated elsewhere. Specific goals of such programmes should be to reduce the number of nets and pieces of net webbing lost and discarded and to alter net manufacture and design to minimise danger from them.
(6) As has happened in Peru and Sri Lanka, a dolphin bycatch can become a directed fishery under certain economic conditions, leading to heavy exploitation of cetacean stocks of unknown size and status. This could happen in regions such as India and the Philippines where the bycatches are already fully utilised. This is a particular danger to cetacean conservation.

It is **recommended** that national and international fishery and environmental agencies monitor such situations closely. Such directed fisheries should not be allowed to develop until the status of affected stocks has been evaluated.

(7) Many developing countries are unable to fund the stock assessment and fishery monitoring programmes that must be carried out to ensure that incidental catches of cetaceans in particular fisheries are sustainable. It is **recommended** that:
  (a) such nations consider the incorporation of such costs in license fees for fishing in their exclusive economic zones (EEZs);
  (b) intergovernmental and private international funding organisations and agencies give high priority to financing such activities.
(8) Given the broad scope of the fishery/cetacean (and other bycatch species) interactions, regional cooperation in examining and addressing the various issues is extremely important. The Workshop **recommends** that such cooperation should be encouraged among, for example, the Baltic and northeastern European states through the agencies of the European Community and International Council for the Exploration of the Sea (ICES), among Caribbean states, between Argentina and Chile

(because of the crab-bait situation – see regional account for Southeastern Pacific), among West African states, among Indian Ocean states, among the North Pacific Rim nations and among the Pacific island nations.

7.1.2 High priority recommendations for specific regions

A series of recommendations for regional action are given above in the report of the sub-group on the global review of fisheries. Some of these recommendations are considered to be of especial urgency and are repeated here for emphasis.

(1) It is **recommended** that solving problems associated with the incidental capture of the vaquita in totoaba gillnets in Mexico and the baiji on longline hooks in China is accorded the highest priority. In the case of the totoaba the fishery is illegal, except for some fishing under experimental permits. The fishery affecting the baiji is totally illegal. However, both fisheries continue to operate at high levels because of inadequate enforcement and continue to threaten the species with extinction.

(2) The Workshop commends Italy for its decision to ban swordfish and albacore driftnets in Italian waters and their use by Italian vessels in other parts of the Mediterranean. It is **recommended** that similar actions be taken elsewhere in the Mediterranean. International cooperation and action by the General Council for Mediterranean Fisheries (CGPM) is required to ensure that large-scale driftnet fisheries do not restart from other nations and that reflagging of vessels for the purpose of continuing the fishery does not occur.

(3) Gillnet fisheries continue to expand rapidly in Pakistan, India, Sri Lanka and Bangladesh. As noted in General Recommendation 4 above, it is **recommended** that new fisheries should not be initiated in this region or existing fisheries expanded until after evaluation of their effects on non-target species.

(4) Throughout the Indo-Pacific region, and particularly in Southeast Asia, drift and set gillnets are widely used, but there is extremely limited information on incidental catches in such gear in these fisheries. It is **recommended** that this area be given high priority for future research into the impacts of gillnets and other fishing gear on marine mammals.

(5) Large numbers of coastal trap and gillnet fisheries exist in Chinese coastal waters; one estimate is that 3,500,000 gillnets are in use. It is **recommended** that incidental mortality of cetaceans in these fisheries be addressed as a matter of urgency.

7.2 Impacts on species and populations

7.2.1 Conclusions

(1) Cetacean populations in general seem unable to sustain rates of kill of more than a small percentage of the population per year. Even kill rates as low as 2% per year may not be sustainable, depending on the life history of the species and the age and sex composition of the kill.

(2) Agencies that are responsible for the management of marine resources should manage from a conservative point of view, i.e. fisheries should not be allowed to operate at a particular level until there is evidence that the kill of cetaceans associated with that level of fishing effort is sustainable.

(3) Information on kill rates and total fishing effort in passive net and trap fisheries and on the size of cetacean populations can be difficult to accumulate. Kill rates and fishing effort can be expected to vary among years, areas and seasons. Estimates of population size will necessarily be imprecise, especially where data on stock structure are lacking. Despite problems with the collection and analysis of data on kill rates, total fishing effort and population size, it is important that the agency responsible for managing a particular fishery collect these data on a systematic basis. In the absence of such information, the environmental impact of most gillnet and trap fisheries cannot be assessed.

(4) The impacts of coastal gillnet and trap fisheries on strictly coastal species are especially noted. Such fisheries and cetacean populations are in urgent need of assessment and in many cases the levels of fishery mortality need to be reduced or eliminated.

(5) The best available information at this time indicates that several stocks of cetaceans are unable to sustain current levels of removal caused by passive net and trap fisheries. These include:

   (a) vaquita in the Gulf of California;
   (b) baiji in the Yangtze River;
   (c) Indo-Pacific hump-backed dolphins on the Natal coast of South Africa;
   (d) striped dolphins in the Mediterranean Sea;
   (e) harbour porpoises in the western North Atlantic;
   (f) bottlenose dolphins on the Natal south coast, South Africa.

Furthermore, there are additional stocks where all of the information needed to evaluate the impact of passive net and trap fisheries is not available, but where the potential for current levels of removals not being sustainable is likely. This is particularly true where rates of kill are known to be large. Of particular concern are the following stocks:

   (a) dusky dolphins in the eastern South Pacific,
   (b) northern right whale dolphins in the central North Pacific;
   (c) sperm whales in the Mediterranean Sea.

7.2.2 Recommendations

Arising from the discussions in the working group on the impact of fisheries on species and populations of cetaceans, the Workshop agreed to the following recommendations.

(1) It is **recommended** that the killing of:

   (a) the vaquita in the Gulf of California;
   (b) the baiji in the Yangtze River;
   (c) Indo-Pacific hump-backed dolphins on the Natal coast of South Africa;
   (d) striped dolphins in the Mediterranean Sea;
   (e) harbour porpoises in the western North Atlantic;
   (f) bottlenose dolphins on the Natal south coast, South Africa;

in passive and trap fisheries be reduced immediately.

Mechanisms for reducing the take of these species will have to be developed by the agencies with management authority.

(2) Where the directed or incidental kill of any cetacean stock is thought to exceed a small percentage of the population or where a particular stock is declining and known to be taken in passive net and trap fisheries, it is

recommended that the fishery bycatch should be limited while the following information is collected:

(a) *Kill rates*. These can be collected either by placing observers on fishing vessels, placing observers on research vessels that can observe fishing vessels or making experimental sets of gear similar to that used in the fishery. Estimates of kill rates from mail surveys to fishermen or dockside interviews alone are not adequate. For directed fisheries, kill rates can be estimated by monitoring the number of cetaceans landed.
(b) *Age and sex composition of the kill*. This will require biological specimens to be collected by trained technicians.
(c) *Stock identification*. Specimen material must be collected.
(d) *Total fishing effort for all passive net and trap fisheries*. These data should be collected and analysed prior to the start of the next fishing season.
(e) *Population size*. Initially, estimates of minimum population size on a stock-by-stock basis are adequate for management purposes. However, these estimates should be replaced by estimates of absolute abundance with their associated levels of precision. Estimates of population trends alone are not adequate.

7.3 Causes and solutions

7.3.1 Conclusions

(1) The incidental capture of cetaceans appears to be almost universal in drift and set gillnets and a common occurrence in some trap fisheries. Wherever cetaceans and gillnets are found in the same area, at least some cetaceans are caught.
(2) However, there is no universal cause or solution to the incidental capture of cetaceans in fishing gear. The precise nature of the interaction varies from area to area, fishing gear type to fishing gear type, species to species, culture to culture, and any combination of these.
(3) Small cetaceans have sensory abilities which can detect the webbing and rigging of gillnets and other passive fishing gear. Encounters with nets may occur as they forage or engage in other activities which increase the chances that they will fail to detect nets. Less is known of the sensory abilities of large cetaceans. There are a variety of environmental, social and sensory conditions which may interfere with detection of nets. Additional study on the role such factors play in entrapment of cetaceans is necessary.
(4) Even if the cetaceans detect nets, a variety of behavioural factors contribute to the entrapment or entanglement. These include curiosity, exploration and perception, escape reactions and social organisation.
(5) There is almost no behavioural information on how and when entanglement of cetaceans occurs. There is little quantitative information on how many animals in the vicinity of a net become entangled, or on how many entangled animals escape. There are few quantitative data on many of the factors which cause entanglement or which might provide solutions. Basic information on entanglement must be collected as a matter of urgency. More rigorous scientific procedures must be followed in experiments so that causes and solutions can be properly evaluated.
(6) As noted in (2) above, at this time there is no practical, universal modification of fishing gear which can be suggested to solve all problems of incidental entrapment of cetaceans. In urgent cases, such as that of the vaquita, there may be no alternative but to ban the fishery.
(7) Some fishing gear modification and management regimes do provide potential solutions and can be suggested for specific fisheries where entanglements of cetaceans occur. In all cases careful assessment and monitoring of the effectiveness and impact of modifications introduced to lower incidental catches of cetaceans must be made.
(8) There are a number of promising research areas which may lead to reduction of incidental catches of cetaceans and which should be further explored; these include time/area restrictions on fisheries, adjustment of gear strategies and selectivity of gear, and the enhanced detection of gear. Management techniques for dealing with the incidental take of cetaceans which are most promising at this time are time/area restrictions and area closures.
(9) In most areas fishermen are unaware of the extent and impact of cetacean entanglement. Fishing communities should be made aware of this and become involved in the process of finding solutions. Methods to accomplish this should be carefully researched and evaluated.

7.3.2 Recommendations

In addition to the specific research recommendations included in the body of the report, the Workshop agreed to the following more general recommendations.

(1) It is **recommended** that research on causes and solutions of entanglements focus on those fisheries where urgent action is required. This should be achieved by organising local workshops including scientists, engineers, fishermen, managers and others.
(2) It is **recommended** that particular priority in research be given to:
    (a) behavioural factors which predispose cetaceans to entanglement including those immediately prior to and during entanglement;
    (b) monitoring time and area closures;
    (c) gear strength and strategy adjustments and alternative gears;
    (d) environmental and ecological factors influencing these behaviour patterns.
(3) It is **recommended** that studies on solutions to cetacean bycatch be conducted in such a manner that bycatch of other species is also considered.
(4) It is **recommended** that significant technological changes within fisheries be preceded by an assessment of their likely impacts.

8. EDITING AND PUBLICATION OF REPORT

Although the major conclusions and recommendations of the sub-groups were adopted in full in plenary session, it was not possible to review fully and finalise the complete sub-group reports during the workshop. It was agreed that the participants would forward comments on the draft reports to the sub-group chairmen for consideration and that the chairmen would finalise the reports, with the help of the rapporteurs and forward them to the workshop

chairman for inclusion in the workshop report. The workshop report will be published in a special issue of *Reports of the International Whaling Commission*, which will include selected working papers from the workshop and submitted papers from the symposium that preceded the workshop and will be edited by Perrin, Donovan and Barlow. It was noted that authors wishing to submit working papers or symposium papers for publication in the special issue should revise them in light of comments received at the meeting and have them reviewed by at least two colleagues before sending them to the Scientific Editor. The submitted papers will then be subject to anonymous peer review.

9. OTHER BUSINESS

The Workshop thanked the Director of the Southwest Fisheries Science Center for hosting the Workshop and the Center staff for their very efficient and cheerful services during the meeting. The Chairman expressed his appreciation to the sub-group chairmen and the rapporteurs for their hard work and dedication to the success of the Workshop.

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Annex A
List of Participants

G=Global Review Sub-Group (Item 4); I=Impact Sub-Group (Item 5);
C=Causes and Solutions Sub-Group (Item 6).

Gordon Anderson (G)
Marine Conservation Unit
Australian Nature Conservation Agency
PO Box 636
Canberra
ACT 2601
Australia

Whitlow Au (C)
Naval Ocean Systems Center
P.O. Box 997
Kailua, Hawaii 96734
USA

Jay Barlow (G)
Fisheries/Marine Mammal Interactions Division
Southwest Fisheries Center
U.S. National Marine Fisheries Service
P.O. Box 271
La Jolla, CA 92038
USA

Arne Bjørge (G)
Norwegian Institute for Nature Research
University of Oslo
PO Box 1037
Blindern
0315 Oslo
Norway

Robert L. Brownell, Jr. (I)
Southwest Fisheries Science Center
PO Box 271
La Jolla
CA 92038
USA

V. N. Burkanov (G)
Kamchatka Department of the Environment
Pacific Institute of Geography
Academy of Sciences
Prospect Ribakov 19/a
Petropavlovsk-Kamchatsk.
683024
Russian Federation

Martin W. Cawthorn (G)
53 Motuhara Road
Plimmerton
Wellington
New Zealand

Bjarne Clausen (G)
DMU
Box 358
Fredriksbergvej 399,
D-4000 Roskilde
Denmark

Victor Cockcroft (G)
Port Elizabeth Museum
P.O. Box 13147
6013 Humewood
South Africa

James M. Coe (C)
NMFS Marine Engtanglement Research
Alaska Fisheries Science Center
7600 Sand Point Way NE
BIN C15700
Seattle, Washington 98115–0070
USA

Enrique A. Crespo (G)
Centro Nacional Patagónico
28 de Julio 28
9120 Puerto Madryn
Chubut
Argentina

Stephen M. Dawson (C)
Zoology Department
Otago University
P.O. Box 56
Dunedin
New Zealand

Douglas P. DeMaster (I)
National Marine Mammal Laboratory
7600 Sand Point Way NE
Seattle
WA 98115
USA

Antonio Di Natale (G)
Aquastudio
Via Trapani isol. 466 n. 6
98121 Messina
Italy

M. Louella Dolar (G)
Marine Laboratory
Silliman University
Dumaguete 6200
Phillipines

G. P. Donovan (C)
Scientific Editor
International Whaling Commission
The Red House
135 Station Road, Histon
Cambridge CB4 4NP
United Kingdom

Steven Drew (I)(C)
Manomet Bird Observatory
Manomet, MA 02345
USA

Michael Earle (G)
Greenpeace International
Rue Cochetay, 54
B-4140 Gomze-Andoumont
Belgium

Shannon Fitzgerald (G)
Resource Ecology and Fishery Management
U.S. National Marine Fisheries Service
7600 Sand Point Way NE
Seattle, WA 98115
USA

Karin Forney (I)
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, CA 92038
USA

Ray Gambell (I)
International Whaling Commission
The Red House
135 Station Road, Histon
Cambridge CB4 4NP
United Kingdom

A. D. Goodson (C)
Sonar and Signal Processing Group
Electronic and Electrical Engineering Department
Loughborough University of Technology
Loughborough, Leicestershire LE11 3TU
United Kingdom

Doyle A. Hanan (C)
California Department of Fish and Game
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, CA 92038
USA

Y. Hatakeyama (C)
National Research Institute on Fishery Engineering
5–5–1, Kachidoki, Chuo-ku
Tokyo
Japan

John E. Heyning (I)
Natural History Museum of Los Angeles County
900 Exposition Boulevard
Los Angeles, CA 90007
USA

Aleta Hohn (I)
National Marine Fisheries Service
Office of Protected Resources, F/PR1
1335 East-West Highway
Silver Spring, MD 20910
USA

P.U. Jepsen (C)
Wildlife Research Station,
Aalholtvej 1
Okstol. DK 6840
Denmark

Linda Jones (C)
Northwest Fisheries Science Center
2725 Montlake Blvd E
Seattle
WA 98112
USA

Toshio Kasuya (I)
Section of Cetacean Research
National Institute of Research on Far Seas Fisheries
5–7–1 Orido, Shimizu-shi
Shizuoka-ken 424
Japan

Michael Kingsley (I)
Maurice Lamontagne Institute
Fisheries and Oceans
P.O. Box 1000
Mont-Joli (Quebec)
Canada

Carl Kinze (G)
Zoological Museum of Copenhagen
Universitetsparken 15
DK-2100 Copenhagen
Denmark

Margaret Klinowska (C)
University of Cambridge
Animal Welfare and Human-Animal
Interactions Group
Dept. of Clinical Veterinary Medicine
Madingley Road
Cambridge
CB3 0ES
United Kingdom

Scott D. Kraus (C)
New England Aquarium
Central Wharf
Boston, MA 02110
USA

Roger Krohn (G)
Benguela Ecology Programme
University of Cape Town
Cape Town
South Africa

John LaGrange (C)
Captain, "Cloud Nine"
533 North Rios Ave.
Solana Beach
CA 92075
USA

David M. Lavigne (C)
Department of Zoology
University of Guelph
Guelph, Ontario N1G 2W1
Canada

J. Stephen Leatherwood (G)
Ocean Park Conservation Foundation
Ocean Park
Aberdeen
Hong Kong

Jon Lien (C)
Whale Research Group
Memorial University of Newfoundland
St. Johns, Newfoundland
Canada A1C 5S7

Ingalill Lindstedt (G)
Institute of Marine Research
P.O. Box 4
S-453 00 Lysekil
Sweden

Jacques Maigret (G)
Museum National d'Histoire Naturelle
Galerie de l'Evolution
45 Rue Cuvier
75231 Paris cedex 05
France

Albert M. Manville (C)
Senior Staff Wildlife Biologist
Defenders of Wildlife
1244 Nineteenth Street, NW
Washington, DC 20036, USA

R.S. Lal Mohan (G)
Conservation of Nature Trust
B/24, Grandhingar, C
Calicut – 673 005
Kerala
India

Kazuhiko Nagao (G)
Fisheries Agency
Ministry of Agriculture, Forestry and Fisheries
2–1, 1-Chome Kasumigaseki
Chiyoda-ku, Tokyo 100
Japan

Mohammad Sadiq Niazi (G)
Deputy Director
Marine Fisheries Department
Government of Pakistan
Fish Harbour, West Wharf
Karachi
Pakistan

Eugene T. Nitta (G)
Pacific Area Office, Protected Species
Management Branch
U.S. National Marine Fisheries Service
2570 Dole St., Rm. 106
Honolulu, Hawaii 96822–2396
USA

Kenneth S. Norris (C)
Institute of Marine Sciences
University of California
100 Shaffer Road
Santa Cruz, CA 95060
USA

Simon Northridge (G)
Renewable Resources Assessment Group
Imperial College of Science, Technology and Medicine
8 Prince's Gardens
London SW7 1NA
United Kingdom

Giuseppe Notarbartolo di Sciara (I) (C)
Tethys Research Institute
Via Giusti 5
20154
Milano
Italy

Jorge A. Oporto B. (G)
CIMMA, c/o Instituto de Biología Marina
Universidad Austral de Chile, casilla 567
Valdivia
Chile

Victoria Ortiz (G)
Laboratorio Oceanográfico
Apdo 240
39080 Santander
Spain

P. Michael Payne (I)
Manomet Bird Observatory
PO Box 936
Manomet
MA 02345,
USA

William F. Perrin (G)
Southwest Fisheries Science Center
U.S. National Marine Fisheries Service
P.O. Box 271
La Jolla, CA 92038
USA

Maria Cristina Pinedo (G)
Lab. Mamíferos Marinhos
Depto. Oceanografia-FURG
C.P. 474
Rio Grande RS 96.200
Brazil

J. Prado (C)
Fishery Industries Division
FAO
Via delle Terme di Caracalla
00100 Rome
Italy

Andrew J. Read (G)
Northeast Fisheries Science Center
Woods Hole
MA 02543
USA

Julio C. Reyes (G)
Casilla 392
Talcahuano
Chile

Marina L. Sequeira (G)
Servico Nacional de Parques,
Reservas e Conservacao da Natureza
R. Filipe Folque, 46 – 3
1000 Lisbon
Portugal

Gregory Silber (C)
Marine Mammal Commission
1825 Connecticut Avenue, NW
Room 512
Washington, DC 20009
USA

Joyce Sisson (G)
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, CA 92038
USA

Ronald Joel Smolowitz (C)
Coonamessett Farm
277 Hatchville Road
East Falmouth, MA 02536
USA

Suraphol Sudara (G)
Faculty of Science
Chulalongkorn University
Bangkok 10500
Thailand

Omar Vidal (G)
Instituto Tecnológico y de Estudios Superiores
de Monterrey – Campus Guaymas
Apartado Postal 484
C.P. 85400, Guaymas, Sonora
Mexico

Koen Van Waerebeek (I)
CEPEC c/o Grupo-Cetáceos-ECCO
Casilla 1536
Lima 18
Peru

Gordon T. Waring (I)
Northeast Fisheries Center
No. 1 Water Street
Woods Hole, MA 02543
USA

Alfredo Ximenez (G)
Div. de Zoologia
Depto. de Biologia
Universidad Federal de
Santa Catarina
Trinidade
88000 Florianópolis – SC
Brazil

A. Yatsu (G)
Squid Section
National Institute of Research on
Far Seas Fisheries
5–7–1 Orido, Shimizu-shi
Shizuoka-ken 424
Japan

Zhou Kaiya (G)
Department of Biology
Nanjing Normal University
122 Ninghai Road
Nanjing 210097
People's Republic of China

Annex B
List of Documents

* = Published in this volume. Please note that these are the titles and authors as presented at the meeting. These may have changed in the published version. Abstracts of those papers not published are included at the end of the volume.

SC/O90/G1 PRADERI, R. Mortality of dolphins in shark gillnet fisheries off Uruguay.

SC/O90/G2 CRESPO, E.A. and CORCUERA, J.F. Interactions between marine mammals and fisheries in some fishing areas off the coast of Argentina and Uruguay.*

SC/O90/G3 PINEDO, M.C. Age structure of the incidental catch of *Pontoporia blainvillei* in southern Brazil and Uruguay.*

SC/O90/G4 KROHN, R. Driftnet fishing in the South Atlantic.

SC/O90/G5 MAIGRET, J. Relationship between marine mammals and the fisheries on the West African coasts.*

SC/O90/G6 READ, A. Gill net and trap fisheries in the Northwest Atlantic.*

SC/O90/G7 VIDAL, O., van WAEREBEEK, K. and ALVAREZ-MANILLA, G. Cetaceans and gillnet fisheries in Mexico, Central America and the Caribbean: a preliminary review.*

SC/O90/G8 YATSU, A. A review of the Japanese squid driftnet fishery.*

SC/O90/G9 HATAKEYAMA, Y., ISHII, K., AKAMATSU, T., SOEDA, H., SHIMAMURA, T. and KOJIMA, T. Studies on the reduction of entanglement of Dall's porpoise, *Phocoenoides dalli*, in the Japanese salmon gillnet.*

SC/O90/G10 [No paper]

SC/O90/G11 REYES, J.C. and OPORTO, J.A. Gillnets, trap fisheries and cetaceans in the South East Pacific.*

SC/O90/G12 LAL MOHAN, R.S. A review of entanglement of small cetaceans in gill nets and the gill net fisheries of the Indian coast.

SC/O90/G13 DAWSON, S.M. Reducing entanglement of dolphins and porpoises via acoustic modifications to gillnets.*

SC/O90/G14 PRADO, J. and SMITH, A. Possibilities of reducing incidental catch and mortality of marine mammals in driftnet fisheries.

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SC/O90/G17 GOODSON, A.D. Environment, acoustics and biosonar perception. Optimising the design of passive acoustic net markers.

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SC/O90/G20 COCKCROFT, V.G. Passive gear fisheries and their possible impact on cetaceans in the south western Indian and south eastern Atlantic Oceans.*

SC/O90/G21 ZHOU, K. and WANG, Z. Brief review of passive fishing gears and incidental catches of small cetaceans in Chinese waters.*

SC/O90/G22 LAL MOHAN, R.S. A Review of the mortality of cetaceans in gillnets and the gillnet fisheries of the northeastern Indian Ocean region.*

SC/O90/G23 HOHN, A. and PERRIN, W. Sources for a global review of mortality of cetaceans in passive fishing nets and traps.

SC/O90/G24 HEYNING, J.E. and WOODHOUSE, C. Mortality of odontocetes from fishing gear off southern California.*

SC/O90/G25 KINZE, C., Chr. Cetacean mortality in passive fishing nets and traps in the Baltic Sea: a review.

SC/O90/G26 CANNELLA, G. and XIMENEZ, A. Review of gillnet and trap fisheries in the Brazilian region.

SC/O90/G27 da SILVA, V. and BEST. R. Freshwater dolphin/fisheries interaction in the Central Amazon (Brazil).

SC/O90/G28 BARLOW, J., BAIRD, R., HEYNING, J., WYNNE, K., MANVILLE, A.M. II, LOWRY, L., HANAN D. and SEASE. J. A review of cetacean mortality in coastal fisheries of the eastern North Pacific and USSR Far East.*

SC/O90/G29 DOLAR, M. L. Interaction between cetaceans and fisheries in the Visayas, Philippines: A preliminary study.*

SC/O90/G30 NIAZI, M. Information on fisheries of Pakistan.

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SC/O90/G35 NORTHRIDGE, S. Driftnet fisheries and their impact on non target species.

SC/O90/G36 TOBAYAMA, T., INAGAKI, Y., RYOHNO, M. and HIRATSUKA, K. Review of the incidental catches of cetaceans in Japan.

SC/O90/G37 SAKUMA, T. Large scale trap net fishery in Japan.

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SC/O90/G39 COE, J.M. Discussion paper on management operations to control marine mammal mortality in passive fishing gear.

SC/O90/G40 SMOLOWITZ, R.J. and GOUDEY, C. Mitigating cetacean mortality in fisheries: appropriate alternatives.

SC/O90/G41 PAYNE, M.P., POWER, G. and YUSTIN, C.T. Interactions between the New England sink-gillnet fishery and the harbour porpoise, *Phocoena phocoena*.

SC/O90/G42 EARLE, M. Observations on tuna and swordfish driftnet fisheries.*

SC/O90/G43 JONES, L., DAHLBERG, M. and FITZGERALD, S. High seas driftnet fisheries of the North Pacific Ocean.

SC/O90/G44 SMITH, T.D., WARING, G.T. and POLACHECK, T.W. Factors important in initial evaluation of biological significance of cetacean bycatch.

SC/O90/G45 LA GRANGE, J. Captain "Cloud Nine" (gillnetter).

SC/O90/G46 NORRIS, K.S. Gillnets and marine mammals.

SC/O90/G47 SEQUEIRA, M. and FERREIRA, C. Portuguese fisheries--- draft report.*

SC/O90/G48 NELSON, D. A review of gear and animal characteristics responsible for incidental catches of marine mammals in fishing gear.

SC/O90/G49 NELSON, D. and LIEN, J. Responses of naive, captive dolphins to prototype whale alarms.

SC/O90/G50 LIEN, J., STENSON. G.B., CARVER, S. and CHARDINE, J. How many did you catch? The effect of methodology on bycatch reports obtained from fishermen.*

SC/O90/G51 LIEN, J., VERHULST, A., HUNTSMAN, T., JONES, J. and SETON, R. Reactions of humpback whales to novel sounds: curiosity and conditioning.

SC/O90/G52 WATANABE, Y. Japanese large-mesh driftnet fishery in the Pacific.*

SC/O90/G53 BONNEMAINS, J. and KANAS, M. The French albacore tuna fishery in the North Atlantic.

SC/O90/G54 Van WAEREBEEK, K. and REYES, J.C. The Peruvian small cetacean fishery interaction catch statistics: 1988–1989 and analysis trends.*

SC/O90/G55 NAGAO, K. Regulation of the high seas driftnet fishery of Japan.*

SC/O90/G56 CLAUSEN, B. Health status and bycatch of harbour porpoise (*Phocoena phocoena*) in Danish waters.

SC/O90/G57 KINZE, C.C. Incidental catches of harbour porpoises (*Phocoena phocoena*) in Danish waters 1986–1989: Recent data and behavioural implications.*

SC/O90/G58 HAYASE, S. and WATANABE. Y. Preliminary report on the Japanese fishing experiment using subsurface gillnets in the south and the north Pacific, 1989–1990.

SC/O90/G59 ANDERSON, G. Encounters with gillnets: preliminary results from a simple model and simulation of the porbability of encounters with long pelagic driftnets by cetaceans.

Annex C
Agenda

1. Welcome and introduction
2. Terms of reference and adoption of agenda
3. Arrangements for meeting
   - 3.1 Procedures and time schedule
   - 3.2 Appointment of rapporteurs
   - 3.3 Establishment of sub-groups
   - 3.4 Typing, photocopying and other services
4. Global review of gillnet and trap fisheries
5. Impacts on species and populations
6. Causes and solutions
7. Conclusions and recommendations
8. Editing and publication of report
9. Other business

Annex D
Re-estimation of Incidental Cetacean Catches in Sri Lanka

S. Leatherwood

Very large catches of cetaceans have been reported in the waters around Sri Lanka. That country's National Aquatic Resources Agency (NARA) estimated that approximately 12,950 individuals are incidentally caught in gillnets, and others (no estimate) are harpooned for use as food and bait in longline fishing (Dayaratne and de Silva, 1990). Methods used to estimate mortality were not presented in sufficient detail to support critical evaluation. Methods of estimating the total catch in Sri Lankan fisheries are reported here as an update from Leatherwood and Reeves (1989).

1. SPECIES COMPOSITION OF THE CATCH

The most complete data on composition of the cetacean bycatch in Sri Lanka are from the fish landing site at Trincomalee, on the northeastern coast, where landings were monitored by the same worker (W. P. Prematunga) for major portions of 1984–86 (Leatherwood and Reeves, 1989: table 12). The species composition of the observed landings at Trincomalee during those years is given in Table 1.

Table 1

Stenella longirostris	45.3%	*Pseudorca crassidens*	1.4%
Stenella attenuata	16.8%	*Globicephala macrorhynchus*	1.1%
Grampus griseus	14.7%	*Kogia breviceps*	0.9%
Stenella coeruleoalba	8.0%	*Mesoplodon* spp.	0.9%
Tursiops truncatus	5.4%	*Steno bredanensis*	0.6%
Kogia simus	2.6%	Unidentified dolphin	0.4%
Feresa attenuata	1.9%	*Lagenodelphis hosei*	0.1%

To obtain some estimate of takes of each species in all of Sri Lanka, the total estimated kill (see below) can be apportioned among species based on the composition of the observed landed catch at Trincomalee. This approach assumes that the species composition throughout the country is the same as that observed in Trincomalee. This assumption is violated to some extent, for example by the presence of other species (e.g. *Ziphius cavirostris*, *Orcinus orca*, *Peponocephala electra*, *Megaptera novaeangliae*, *Physeter macrocephalus* and *Balaenoptera physalus*) in small numbers in landed catches in western and southwestern Sri Lanka as well as at Trincomalee during recent seasons since monitoring ceased (e.g. *Delphinus delphis*, 1987) and by the fact that some species (e.g., *Lagenodelphis hosei*, *Kogia breviceps* and *Feresa attenuata*) are found more frequently in the fish landing sites in the west and southwest than they are in Trincomalee. However, in the absence of more detailed data for the country as a whole, estimates based on landed catches observed at Trincomalee are probably the best that can be made at present.

2. EFFORT PER BOAT/FISHING VILLAGE

Prematunga attempted to examine every cetacean landed at the Trincomalee fish landing site for three years, 1984–6, although his work was compromised to an unknown extent in 1986 by the civil strife in the region, resulting in lower counts of cetaceans than in previous years. Therefore, the total observed kills for 1984 and 1985 (310 and 323, respectively) were used to estimate average minimum landings per year at this site (316.5). There were 103 inboard boats registered at Trincomalee during that period, but Prematunga was not able to note how many of these boats were fishing and, therefore, contributing to the cetacean kill, at any given time (Leatherwood and Reeves, 1989, p.47)

3. NUMBER OF INBOARD FISHING BOATS IN SRI LANKA AND NUMBER OF FISHING DAYS PER YEAR (TOTAL EFFORT)

According to government statistics, there were an average of 2,943.8 inboard fishing boats registered in Sri Lanka 1984–1986 (Leatherwood and Reeves, 1989: table 3). However, not all registered boats are thought to be fishing all or even part of the year; so workers have used the figures 2,284 (Josephs and Siddeek, 1985) to 2,568 (Leatherwood and Reeves, 1989: table 7) in characterisations of fishing effort.

In the absence of better statistics, the more conservative of these two figures is used for the present calculations. A total of 1,385 of the boats are believed to fish in the Mannar District to Kulmanai District (west and southwest region); 899 in the Batticaloa District to the Jaffna District (east and northeast region) (Joseph and Siddeek, 1985; Leatherwood and Reeves, 1989: table 7). In previous calculations by Sri Lankan government scientists, it has been assumed that inboard vessels in the country fish at least 75% of the time (274 days/year) (Joseph and Siddeek, 1985).

4. CATCH RATES

The catch rate for the east and northeast coast can be estimated only with the data from Trincomalee. The resultant catch rate will be biased downward to an unknown extent because of overestimates in the number of vessels actually fishing at any time and the fact that some animals were discarded at sea and some of the animals landed were very probably not accounted for in Prematunga's tallies.

When the average minimum annual catch observed landed at Trincomalee in 1984 and 1985 (316.5) is divided by the maximum number of inboard boats registered in Trincomalee in that period (103), and the resultant minimum annual catch rate (3.07 cetaceans/boat/year) is

then multiplied by the minimum number of inboard boats thought to be operating in the east and northeast region (899), one obtains a minimum estimate of 2,763 cetaceans landed per year in the region. This is lower than the range reported by Leatherwood and Reeves (1989: table 7). However, their calculations of minimum mortalities for this area as presented in that table contain an error (the catch rate is off by one decimal point). When the erroneous catch rates are replaced with the catch rate for Trincomalee recalculated for this report (0.0084), the resultant estimates of minimum annual mortality in the east and northeast region ranged from 2,297 – 3,729.

For the west and southwest region, Mannar District to Kulmanai District, the best catch rates available are those from observers stationed in four villages for 21–98 days each. These observers noted minimum landings of cetaceans (466) (Other duties prevented complete tallies.) and total numbers of inboard boats actually fishing during periods of observation (mean for the four combined = 134.3) (calculated from Leatherwood and Reeves, 1989: table 5). These estimates of fishing effort are more likely to be accurate than those calculated, as in Trincomalee, based on the total number of boats registered. The general utility of these estimates is further enhanced by the fact that the observers worked in four fish landing sites rather than one, suggesting that their figures are more likely to be representative of the entire region than figures from a single landing site would be. When catch rates for the west and south coasts are recalculated using this minimum estimated catch rate (0.0163 cetaceans/vessel/day) and multiplied by the minimum number of fishing boats thought to be in the area (1,385) and the number of fishing days (274), following Josephs and Siddeek (1985), one obtains a minimum estimate of 6,182 cetaceans killed in the west and southwest region each year. When the same conservative catch rate is used to recalculate the estimates in Leatherwood and Reeves (1989: table 7), the range of estimates corrects to 5,745–8,092.

The minimum annual landed kill for all of Sri Lanka, derived by combining the above two regional estimates, is 8,951 using the very conservative approach outlined above and 8,042–11,821 using the conservative approach taken by Leatherwood and Reeves (1989) in revising their table 7. The numerical catch estimates in Table 1 of the Workshop report are derived from the minimum estimate of 8,951 and the species composition of observed landings at Trincomalee.

It must be emphasised that all these estimates are biased downward to an unknown extent by cetaceans which are killed but not landed or landed but not tallied, and most are further biased downward by the use of the number of registered vessels rather than number of vessels actually fishing. As stated by Leatherwood and Reeves (1989:47)

> "All attempts to estimate mortality of cetaceans in Sri Lankan fisheries from the data available are compromised in significant ways...The best (one) could do was to calculate a series of estimates using conservative assumptions and present the basis and details for those estimates in sufficient detail that they can be recalculated as more information becomes available."

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Annex E
Guidelines for the Correct Description of a Gillnet (either driftnet or bottom set)

(1) Target species:
(2) Country or region:
(3) Mesh size: preferably to be given as stretched length, if not (e.g. bar length), specify precisely
(4) Twine webbing material: e.g. PA for nylon, PE for polyethylene, PP for polypropylene, PES for polyester. For other material, indicate the full trade name
(5) Twine construction: multifilament, monofilament or multimonofilamemt
(6) Twine size:
— for multifilament, indicate either number of denier, Rtex, or yard/lbs, m/kg. For any other measurement indicate its equivalence with one of the above or give the diameter
— for monofilament, indicate the diameter
— for multimonofilament, indicate the number of monofilaments and the diameter of one of these
(7) Height of the net: number of meshes or stretched height of the netwebbing, specify
(8) Length of the net: total strengthed length of the net webbing or number of meshes in the horizontal direction
(9) Hanging ratio (E): if possible
(10) Framelines (upper=floatline, lower=leadline, side=sidelines): indicate their material (see 4), diameter, length
(11) Floatation: needed measure is floatation per meter, so indicate: float material + main dimensions of the float + number of floats either per metre of the floatline or per given length of gillnet
(12) Weight on the leadline: indicate either: weight of a unit of lead + number of units either per metre of leadline or on the whole net or if the lower frameline is made of a lead core rope, indicate the weight of this rope per metre
(13) Make a drawing or sketch of the net in the fishing position: show the position of the gillnet versus the surface or the bottom, the anchor if any, buoy(s) and buoyline(s), secondary floatlines or leadlines if any (in this case give an indication of the floatation and the ballast)
(15) Total length of the string (or fleet) of net:
(16) Time of fishing:
(17) Duration of soak:
(18) Areas:
(19) Depth range:
(20) Approximate price:
(21) Vessel length:
(22) Vessel horsepower:
(23) Source of information and date:

Annex F
A Review of Modifications to the Webbing and Setting Strategies of Passive Fishing Gear to Reduce Incidental Bycatch of Cetaceans

Sean Todd and Dawn Nelson

Biopsychology Programme, Department of Psychology, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, A1B 3X9

INTRODUCTION

This Annex reviews all known studies to date in which gear was modified to reduce cetacean bycatch. Certain fields have been deliberately excluded; for example, the methods used in pinniped-fishery interactions have been omitted, as well as studies in which modifications were not actually attached to nets. As a result, this review focuses specifically on in situ research. For a detailed review of the practicalities of gear modification, see Dawson (1991).

Modifications to passive fishing gear

Modifications can be divided into three broad categories; active sound generators, passive reflectors and changes in setting strategy. Active sound generators and passive reflectors are used on the assumption that they increase the acoustic and/or the visual detectability of fishing gear, whereas changes in setting strategy attempt to reduce the initial interaction between the bycatch species and the gear. Each type of modification is dealt with in turn.

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The authors would like to thank Dr. Jon Lien, Julie Huntington and Frank Chopin for their constructive criticisms in writing this paper and the members of the Causes and Solutions Sub-Committee at the IWC Workshop on the Mortality of Cetaceans in Passive Fishing Gear and Traps, especially Linda Jones, for their help in supplying source material.

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Modification type	Results/Comments	Source[1]
Active Sound Generators		
SG-1 9kHz pulse generator	No significant reduction in bycatch, awkward operation.	Hatakeyama, 1986a Hatakeyama *et al.*, 1991a,b Kumagai *et al.*, 1983 Ogiwara, 1986 Ogiwara *et al.*, 1985
SG-2 145kHz, simple form	Avg. <10% reduction in bycatch In 1984, a 5% decrease in directed catch was reported (no significance given).	Hatakeyama, 1986a Hatakeyama *et al.*, 1990a,b Kumagai *et al.*, 1983 Ogiwara, 1986 Ogiwara *et al.*, 1985 Ogiwara *et al.*, 1986
SG-3 145kHz, `porpoise-like'	Avg. <10% reduction in bycatch, significant in 1983, 1984, but not 1985.	Hatakeyama, 1986a Hatakeyama *et al.*, 1990a,b Kumagai *et al.*, 1983 Ogiwara, 1986 Ogiwara *et al.*, 1985 Ogiwara *et al.*, 1986 Hatakeyama, Ishii and Taketomi, 1985
SG-4 20-50kHz, random pulse	Avg. <30% non-significant reduction in bycatch. Generally, entrapment occurred in areas of net where alarms were not positioned. Some problems with alarm entanglement.	Hatakeyama, 1986a,b, 1987 Hatakeyama *et al.*, 1990a,b Ogiwara, 1986 Ogiwara *et al.*, 1986 Takagi, 1987
0.5-1kHz `clanger'	No significant reduction in bycatch, awkward operation.	Lien *et al.*, 1990
27-50kHz `pinger'	No significant reduction in bycatch, but a significant decrease in damage cost.	Lien *et al.*, 1990
3.5kHz `beeper'	Significant reduction in bycatch and damage cost.	Lien *et al.*, 1990
Low frequency `clanger'	No change in dolphin movements near nets. Increase in directed catch. Corrosion problems.	Peddemors *et al.*, 1991 Peddemors and Cockcroft, 1990
Low frequency `rattle'	No change in dolphin movements near nets. Reliant on sea state. Awkward operation.	Peddemors *et al.*, 1991 Peddemors and Cockcroft, 1990
Low frequency bell buoy	No change in dolphin movements near nets. Reliant on sea state. Awkward operation.	Peddemors *et al.*, 1991 Peddemors and Cockcroft, 1990
Passive Devices		
1m ABS air-filled piping	No significant reduction in bycatch.	Lien, 1980
1m ABS water-filled piping	No significant reduction in bycatch.	Lien, 1980
White plastic disc	No significant reduction in bycatch.	Lien, 1980
Plasticised aluminium foil squares	Tests inconclusive, problems with corrosion.	Peddemors *et al.*, 1991 Peddemors and Cockcroft, 1990
Aluminium discs	Tests inconclusive, problems with corrosion, awkward operation.	Peddemors *et al.*, 1991 Peddemors and Cockcroft, 1990
Stainless steel twine	Tests inconclusive, unmanageable.	Peddemors *et al.*, 1991 Peddemors and Cockcroft, 1990
AT-1 3 air-filled tubes in central portion of net	Avg. <30% reduction in bycatch, significant for years 1981 and 1982, but not for 1983. Data for 1984, 1985 and 1986 show an ambiguous significant decrease in bycatch (depending on type of statistical test).	Hatakeyama *et al.*, 1990a,b Hatakeyama, 1987 Jones, Bouchet and Turnock, 1987 Kumagai *et al.*, 1983 Ogiwara, 1986 Ogiwara *et al.*, 1985 Ogiwara *et al.*, 1986 Ogiwara *et al.*, 1987 Snow *et al.*, 1988 Takagi, 1987

Modification type	Results/Comments	Source
AT-2 5 air-filled tubes in central portion of net	<10% non-significant reduction in bycatch.	Kumagai *et al.*, 1983 Ogiwara, 1986 Takagi, 1987
AT-3 3 air-filled tubes in top 1/3 of net	<25% non-significant reduction in bycatch.	Hatakeyama *et al.*, 1990b Ogiwara, 1986 Ogiwara *et al.*, 1986 Takagi, 1987
MT-1 multi-filament thread	<30% reduction in bycatch, but of ambiguous significance. In 1987, there was a significant reduction in bycatch relative to AT-1 (solo) tests, with a slight non-significant) reduction in directed catch.	Hatakeyama *et al.*, 1990b Ogiwara, 1986 Ogiwara *et al.*, 1987 Snow *et al.*, 1988
Air filled tubes	No significant reduction in bycatch, problems with maintenance.	Hembree and Harwood, 1987
Bead chain	No significant reduction in bycatch, but decrease in directed catch.	Hembree and Harwood, 1987
Vinyl string (horizontal)	Tests inconclusive, some losses of strings from net.	Hasegawa *et al.*, 1987 Hatakeyama *et al.*, 1990a
1 rope (vertical)	Tests inconclusive.	Hasegawa *et al.*, 1987 Hatakeyama *et al.*, 1990a
3 ropes (vertical)	Tests inconclusive.	Hasegawa *et al.*, 1987 Hatakeyama *et al.*, 1990a
Blister sheet	Tests inconclusive, some losses of blister sheets from net.	Hasegawa *et al.*, 1987 Hatakeyama *et al.*, 1990a
Setting Strategies		
Lowering net by 2m	No bycatch in modified net, but some experimental design problems. Also a significant decrease in directed catch.	Hayase *et al.*, 1990
Lowering net by 4.5m	Significant decrease in bycatch by 50% (approx.). Also a decrease in directed catch, significant for one species only.	Hembree and Harwood, 1987
Lowering net by 2m	Tests inconclusive, but some decreases in bycatch.	Hayase *et al.*, 1990
Lowering trap leader by 5m	Modified traps resulted in no entrapments.	Kingsley, 1982
Combinations		
AT-1 with SG-1	<40% reduction in bycatch, no significance reported.	Ogiwara, 1986 Takagi, 1987
AT-1 with SG-2	<20% non-significant decrease in bycatch.	Hatakeyama *et al.* 1990b Ogiwara, 1986 Ogiwara *et al.*, 1987 Takagi, 1987
AT-1 with SG-3	<30% non-significant decrease in bycatch.	Hatakeyama *et al.*, 1990b Ogiwara, 1986 Ogiwara *et al.*, 1987 Takagi, 1987
AT-1 with SG-4	<40% non-significant decrease in bycatch. In 1987, inconclusive tests showed a reduction in bycatch relative to AT-1 (solo) tests.	Hatakeyama, 1988 Hatakeyama *et al.*, 1990b Ogiwara, 1986 Ogiwara *et al.*, 1987 Snow *et al.*, 1988 Takagi, 1987

[1] In several cases, different sources may refer to the same study; all sources are included here.

Annex G
List of Cetacean Species

There follows a list, in taxonomic order, of the living cetacean species recognised by the IWC Scientific Committee (scientific names and English common names).

Order Cetacea (whales and porpoises)
Suborder Mysticeti (baleen whales or mysticetes)
Family Balaenidae
Eubalaena australis — southern right whale
Eubalaena glacialis — northern right whale

Family Neobalaenidae
Caperea marginata — pygmy right whale

Family Eschrichtiidae
Eschrichtius robustus — gray whale

Family Balaenopteridae
Subfamily Balaenopterinae
Balaenoptera acutorostrata — minke whale
Balaenoptera borealis — sei whale
Balaenoptera edeni — Bryde's whale
Balaenoptera musculus — blue whale
Balaenoptera physalus — fin whale

Subfamily Megapterinae
Megaptera novaeangliae — humpback whale

Superfamily Physeteroidea
Family Physeteridae
Physeter macrocephalus — sperm whale

Family Kogiidae
Kogia breviceps — pygmy sperm whale
Kogia simus — dwarf sperm whale

Suborder Odontoceti (toothed whales including porpoises)
Superfamily Platanistoidea
Family Platanistidae
Platanista gangetica — Ganges river dolphin
Platanista minor — Indus river dolphin

Family Pontoporiidae
Subfamily Lipotinae
Lipotes vexillifer — baiji
Subfamily Pontoporiinae
Pontoporia blainvillei — franciscana

Family Iniidae
Inia geoffrensis — boto

Superfamily Delphinoidea
Family Monodontidae
Subfamily Delphinapterinae
Delphinapterus leucas — white whale
Subfamily Monodontinae
Monodon monoceros — narwhal

Family Phocoenidae
Subfamily Phocoeninae
Phocoena phocoena — harbour porpoise
Phocoena spinipinnis — Burmeister's porpoise
Phocoena sinus — vaquita
Neophocaena phocaenoides — finless porpoise
Subfamily Phocoenidinae
Australophocaena dioptrica — spectacled porpoise
Phocoenoides dalli — dall's porpoise

Family Delphinidae
Subfamily Stenoninae
Steno bredanensis — rough-toothed dolphin
Sousa chinensis — Indo-Pacific hump-backed dolphin
Sousa teuszii — Atlantic hump-backed dolphin
Sotalia fluviatilis — tucuxi
Subfamily Delphininae
Lagenorhynchus albirostris — white-beaked dolphin
Lagenorhynchus acutus — Atlantic white-sided dolphin
Lagenorhynchus obscurus — dusky dolphin
Lagenorhynchus obliquidens — Pacific white-sided dolphin
Lagenorhynchus cruciger — hourglass dolphin
Lagenorhynchus australis — Peale's dolphin
Grampus griseus — Risso's dolphin
Tursiops truncatus — bottlenose dolphin
Stenella frontalis — Atlantic spotted dolphin
Stenella attenuata — pantropical spotted dolphin
Stenella longirostris — spinner dolphin
Stenella clymene — clymene dolphin
Stenella coeruleoalba — striped dolphin
Delphinus delphis — short-beaked common dolphin
Delphinus capensis — long-beaked common dolphin
Lagenodelphis hosei — Fraser's dolphin
Subfamily Lissodelphinae
Lissodelphis borealis — northern right whale dolphin
Lissodelphis peronii — southern right whale dolphin

Subfamily Cephalorhynchinae	
Cephalorhynchus commersonii	Commerson's dolphin
Cephalorhynchus eutropia	black dolphin
Cephalorhynchus heavisidii	Heaviside's dolphin
Cephalorhynchus hectori	Hector's dolphin
Subfamily Globicephalinae	
Peponocephala electra	melon-headed whale
Feresa attenuata	pygmy killer whale
Pseudorca crassidens	false killer whale
Orcinus orca	killer whale
Globicephala melas	long-finned pilot whale
Globicephala macrorhynchus	short-finned pilot whale
Subfamily Orcaellinae	
Orcaella brevirostris	Irrawaddy dolphin

Superfamily Ziphioidea

Family Ziphiidae	
Tasmacetus shepherdi	Shepherd's beaked whale
Berardius bairdii	Baird's beaked whale
Berardius arnuxii	Arnoux's beaked whale
Mesoplodon pacificus	Longman's beaked whale
Mesoplodon bidens	Sowerby's beaked whale
Mesoplodon densirostris	Blainville's beaked whale
Mesoplodon europaeus	Gervais' beaked whale
Mesoplodon layardii	strap-toothed whale
Mesoplodon hectori	Hector's beaked whale
Mesoplodon grayi	Gray's beaked whale
Mesoplodon stejnegeri	Stejneger's beaked whale
Mesoplodon bowdoini	Andrews' beaked whale
Mesoplodon mirus	True's beaked whale
Mesoplodon ginkgodens	ginkgo-toothed beaked whale
Mesoplodon carlhubbsi	Hubbs' beaked whale
Mesoplodon peruvianus	pygmy beaked whale
Ziphius cavirostris	Cuvier's beaked whale
Hyperoodon ampullatus	northern bottlenose whale
Hyperoodon planifrons	southern bottlenose whale

Significant Direct and Incidental Catches of Small Cetaceans

A REPORT BY THE SCIENTIFIC COMMITTEE OF THE INTERNATIONAL WHALING COMMISSION TO THE UNITED NATIONS CONFERENCE ON ENVIRONMENT AND DEVELOPMENT (UNCED)

EDITED BY

A. Bjørge
Norwegian Institute for Nature Research
University of Oslo
Norway

R.L. Brownell Jr
Southwest Fisheries Science Center
La Jolla, California
USA

G.P. Donovan
International Whaling Commission
Histon, Cambridge
UK

W.F. Perrin
Southwest Fisheries Science Center
La Jolla, California
USA

This report originally formed part of the report of the sub-committee on small cetaceans, published in 1992 in *Rep. int. Whal. Commn* 42: 178–234.

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Significant Direct and Incidental Catches of Small Cetaceans

Edited by A. Bjørge, R.L. Brownell Jr, G.P. Donovan and W.F. Perrin

INTRODUCTION

Background to the Review

The Commission's Resolution

In the Resolution on Small Cetaceans (IWC, 1991a) adopted by the IWC last year, the Commission requested the Scientific Committee to commence a process of drawing together all available relevant information on the present status of those stocks of small cetaceans which are subjected to significant directed and incidental takes and on the impact of those takes on the stocks, and to provide such scientific advice as may be warranted.

The report to UNCED

The Commission also decided to present a report on the work carried out under the terms of the Resolution on Small Cetaceans to the United Nations Conference on Environment and Development (UNCED) in June 1992.

Editors' notes on the 1994 version

The present report comprises the relevant section (section 5) of the review of small cetacean stocks subjected to significant directed and incidental takes carried out by the sub-committee on small cetaceans and agreed by the full Scientific Committee and sent to the UNCED meeting. For convenience, the report follows the numbering system of the report of the sub-committee on small cetaceans published in *Rep. int Whal. Commn* 42: 178–234. Similarly the use of the word 'sub-committee' has been retained. The only changes that have been made to that report is the updating of 'In press' or 'unpublished' references where these have subsequently been published; Appendices 1 and 4 of the sub-committee report are not included as they are not relevant to the review.

Species names

The report uses English common names recognised by the IWC for small cetacean species as of October 1994. A full list of species in taxonomic order is given in Appendix 2. It should be noted that at the time of the report, only one species of common dolphin, *Delphinus delphis* was recognised. Since then two species, the short-beaked common dolphin (*D. delphis*), and the long-beaked common dolphin (*D. capensis*) have been recognised. Appendix 2 has been modified to this effect, but in most cases it is impossible to retrospectively reallocate animals assigned originally to 'common dolphin' to the two species.

5. REVIEW OF SIGNIFICANT DIRECTED AND INCIDENTAL CATCHES OF SMALL CETACEANS

Four categories of catches were identified and discussed; directed fisheries, incidental catches, deliberate incidental catches and live-capture fisheries. Information published in *Rep. int. Whal. Commn* or elsewhere, information presented to the IWC Workshop on Incidental Mortality in Passive Fishing Nets and Traps (IWC, 1994) and new information submitted to the sub-committee were reviewed. Priorities were given to those fisheries in each category where significant impacts on stocks are likely to occur. For these fisheries, previous recommendations made by the Scientific Committee, and any management response upon such recommendations were evaluated. New recommendations were made where appropriate.

The sub-committee, however, reviewed only those fisheries and stocks of small-cetaceans for which detailed information was available for consideration. It was emphasised, therefore, that while the review addresses many of the stocks which are significantly impacted by directed or incidental catches, it cannot be considered to be comprehensive, either with regard to species or to geographic regions covered. The sub-committee emphasised this problem that apply to all four categories of catches, and **recommends** that areas should be identified where there are urgent needs for basic information on status of small cetacean stocks and on impacts of any takes of those stocks. The sub-committee further **recommends** that areas should be specified where international cooperation is required (or beneficial) for developing further competence in research and management.

Problems related to pollution and habitat degradation were not addressed in the IWC Resolution on Small Cetaceans. These factors may have significant impacts on small cetaceans, in particular for those species occurring in coastal, inshore and riverine habitats. The sub-committee **underlines**, therefore, that these factors should be emphasised in a comprehensive assessment of threats to small cetaceans.

5.1 Directed fisheries[1]

5.1.1 Directed fisheries on small cetaceans in Japan

Over 20 species of small cetaceans are found in the nearshore waters around Japan. Various local fisheries for some of these species have a long history. This section

[1] Initial draft by Kasuya and Brownell.

reviews the history of exploitation for the four main small cetaceans (Dall's porpoise, striped dolphin, short-finned pilot whale, and Baird's beaked whale) hunted in Japanese waters and presents a brief review of the situation with other small cetaceans caught in direct Japanese fisheries.

5.1.1.1 *Phocoenoides dalli*

COMMON NAMES

Dall's and True's porpoise, *ishi iruka* and *rikuzen iruka* (Japanese names for *dalli* and *truei* forms, respectively), *belokrylaya morskaya svin'ya* (Russian).

DISTRIBUTION

This genus is endemic to the North Pacific basin. Its southern limits during winter are around the Boso Peninsula, near Tokyo (about 35°N) in the western Pacific and off northern Baja California, Mexico (approximately 28°N) in the eastern Pacific. The southern boundary in the central Pacific is about 39°N during summer (Jones *et al.*, 1987). In northern waters, sightings are infrequent above 62°N in the Bering Sea (Nishiwaki, 1967). In the western Pacific, these porpoises are also widely distributed in the Sea of Japan and the Okhotsk Sea (Kasuya, 1982; IWC, 1991c).

Based on the distribution of cow-calf pairs in August-September, colour pattern, body size, and geographical variation in parasite loads, the Scientific Committee proposed seven stocks of Dall's porpoises (IWC, 1991c). These are: (1) the central Bering Sea (*dalli*-type), (2) south of the Kamchatka Peninsula (*dalli*-type), (3) south of the Aleutian Islands (*dalli*-type), (4) central Gulf of Alaska (*dalli*-type), (5) northern Okhotsk Sea (*dalli*-type), (6) central Okhotsk Sea (*truei*-type) and (7) eastern North Pacific (*dalli*-type).

Understanding of the Okhotsk Sea stocks has since been refined (Miyashita, In press-b). During recent surveys the density of the *dalli*-type was low in the central Okhotsk Sea where the density of the *truei*-type (including cow-calf pairs) was high. Cow-calf pairs of *dalli*-type were concentrated to the north and south of this area of concentration of the *truei*-type in the central Okhotsk Sea (Miyashita, In press-b). The breeding ground (for the *truei*-type) south of the Kamchatka Peninsula (east of the Kuril Islands) was discontinuous with those in the Okhotsk Sea. Thus, Miyashita (In press-b) proposed three Dall's porpoise breeding stocks for the Okhotsk Sea (i.e. northern Okhotsk Sea – *dalli*-type; central Okhotsk Sea – *truei*-type; and southern Okhotsk Sea – *dalli*-type). This brought to eight the number of stocks known or postulated in the North Pacific.

PROBLEMS AND CATCH STATISTICS

This species has been hunted in Japanese waters since at least the early 1940s (Hirashima and Ohno, 1944). Porpoises are caught from two stocks (i.e. the *dalli*-type, southern Okhotsk Sea stock, and the *truei*-type, central Okhotsk Sea stock). During the 1960s and 1970s, the hand harpoon fishery in northern Japanese waters landed between 5,000 and 10,000 porpoises annually. In its early years, the hand harpoon fishery operated during winter off the Iwate coast (northern Honshu), but as the fishery started to expand, the season lengthened and the fishing ground moved into waters around Hokkaido. By 1988 the reported catch had increased to over 40,000 individuals. The Government of Japan established regulations for the hand harpoon fishery in early 1989, which resulted in a reduction of the annual catch to a total of 29,048 for that year. The estimated removals by the direct fishery from both stocks between 1986 and 1989 totalled 111,530 porpoises (IWC, 1991c). The large increases in take of this species since 1986 have been used to compensate for the shortage of whale meat due to the IWC moratorium on whaling. The increase has also been intended to compensate for the decrease in catches of striped dolphins in recent years. During the 1970s, Dall's porpoises were consumed largely in the Shizuoka area, but they are now shipped to Taiji as well. In addition to these high numbers caught and landed, other Dall's porpoises are struck and lost and therefore, probably die in this fishery. Struck and loss ratios in this fishery have been found to be highly variable by vessel, crew and area (Fujise, 1991).

The reported catches since 1963 are given Table 1. Recent catch statistics are reported as meat weight or whole animals, and the factor used to convert values for meat landed to whole animals taken is not consistent. Therefore, the Scientific Committee has expressed concern about the accuracy of the reported catches. It was also noted that meat products cannot accurately be attributed to stocks if the hunting operations are conducted in areas where both stocks occur.

Table 1

Reported landed catches of Dall's porpoises from the hand harpoon fishery in Japanese coastal waters (IWC, 1991c). Both *dalli* and *truei* types are included.

Year	Catch	Year	Catch	Year	Catch
1963	9,040	1972	5,190	1981	9,767
1964	9,440	1973	7,230	1982	12,833
1965	9,180	1974	6,470	1983	12,776
1966	7,980	1975	7,350	1984	9,764
1967	5,150	1976	9,899	1985	10,378
1968	6,020	1977	9,358	1986	16,515
1969	7,020	1978	8,426	1987	25,600
1970	8,060	1979	6,843	1988	40,367
1971	5,210	1980	6,920	1989	29,048
				1990	21,802

POPULATION ESTIMATED

Bouchet (1981) estimated that 920,000 Dall's porpoises occur in the North Pacific and Bering Sea portions of their range, excluding the Sea of Japan and Okhotsk Sea. This estimate was revised upwards to 953,000 (Turnock, 1987). The latter estimate included 212,000 porpoises in the Bering Sea stock and 741,000 porpoises in the western and central North Pacific between 150°E and 172°W. A large but unknown population(s) occurs in the eastern North Pacific.

Miyashita and Kasuya (1988) reported minimum estimates for the *dalli*-type stock in the southern Okhotsk Sea of 47,000 (plus an unknown number of animals in adjacent Soviet waters) and for the *truei*-type stock in Japanese and USSR waters of 58,000. Using porpoise sightings from 1990 surveys, Miyashita (Miyashita, In press-b) estimated the three stocks off Japan to be: 111,000 (CV=0.29), *dalli*-type, northern Okhotsk Sea stock; 226,000 (CV=0.15), *dalli*-type, southern Okhotsk stock; and 217,000 (CV=0.23), *truei*-type, central Okhotsk Sea stock.

These estimates are substantially different from the previous estimates for part of the area; so, with help from a review by Buckland the sub-committee examined the new results in some detail. The design was found to be acceptable. Although bad weather did prevent surveys from achieving uniform coverage, it did not significantly affect results. Buckland suggested that a more appropriate method of calculating variance would yield a higher variance. If the porpoises are attracted to vessels, as are Dall's porpoises in other areas, results will be biased upward; if they avoid vessels the results will be biased downward. This was not possible to assess with the data available.

ASSESSMENT AND STATUS

From data then available (catches through 1987, population estimates from Miyashita and Kasuya (1988)) the Scientific Committee concluded in 1989 that the take of Dall's porpoises in the Japanese hand harpoon fishery was clearly not sustainable (IWC, 1991b; c). In 1988 and 1989, respectively, totals of 40,367 and 29,048 porpoises were taken in this fishery. These represented 38% and 28%, respectively, of the minimum population estimates then available. Takes during the 1990 season were estimated to consist of 9,360 of the *dalli*-type and 12,442 of the *truei*-type (uncorrected for animals struck but lost). The Japanese statistics report the catch by colour type based on the area of operation for catches landed as meat (i.e. 100% *dalli*-type off Hokkaido and 90–95% *truei*-type off Sanriku). In 1990, then, the reported takes of Dall's porpoises in the Japanese harpoon fishery comprised 4.1% of the revised estimated population of *dalli*-type from the southern Okhotsk Sea stock and 5.7% of the estimated population of the *truei*-type from the central Sea of Okhotsk stock. These percentages must be increased by some amount to account for porpoises struck but lost. Estimates of the average struck-and-lost ratio ranged from 3.3% to 9.8% of those struck, depending on region (Fujise, 1991). Although some of these struck and lost animals may survive, applying the above range of struck and lost ratios suggests that 1990 takes accounted for 4.2–4.6% of the southern Okhotsk Sea stock and 5.9–6.3% of the central Okhotsk Sea stock. While these levels are very much lower than the catch rates reported for 1988 and 1989, it cannot necessarily be assumed that they are sustainable. The sub-committee in 1990 (IWC, 1991c) stated that it believed 'that allowable harvest and incidental take rates should be lower than half of the estimated value for r_{max}' and noted that 'all estimates of r_{max} presented in the submitted papers in 1990 are less than 0.10'. This implies that annual takes should be less than 5% of the estimated population size; how much less is still open to question. In addition, demographic implications of the sharp differences in age and sex structures of catches in different regions (Fujise *et al.*, 1991) must be taken into account in assessing impact.

RECOMMENDATIONS

In 1990 the highest priority recommendations of the Scientific Committee related to small cetaceans were that the planned Japanese sightings surveys be carried out and that new population estimates be developed for the stocks taken in the hand harpoon fishery (see new results in Miyashita, In press-b). It was also recommended that a plan for monitoring trends in the populations be developed. The sub-committee was pleased to receive the new estimates and **recommends** that surveys be continued as a basis for monitoring trends in population sizes for hunted stocks.

Additional recommendations in 1990 were that analyses of parasite loads in the eastern North Pacific and other areas be compared to those already studied (Walker, 1990) to help identify other possible stocks. Along these lines, it was also recommended that studies be continued or undertaken to differentiate stocks using a combination of techniques, such as differences in life-history parameters (e.g., asymptotic length), parasite and contaminant loads, reproductive seasonality, DNA and isozymes.

In 1989, the Scientific Committee recommended that catch statistics for this fishery be collected and reported on a stock-by-stock basis. Considering the possible take from the stocks off Japan, it was also recommended that the Republic of Korea be requested to report to the IWC by-catches of Dall's porpoises (and other cetaceans) in its squid driftnet fishery (IWC, 1990b).

In 1990, the Scientific Committee recommended that information on struck-and-lost rates be collected and analysed for each gear type in the Japanese harpoon fishery, to allow more accurate estimation of total mortality. It also recommended a clarification of the basis for revision of the 1986 and 1987 catch statistics (IWC, 1991c). The sub-committee was pleased to acknowledge the Japanese Government's quick response to these requests. Given that continuing problems have been identified, however, the sub-committee **advises** that there be increased effort in improving catch statistics for this fishery, and that this includes steps to distinguish the two colour types in landings of meat only. Noting the high variability in estimates currently available for struck-but-lost rates, the sub-committee **advises** that additional information be collected on these rates by area, season, vessel and other significant variables. Further, it **encourages** the continuation of steps taken to improve precision in estimates of take (Kasuya, 1991).

The sub-committee is pleased that catches have been reduced, perhaps to levels very near sustainable rates. However, given the uncertainty about the age and sex structure of catches, and pending a detailed age-structure assessment, it is again **reiterates** that catches in this fishery be further reduced.

5.1.1.2 *Globicephala macrorhynchus*

COMMON NAMES

Short-finned pilot whale, *tappa-naga* for the northern stock and *ma-gondo* for the southern stock (Japanese).

DISTRIBUTION

This species is found in tropical and warm temperate waters world wide. Short-finned pilot whales from at least two different stocks are hunted in Japanese waters (Kasuya *et al.*, 1988). The northern stock is found along the Pacific coast of northern Japan between 35°N and 43°N (IWC, 1987). Most sightings of whales in this stock during recent surveys were concentrated between 40°N and 43°N and west of 143°E (Kasuya *et al.*, 1986). Whales belonging to the southern stock were found during summer survey cruises in 1984 and 1985 in Japanese waters south of 37°N from the coast east to 125°E. No whales were seen south of 25°N or east of 152°E. This suggests that whales of the southern stock are restricted to this area off the Pacific coast of Japan. Wada (1988) reported, based on electrophoretic data, that the two stocks were genetically isolated.

PROBLEMS AND CATCH STATISTICS

Northern stock

The northern stock of pilot whales was exploited by Japanese small-type whaling vessels before World War II, but no statistics are available. During the late 1940s and early 1950s, the annual catches declined rapidly from 400 to less than 50 animals. In addition, the proportion of males in the catch declined. After a pause of about 25 years, small-type whaling on this stock resumed in 1982. Two to seven vessels have operated and landed their catch at three land stations in Ayukawa. The gunners select large whales. The total reported catch for eight seasons (1982–1990) was 700 whales (see Table 2).

Table 2

Catch statistics for northern stock of short-finned pilot whales taken by Japanese small-type whaling vessels, based on gunner's reports.

Year	No. of whales	No. of vessels	Operational-vessel days
1982	172	5	119
1983	125	7	100
1984	160	6	94
1985	62	7	77
1986	28	3	14
1987	0	0	0
1988	98	4	90
1989	50	2	78
1990	10	2	58

Since 1982, the regulations by the central government have changed several times: (1) no catch limit was set during the October-November 1982 season; (2) a quota of 175 was set for the 1983 and 1984 seasons; (3) a fixed fishing season of 255 vessel days was established for seven small-type whaling vessels during the 1985 season; (4) the government and industry decreased the fishing effort for the 1986 season to 40% of the previous season and set a quota of 50 whales from 5 October to 18 November for three vessels; (5) no whaling occurred during the 1987 season and the quota of 50 whales was carried over to the 1988 season; (6) four vessels were allowed to operate from 5 September to 30 November in 1988 with a two year quota of 100 whales; and (7) an annual quota of 50 whales was set for the 1989 and 1990 seasons and only two of the four vessels previously involved were allowed to operate from 1 September to 18 November each year.

Southern stock

In Japanese waters the southern stock has been exploited since before World War II by local fishermen in three isolated areas. Fishermen from various villages have operated a drive fishery for pilot whales along the Izu Peninsula since the early 1900s. Statistics are available since 1950. Annual catches ranged between 31 and 650 from 1950 to 1956. Statistics are incomplete between 1957 and 1971. From 1972 to the present, the annual catches have ranged from 0 to 80 whales. Today, only the fishermen from Futo (Izu Peninsula) still hunt pilot whales, but the last catch was 20 whales in 1981. Available catch records are summarised in Table 3. No catch limits are set for this fishery by the Shizuoka Prefectural government, but the Fisheries Agency requested a limit of 657 individuals of all dolphin species for the 1991 season.

Table 3

Drive fishery statistics for southern stock of short-finned pilot whales landed at Izu Peninsula, Japan.

Year	Catch	Year	Catch	Year	Catch	Year	Catch
1950	224	1958	---	1966	---	1974	0
1951	425	1959	---	1967	30	1975	0
1952	650	1960	---	1968	---	1976	0
1953	349	1961	---	1969	---	1977	73
1954	31	1962	---	1970	---	1978	80
1955	86	1963	---	1971	---	1979	0
1956	126	1964	---	1972	0	1980	0
1957	---	1965	33	1973	0	1981	20

Off Nago, Okinawa, the fishermen have hunted pilot whales in a drive fishery for a long time, but catch statistics are only available for years since 1960. Annual catches have varied from 0 to 500 animals per season (not calendar year). In 1975, the fishermen started to harpoon pilot whales from 5–7 fishing vessels. This method has replaced the traditional drive fishery in the area. The reported catches since 1960 are given in Table 4. This crossbow fishery came under regulation in 1989. A quota of 100 individuals (all species) was established for the Nago fishery with four vessels licensed for the 1991 season by the local governor.

The major pilot whale fishery is the one at Taiji (Kii Peninsula) that started in the 17th century (Kasuya and Marsh, 1984). Statistics are fragmentary for years before World War II. After the war, both small-type whaling and a drive fishery operated in the waters off Taiji. A total of 200–300 whales was taken annually between 1949 and 1951 by small-type whaling vessels. After 1951, lower catches were made and only a single small-type whaling vessel operated to meet local demand for pilot whale meat. The drive fishery started in 1969 and, since 1980, has been the only pilot whale fishery operating off Taiji. Annual catches ranged between 90 and 605 whales between 1975 and 1985. In 1982, the Japanese government placed all drive fishermen under the control of the relevant Prefectural governments (IWC, 1987). The Wakayama Prefecture (Taiji) has set an annual catch limit of 500 pilot whales since that time. Recent catch statistics are summarised in Table 5. Small-type whaling from Taiji started again on the southern stock of short-finned pilot whales in 1988 when 20 whales were caught (Kishiro and Kasuya, 1993); 3 vessels operated that year. An annual quota of 50 whales was set

Table 4

Drive and crossbow fishery for southern stock of short-finned pilot whales landed in Okinawan waters (Kasuya, In press).

Year	Catch	Year	Catch	Year	Catch
1960	243	1970	0	1980	80
1961	281	1971	165	1981	0
1962	0	1972	170	1982	5
1963	189	1973	87	1983	0
1964	318	1974	53	1984	88 *
1965	0	1975	49	1985	70 *
1966	0	1976	36	1986	82 *
1967	150	1977	301	1987	92 *
1968	150	1978	0	1988	116 *
1969	500	1979	0	1989	93 *
				1990	74 *

*Taken in crossbow fishery - crossbow and drive fisheries not seperated between 1975 and 1982.

Table 5

Catch statistics for southern stock of short-finned pilot whales taken by small-type whaling and drive fishery off Taiji, Japan, by calendar year (Kishiro and Kasuya, 1993).

Year	Harpoon	Drive	Year	Harpoon	Drive
1948	38	0	1970	108	0
1949	283	0	1971	111	24
1950	233	0	1972	60	30
1951	227	0	1973	66	52
1952	131	0	1974	65	94
1953	141	0	1975	53	410
1954	20	0	1976	14	370
1955	12	0	1977	6	170
1956	141	0	1978	13	309
1957	98	0	1979	3	87
1958	---	0	1980	0	605
1959	---	0	1981	0	476
1960	---	0	1982	0	305
1961	---	0	1983	0	378
1962	---	0	1984	0	424
1963	---	0	1985	0	589
1964	---	0	1986	0	264
1965	121	0	1987	0	294
1966	---	0	1988	20	327
1967	---	0	1989	5	71
1968	97	0	1990	8	75
1969	75	77			

for 1989 and 1990 but only 5 and 8 whales were taken, respectively. This quota was set by the Japanese Fisheries Agency.

ASSESSMENT AND STATUS

Northern stock

The provisional total estimated population size of the northern stock, based on summer surveys during 1984 and 1985, was 5,344. In 1986, the Scientific Committee expressed considerable concern that the available data suggested a decline in the northern stock (IWC, 1986b). Using data collected in September and October of 1982 through 1988, Miyashita (1993) re-estimated the population size of the northern stock to be 4,239 (CV=0.61). The annual catch of about 87 whales since 1982 represents more than 2% of the estimated present population size, but the current quota of 50 is about 1% of the estimate.

Southern stock

The estimated size of the southern population based on five cruises conducted during the summers of 1984 and 1985 was 53,000 (IWC, 1987). Based on new sighting data collected in 1986 through 1988, Miyashita (1993) revised the estimate for the southern stock of pilot whales down to 24,474 (CV=0.61). Recent total annual catches (uncorrected for any struck/lost whales) represent 1 to 2% of the estimated present population size of this stock.

RECOMMENDATIONS

In 1986, the Scientific Committee recommended that the biological monitoring programme be expanded on the northern stock and that additional vessel surveys be conducted to improve the population estimate and to collect data on the proportion of adult males present (IWC, 1986b). Additional sighting surveys were conducted by the Japanese and the results presented in Miyashita (1993). The sub-committee understands that biological materials have been collected routinely from whales landed in this fishery. It is requested that these materials be studied and reported on.

In 1986, the Committee also requested that fishing effort, sighting and catch data continue to be collected for the drive fishery along with the collection of biological materials from the catch. The Committee noted that no biological materials had been collected from the drive fishery since 1981. The Committee also suggested that investigations be initiated on stock identity of the whales taken in the three different southern fishing areas.

In 1986, the Scientific Committee felt it appropriate, from a biological point of view, that no animals be taken from the northern stock until a clearer understanding of the status of this population became available (IWC, 1986b). It recommended that if a pause in whaling was not possible, the catch should be reduced by significantly curtailing the total effort in the fishery. Japan reduced the annual catch limit from 175 whales in 1984 to 50 in 1987 and the number of vessels licenced to hunt pilot whales from the northern stock were reduced; from 6 vessels in 1984 to 2 vessels in 1989.

In 1986, the Committee also considered that the exploitation of the southern stock should not be intensified because of the recent catch levels and the fact that gross productivity of this species is low. However, effort on this stock has increased since small-type whaling on the southern stock started again in 1988. The sub-committee again **recommends** that catches from the southern stock not exceed levels prior to those in 1986.

5.1.1.3 *Berardius bairdii*

COMMON NAMES

Baird's beaked whale, *tsuchi kujira* (Japanese), *severnyi plavun* (Russian).

DISTRIBUTION

These whales are found only in the North Pacific Ocean and adjacent seas. Based on migration patterns, at least three stocks exist in the western Pacific around Japan: a western Pacific stock; a Sea of Japan stock; and an Okhotsk Sea stock (Kasuya and Miyashita, 1988).

PROBLEMS AND CATCH STATISTICS

Japanese fishermen have hunted Baird's beaked whales since at least the 17th century. Fishermen using hand harpoons from small boats operated out of Katsuyama in Chiba Prefecture (near Tokyo) until the start of the Meiji era (1867). The annual catch was only four or five whales. In 1908 *tsuchi-kujira* whaling resumed again off Chiba Prefecture from a small wooden boat with a Norwegian-type harpoon gun. After the end of World War II, coastal whaling increased, and by 1952 the Fisheries Agency of Japan had licensed 76 small-type whaling vessels. The largest catch was in 1952 when 322 Baird's beaked whales were landed (Omura *et al.*, 1955). Since 1952 the catches have declined. The Government of Japan established a national quota of 40 whales in 1983 (IWC, 1984b). The small-type whaling association divided this quota into 35 for the western Pacific and 5 for the Okhotsk Sea. In 1988 the national quota was increased 50% (from 40 to 60) as a one-year emergency increase for the small-type whaling vessels to partially replace the former catch of minke whales (IWC, 1980c). However, this higher quota was maintained in 1989 and 54 whales were landed. In 1989 one vessel with a quota of six whales did not operate in the fishery. During 1990 the quota was 54 whales and all were

taken. Table 6 lists the catch of Baird's beaked whales between 1961 and 1990.

Soviet whaling operations were reported to have taken 143 whales between 1934 and 1964 off Kamchatka and the Kuril Islands. Small numbers were also taken in the eastern North Pacific and landed at various shore stations in the USA (14 whales) and Canada (135 whales) between 1934 and 1966.

A few Baird's beaked whales are known to have been caught incidentally in the Japanese salmon driftnet fishery (from both research and commercial vessels) (Ohsumi, 1975). None has been identified as incidentally taken in any of the high seas pelagic driftnet fisheries in the North Pacific (L. Jones, pers. comm.). A few have been taken in gillnets off California (California Department of Fish and Game records).

Table 6

Statistics for Baird's beaked whales taken in Japanese coastal waters.

Year	Catch	Year	Catch	Year	Catch
1961	133	1971	118	1981	39
1962	145	1972	86	1982	60
1963	160	1973	32	1983	37
1964	189	1974	32	1984	38
1965	172	1975	46	1985	40
1966	171	1976	13	1986	40
1967	107	1977	44	1987	40
1968	117	1978	36	1988	57
1969	138	1979	28	1989	54
1970	113	1980	31	1990	54

ASSESSMENT AND STATUS

Based on sightings data, Miyashita (1986) estimated that 4,220 Baird's beaked whales occurred in the western North Pacific. The most recent estimate of abundance for this species – 5,870 whales in the western North Pacific and adjacent seas (Miyashita, 1990), based on 11 surveys conducted between 1983 and 1989 (IWC, 1991c) was presented to the Committee in 1990. This new estimate included 3,950 (CV=0.28) for the Pacific coast, 1,260 (CV=0.45) for the Sea of Japan and 660 (CV=0.27) for the Okhotsk Sea. The Committee noted that the estimates of 3,950 and 4,220 whales were not statistically different from each other but that they did differ from the estimate of 2,500 from 1989 that was based on data from all months rather than just the survey data for the season of greatest abundance in coastal waters (August).

The CPUE data did not show a clear annual trend from 1947 to 1983 (Kasuya, 1984). It is not known if the population is declining or stable (IWC, 1989).

At the 1985 Scientific Committee meeting, it was noted that the national quota of 40 whales was approximately 1% of the population estimate of 4,220 (Miyashita, 1986). It is 2.4% of the 1989 estimate (2, 500). It was also noted that historically, approximately 70% of the annual catch has been males (Ohsumi, 1983). In the absence of an estimate of gross reproductive rate, the Committee did not know whether or not the population could sustain the present level of catch. During the past five years the average catch in the western Pacific by Japan has averaged about 41 whales. This is around 1% of the population size depending on the estimate used. The corresponding figures for the Okhotsk Sea stock are 8 whales and about 1.2%.

RECOMMENDATIONS

In 1990, the Committee recommended that monitoring of trends in these populations in Japanese waters continue, taking special notice about the complications to stock assessments introduced by migration of animals (IWC, 1991c).

In 1990, the Committee again noted that there was insufficient data to judge whether annual catches of approximately 60 whales are sustainable and recommended 'as in the past (IWC, 1989) that research to develop an understanding of the life history, behaviour and social system that will allow estimation of growth rate potential be continued.' It was also noted that 'this should include continued collection and analysis of data and samples from the catch'. The sub-committee noted that Japan had increased its biological sampling to 100% of the catches; the sub-committee **encourages** continuation of that level of sampling and prompt evaluation and publication of results.

5.1.1.4 *Stenella coeruleoalba*

COMMON NAMES

Striped dolphin, *suji-iruka* or *suzi-iruka* (Japanese).

DISTRIBUTION

This species is found in tropical and warm-temperate waters around the world. In Japanese waters it is associated with the advancing northern front of the warm Kuroshio Current (Miyazaki *et al.*, 1974). During the winter, the northern boundary is around 33°N; during the summer it extends to 46°N. Ohsumi (1972) and Miyazaki *et al.* (1974) suggested that all striped dolphins caught in Pacific Japanese waters belong to one stock. Recently, Kasuya and Miyashita (1989) suggested there were coastal and offshore stocks of striped dolphins off the Pacific coast of Japan.

PROBLEMS AND CATCH STATISTICS

Drive fisheries for small cetaceans have a long history in Japanese waters. The first known drive fishery operated during the Genroku Age (1688–1703), but the types of dolphins caught were not recorded. The first recorded drive fishery for striped dolphins was started by the Kawana fishermen on the Izu Peninsula on 17 December 1888 (Miyazaki, 1983). Ten villages are known to have operated the fishery in the early 1900s (Kasuya, 1985). The number has declined, and since 1984 only Futo has continued to operate. Catch statistics for the Izu area are found in Table 7.

Striped dolphins were also caught in the harpoon fishery off Taiji until 1972. Starting in 1973 a local group of fishermen formed a new drive fishery for these dolphins. Catches by this drive fishery at Taiji between 1963 and 1990 are given in Table 8. The highest catch was 11,017 in 1980. Beginning in 1982 a voluntary catch limit of 5,000 dolphins was set by the fishermen in Taiji based on advice provided by the prefectural government. In 1989 the 5,000 limit became a condition of the license. In addition, the Fisheries Agency of Japan has requested a voluntary limit of 3,100 for 1991. Striped dolphins have made up 15% – 67% of the catch at Taiji between 1982 and 1990. No catch limit has been set for the Izu Peninsula area, but the Fisheries Agency requested a limit of 657 for all species of dolphins for 1991.

Matsuoka stated that these catch limits can be achieved by adjusting the catch by releasing a certain proportion of schools driven into a bay. For example, in early 1991, when

Table 7

Catch statistics for striped dolphins landed along the Izu Peninsula. Statistics are incomplete before 1961. Data for 1942-81 from Miyazaki (1983) and 1982-1990 from Japanese Progress Reports to the IWC.

Year	Catch	Year	Catch	Year	Catch
1942	21,591	1959	21,953	1976	5,175
1943	7,763	1960	14,418	1977	4,020
1944	7,660	1961	10,569	1978	2,028
1945	7,319	1962	8,554	1979	1,300
1946	8,180	1963	8,509	1980	5,278
1947	395	1964	6,428	1981	73
1948	5,892	1965	9,696	1982	246
1949	13,441	1966	8,371	1983	40
1950	15,186	1967	3,664	1984	925
1951	11,899	1968	9,250	1985	578
1952	8,032	1969	3,130	1986	0
1953	4,028	1970	5,348	1987	0
1954	298	1971	3,315	1988	356
1955	2,552	1972	7,235	1989	102
1956	8,507	1973	6,799	1990	0
1957	2,751	1974	11,715		
1958	3,681	1975	5,996		

approximately 2,000 striped dolphins out of 7,000–12,000 sighted were driven into the bay of Taiji, only 600 of them were killed; the rest were released.

Striped dolphins have also been reported taken in gillnets and set nets in Japanese waters (Miyazaki, 1983). Between 1976 and 1981, a total of 772 striped dolphins was taken in fishing gear. Recent reports of incidental catches in various types of gear in Japanese waters are also available (Anonymous, 1990d). Watanabe (1994) has also reported catches in large-mesh drift nets during research cruises in the central North Pacific. Estimates of total catches of striped dolphins in this fishery are not yet available.

ASSESSMENT AND STATUS

The largest directed fishery (both drive and hand-harpoon) for small cetaceans in Japanese waters was that conducted on the striped dolphin, until the Dall's porpoise fishery expanded in the mid 1970s. Kasuya and Miyazaki (1982) estimated that the initial population of striped dolphins off Japan had been 320,000–340,000, but by the late 1970s it was down to between 130,000 and 180,000. At the 1982 Scientific Committee meeting, Kasuya reported that recent life-history and populations studies led him to believe that these estimates were unreliable, for the reasons noted below.

The full statistics for the earlier years (before 1961) of the fishery on striped dolphins are not available, but in some years the catches exceeded 20,000 animals. Catch statistics from 1961 onward indicate a statistically significant downward trend in the total catches on the Izu Peninsula between 1961 and 1981, with a high of 11,715 landed in 1974 (Miyazaki, 1983). Catches of around 10,000 in the early 1960s declined to about 1,000 or less after 1980 using the same equipment (four vessels) and driving teams (Kawana and Futo). This decline occurred while the demand for dolphin meat remained high in the area. Kasuya and Miyashita (1989) reported that after the catch of striped dolphins decreased, the people in the Shizuoka area increased their use of Dall's porpoises. Kasuya (1976), Kasuya and Miyazaki (1982) and Kasuya (1985) noted that the striped dolphin population in Japanese waters has declined in abundance due to over-exploitation. Kasuya and Miyashita (1989) reported a hiatus in the density of sightings of this species at about 30°N during the summer, and suggested the possibility that there was another stock to the south of 30°N. They also identified a large number of striped dolphin sightings in the offshore water (145–160°E) between 33° and 40°N. During the same surveys, sightings of striped dolphin were scarce in the Japanese coastal waters. These data suggest that the stock of coastal striped dolphins is depleted and that the striped dolphins found offshore belong to another stock or stocks.

Table 8

Catch statistics for striped dolphins landed at Taiji, Japan between 1963 and 1990. Data for 1963-1978 from Miyzaki (1980), 1979-1981 from Miyazaki (1983) and 1982-1990 from Japanese Progress Reports to the IWC.

Year	Catch	Year	Catch	Year	Catch
1963	331	1972	700	1981	4,710
1964	934	1973	727	1982	1,758
1965	642	1974	967	1983	2,179
1966	422	1975	759	1984	2,812
1967	819	1976	1,053	1985	2,639
1968	400	1977	562	1986	2,720
1969	499	1978	1,644	1987	358
1970	997	1979	2,397	1988	1,767
1971	1,717	1980	11,017	1989	1,000
				1990	682

RECOMMENDATIONS

At the 1982 meeting, the Committee noted that the catches of these dolphins had declined over a long time period on the Izu Peninsula, that reproductive parameters had possibly changed in response to this heavy exploitation and that available analyses of CPUE were not adequate to determine the status of the stock (IWC, 1982b). Therefore, it recommended that Japan be urged to collect and analyse more detailed effort data and other relevant information on this species including:

(a) effort data in hours and days, by vessel, area, season and year;
(b) detailed oceanographic data;
(c) data on other major fisheries in the area, especially for squid, and;
(d) information on yearly changes in seasonal abundance, effort and catch.

Noting that catch limits are now voluntary, the sub-committee **advises** the establishment of mandatory catch limits on a species and stock basis, according to the status of the population.

Noting that the fisheries department has not sampled the catch of striped dolphins in ten years, the sub-committee **recommends** that Japan be encouraged to undertake a study of the age and sex composition of the catch and of reproductive parameters of the affected population.

Given reports that there have been changes in drive procedures, and total effort, the sub-committee **requests** an updated description of the drive fishery's current methods and procedure.

5.1.1.5 *Other species*

Several additional species are taken in Japanese direct fisheries (see past Japanese progress reports to the Committee, e.g. Anonymous, 1985a; 1986; 1987b; 1990d).

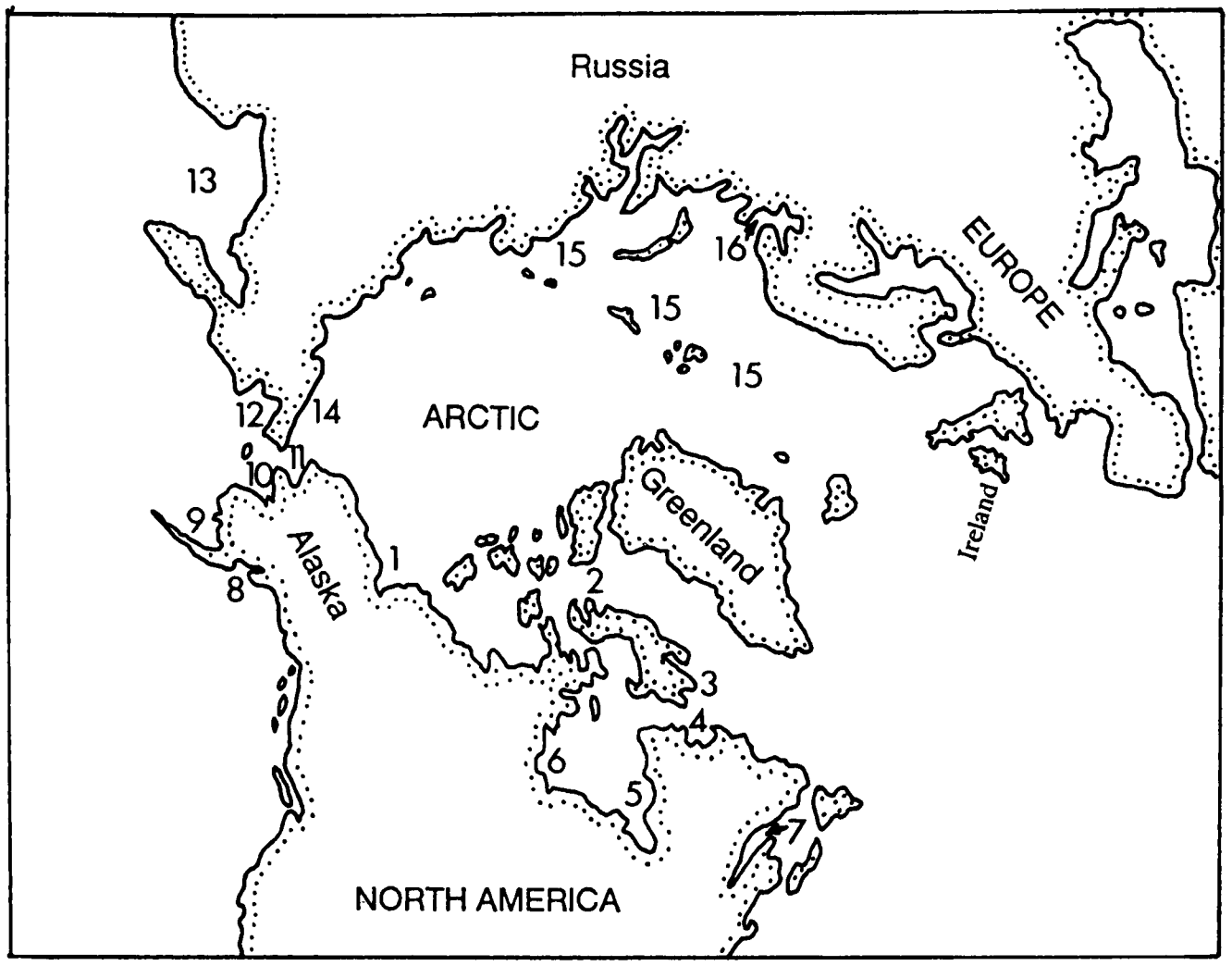

Fig. 1. White whales. Numbers refer to those in Table 9.

For example, 1,274 bottlenose dolphins were taken in drive fisheries in 1990 (SC/43/ProgRep Japan). The impacts of these takes on the populations are unknown.

5.1.2 Direct fisheries for small cetaceans in the Arctic[2]

Two species of small cetacean – the white whale and the narwhal – have distributions centred in the Arctic, and both have been exploited for centuries. In the past, commercial operations took thousands of white whales and hundreds of narwhals in some years. In recent years, most of the hunting for both species has been done by aboriginal peoples for domestic subsistence use and for the sale of muktuk and ivory. This section reviews recent developments in the exploitation of white whales and narwhals throughout their ranges, with emphasis on those areas where an immediate conservation problem is recognised or suspected.

5.1.2.1 *Delphinapterus leucas*

COMMON NAMES

White whale, beluga, belukha (Alaska and USSR), *qilaluaq* or *qaqortoq* (Greenlandic), *qilalugaq* (Inuktitut), *hvidhval* or *hvidfisk* (Denmark), *situaq* (Bering Strait Inupiat), *sisuaq* (Northern Alaskan Inupiat), *cetuaq* (Alaska mainland Yupik).

DISTRIBUTION

The white whale has a circumpolar distribution in the Arctic and subarctic, mainly north of 55°N. The world population is subdivided into at least 16 stocks that are isolated from one another to varying degrees (see Fig. 1 and Table 9). White whales tend to congregate in estuaries in summer, and the resulting aggregations have provided the basis for defining some of the stocks. Most populations are migratory, and their distribution is partly shaped by seasonal changes in ice conditions. Several stocks may mix during winter when they are excluded from the summering areas by ice (IWC, 1980c). For analytical convenience, distribution and other topics are discussed below by country. It is important to bear in mind that some of the stocks occur within the coastal jurisdictions of more than one country.

[2] Initial draft by R.R. Reeves.

Greenland

White whales occur infrequently in East Greenland coastal waters, and those that do occur there are considered wanderers from the Svalbard area (i.e., the Barents Sea) (Dietz *et al.*, 1985).

The white whales off the west coast of Greenland belong to a stock probably shared with Canada. They ranged historically all along the coast to at least as far south as Qaqortoq (Julianehaab, *ca* 61°N), where they were hunted in winter (Winge, 1902; Degerboel and Nielsen, 1930). They now occur as far south as Nuuk (Godthaab, *ca* 64°N) only infrequently but are still abundant in outer Disko Bay and in the open pack ice along the Greenland coast south to approximately Sisimiut (Holsteinsborg, *ca* 67°N) in winter (McLaren and Davis, 1981; 1982). Surveys in 1990 and 1991 confirmed that this is the core area for white whales in winter; most animals were observed within 50km of the coast (M.P. Heide-Jørgensen, pers. comm. to Reeves, 30 April 1991).

Canada

Seven white whale stocks are provisionally recognised in Canada, based on varying degrees of difference in body sizes, catch histories and hiatuses in distribution. These are Beaufort Sea-Mackenzie Delta, High Arctic (Lancaster Sound region), Southeast Baffin (Cumberland Sound, Frobisher Bay and Lake Harbour area in Hudson Strait – see Richard and Orr, 1986), Ungava Bay, East Hudson Bay-James Bay, West-South-North Hudson Bay (=West

Table 9

Status of world white whale stocks (modified from Braham, 1984). Fig. 1 shows the stock areas. Status: (A) large (3000+) and lightly or sustainably exploited; (B) large and exploited at rates that give cause for concern; (C) medium (500-3,000) and lightly or sustainably exploited; (D) medium and exploited at rates that give cause for concern; (E) small (500 or less) and vulnerable to hunting or habitat deterioration.

Centre of Summer distribution	Est. abundance		Est. ann. removal rate		Refs	Status
	Init.[1]	Current	Kill	(% stock size)		
Canada						
1. Beaufort Sea/Mackenzie Delta	--	11,500	232[2]	2.0	1,2	A
2. High Arctic/West Greenland	12,000	6,300-18,600	1,200[3]	6.5-19.0	3,4,5	B
3. SE Baffin	5,000	500	92-119	18-24	6,7	E
4. Ungava Bay	1,000	low	50+	high	8,9	E
5. E Hudson Bay/James Bay	6,600	1,864-3,874	199-203[4]	5.1-10.9	9,10	D
6. W, S and N Hudson Bay	--	25,000[5]	431-9[6]	1.7	11	A
7. St. Lawrence R.	5,000	500	0	0	12,13	E
Alaska (USA)						
8. Cook Inlet	--	300-400	10-15[7]	2.5-5.0	14	E
9. Bristol Bay	--	1,000-1,500	7-9[8]	0.5-1.0	2,15,16	C
10. Norton Sound/Yukon Delta	--	2,000[9]	155-181[8]	?	2,15,16	?
11. E Chukchi Sea	--	2,500-3,000	91-94[8]	3.0-3.8	2,15,16	?
USSR						
12. Anadyr Gulf (Bering Sea)	--	2,000-3,000	low	low	17	C
13. Sea of Okhotsk	--	25,000-30,000	low	low	18	A
14. E Siberian (W Chukchi and E Siberian Seas)	--	2,000-3,000	150[10]	5-7.5	19,20	?
15. W Siberian (Barents, Kara and Laptev Seas)	--	7,000-10,000	?	?	17	?
16. White Sea	--	500-1,000	?	?	17	?

[1]Based on cumulative catches, to be regarded as minimum estimates of pre-exploitation population size.
[2]Assumes an average catch of 123 per year in Mackenzie Delta, 1985-89, corrected on the basis of 1 killed and lost for 4 landed (ref. 21), giving an estimated total kill (ETK) of 151. Assumes an average catch of 43 (40-46) in Alaskan waters, 1987-90 (Table 4), corrected on the same basis as in Ref. 2:table 5, giving an ETK of 81.
[3]Assumes an average catch of 813 per year in West Greenland (Table 2, 1975-85); corrected on the basis of a 25% loss rate (1 killed and lost for 3 landed) (ref. 5), giving an ETK of 1084. Assumes an average catch of 87 per year in Canada, 1974-87 (Table 3); corrected on the basis of a 25% loss rate, giving an ETK of 116.
[4]Assumes that 40% of the catch in Hudson Strait and 100% of the catch on the east side of Hudson Bay is from this stock (Table 3). A loss rate of 30% of the total kill is applied arbitrarily.
[5]Combines estimates for west, south and north Hudson Bay (ref. 11).
[6]Assumes that 60% of the catch in Hudson Strait and 100% of the catch in western and northern Hudson Bay is from this stock (Table 3; and see text). A loss rate of 30% of the total kill is applied arbitrarily.
[7]Based on total kill estimate of 10 (ref. 14) and secured catch estimate 10-12 (ref. 15).
[8]Catches from Table 4, corrected for hunting loss by ETL:ETK ratio of Ref. 2:Table 5. Norton Sound loss rate may have declined in recent years with the use of aeroplanes to locate animals that sink during the hunt (ref. 21).
[9]Considered to include Kuskokwim Delta. Population estimate is not based on survey data; a single sighting of more than 2000 white whales was made near the mouth of the Yukon River in 1956 (ref. 21)
[10]Based on a guesstimate for the total annual kill at or near Sireniki in the mid-1980s (ref. 20).

References: 1. Davis and Evans (1982), 2. Lowry *et al.* (1989), 3. Reeves and Mitchell (1987c), 4. Smith *et al.* (1985), 5. Heide-Jørgensen (1990), 6. Mitchell and Reeves (1981), 7. Richard (1991), 8. Reeves and Mitchell (1987b) and Anonymous (1987), 9. Smith and Hammill (1986), 10. Reeves and Mitchell (1987a), 11. Richard *et al.* (1990), 12. Reeves and Mitchell (1984), 13. Sergeant and Hoek (1988), 14. Hazard (1988), 15. K.J. Frost (*in litt.* to Reeves, 1 April 1991), 16. Frost and Lowry (1990), 17. Yablokov (1979), 18. Ivashin (1990), 19. Ivashin (1988), 20. Burns and Seaman (1985), 21. K.J. Frost (*in litt.* to Reeves, 1 May 1991).

Hudson Bay in previous IWC reports) and St. Lawrence River. There is considerable uncertainty about the relations among the groups of whales in Hudson Bay and adjacent waters (Richard *et al.*, 1990). The delineation of stocks based on body size differences (Sergeant and Brodie, 1969) has been found by Doidge (1990) to be less useful for some stocks than was thought previously. However, white whales in Hudson Bay are consistently smaller than those in other areas studied. Preliminary attempts to use mitochondrial DNA markers to distinguish white whale stocks suggested that white whales in eastern Hudson Bay are distinct from those in the Mackenzie Delta, western Hudson Bay, Cumberland Sound and Jones Sound (Helbig *et al.*, 1989). The Beaufort Sea-Mackenzie Delta stock is shared with Alaska (USA) and possibly the USSR; the High Arctic stock probably with Greenland.

The winter and spring distribution of the Hudson Bay, Ungava Bay and SE Baffin populations is centred in Hudson Strait, the Labrador Sea and Davis Strait (Boles, 1980; Finley *et al.*, 1982; Richard and Orr, 1986), although some white whales overwinter in Hudson and James bays (Reeves and Mitchell, 1989a). Whales from several stocks may have a common wintering area. Those that summer in the Canadian High Arctic and off northwest Greenland probably winter primarily along the east side of Baffin Bay and Davis Strait in open water or unconsolidated pack ice. Some winter in the Baffin Bay North Water (Vibe, 1950; Freeman, 1968; Finley and Renaud, 1980).

Alaska (USA)

Four provisional management stocks are recognised in Alaskan waters, in addition to the Beaufort Sea-Mackenzie Delta stock shared with Canada. These are the Cook Inlet, Bristol Bay, Norton Sound-Yukon Delta and eastern Chukchi Sea stocks (Hazard, 1988; Lowry *et al.*, 1989). All the populations except the one in Cook Inlet are believed to winter mainly in the Bering Sea. The evidence for stock differences is mainly the discontinuity of summer distributions (Lowry *et al.*, 1989; Frost and Lowry, 1990). Burns and Seaman (1985) have argued that all the 'stocks'

that winter in the Bering Sea comprise a single genetic population, although no direct genetic evidence is available to evaluate this argument.

USSR

White whales are widely distributed along the Soviet Arctic coast, and they have been exploited intensively in many areas (Ivashin and Mineev, 1981; Ognetov and Potelov, 1984). The estuaries of all the major rivers along the coast of Siberia are said to be visited by white whales in summer. Yablokov (1979) proposed eight stocks in Soviet waters, as follows: White Sea (2), West Siberian (Barents-Kara-Laptev seas) (2, possibly 3), East Siberian (Chukchi-East Siberian seas), Anadyr Bay (Bering Sea) and Sea of Okhotsk (2). Berzin *et al.* (1986) showed major concentrations in three areas of the Okhotsk Sea: Sakhalin-Amur, Shantar and the northern bays (Gizhiginskaya and Penzhinskaya). Five stocks are provisionally listed in Table 9, pending a more detailed justification for subdividing them.

The East Siberian and Anadyr Bay stocks probably winter mainly in the Bering Sea, where they could mix with whales belonging to the Alaskan stocks (Burns, 1984; Burns and Seaman, 1985; Hazard, 1988). Some white whales overwinter in offshore areas of the Barents, Chukchi and probably Kara seas (Belikov *et al.*, 1990).

PROBLEMS AND CATCH STATISTICS

Greenland

Preliminary summaries of white whale catch statistics for Greenland have been published by Kapel (1977; also see Kapel *in* Reeves and Mitchell, 1987b). Reported secured catches for 1975–87 are summarised in Table 10. These are consistent with the estimate of recent annual catches of 500–1,000 by Heide-Jørgensen (1990). The completeness and reliability of the Greenland catch statistics has declined in recent years as fewer hunters have participated in the reporting scheme (E.W. Born, *in litt.* to Reeves, 3 October 1985; Heide-Jørgensen,MP, 1990). The reporting system is no longer functioning reliably. High catches have been made in some years at *savssats* (ice entrapments) in Disko Bay (e.g. about 500 in February 1990 – M.P. Heide-Jørgensen, pers. comm. to Reeves, 30 April 1991). Most of the Greenlandic catch of white whales (except for *savssats*) is made in the drive fishery in Upernavik district (Heide-Jørgensen, 1990).

The demand for white whale muktuk and meat in Greenland is strong and likely to grow along with the human population. Although much of it is consumed in the villages after being shared according to local customs, some is also sold for resale in urban centres (Dahl, 1989). There are no catch limits. Local regulations and customary rules govern some aspects of the hunting (Dahl, 1990; Qujaakitsoq, 1990), but these may not be adequate in the light of changing hunt technology and consumption patterns (Dahl, 1990; Heide-Jørgensen, 1990).

Canada

White whales are protected from commercial hunting under the Beluga Protection Regulations (Fisheries Act) introduced initially in 1949 and amended many times since (Reeves and Mitchell, 1989b; Department of Fisheries and Oceans, 1990a). The St. Lawrence stock was given full protection from exploitation in 1979 and a quota of 40 whales per year (secured catch; no allowance for hunting loss) was set for Pangnirtung in Cumberland Sound in 1980. The reported catch since 1980 at Pangnirtung has exceeded the quota in some years (Richard and Orr, 1986; Cosens *et al.*, 1990). White whale products cannot be exported from the Northwest Territories (NWT) but are traded or sold within the NWT. Some is shipped to urban centres where it is sold (Reeves, unpubl. data).

Prior to 1975, there was no monitoring or reporting of catches in northern Quebec (primarily East Hudson Bay – James Bay, West-North and South Hudson Bay and Ungava Bay stocks in Tables 9 and 11). Estimates of secured catches in 13 northern Quebec communities were derived from 'harvester recall' surveys and a self-monitoring programme begun in 1975 (Boulva, 1981; Usher and Wenzel, 1987). The introduction of regular reporting from northern Quebec in the mid-1970s may give the impression of a dramatic increase in the total Canadian white whale catch, but there is no reason to believe that

Table 10

Reported white whale catches in Greenland, 1975-87, from IWC Denmark progress reports. For previous years, see Kapel (1977). Note that figures listed for 1983-85 are estimates which include an allowance for unreported catches (but not for hunting loss). The figures for 1986 and 1987 are incomplete and preliminary.

	Year												
Area[1]	75	76	77	78	79	80	81	82	83	84	85	86	87
West Greenland													
N Greenland	-	50/yr[2]	-	20	25	30	76	127	53	21	190	?	?
NW Greenland	169	89	289	148	272	291	438	346	252	348	194	244	563
CWe Greenland	105	154	108	231	195	210	198	200	100	158	50	?	?
CWw Greenland	163	799	271	221	184	202	142	113	94	194	127	114	29
SW+S Greenland	167	120	122	99	65	156	163	108	102	42	50	2	14
Total	654	1212	840	719	741	889	1017	894	601	763	611	378	606
East Greenland													
Ammassalik	2	1	1	0	0	0	0	5	0	0	0	15	76
Scoresbysund	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2	1	1	0	0	0	0	5	0	0	0	15	76

[1]For communities assigned to each area, see Kapel (1977). [2]Annual estimate - Kapel (1983).

Note: The relatively large catches assigned to Ammassalik in 1986-87 are in error. (M.P. Heide-Jørgensen, pers. comm. to Reeves, 30 April 1991). West Greenland catches for 1988-90, as estimated by the Greenland Fisheries Research Institute, are: West Greenland - 275 in 1988, 457 in 1989 and 1,000 in 1990.

catches in northern Quebec were much different immediately before 1973–74 than since then.

A confounding aspect of the catch statistics for settlements along the coasts of northern Hudson Bay and Hudson Strait is that more than one management stock uses these areas (Finley *et al.*, 1982; Anonymous, 1987a; Richard *et al.*, 1990). Attempts to prorate catches and assign them to the different stocks are made difficult by the lack of an easily applied genetic, morphometric, behavioural or other marker.

Statistics on catches of white whales in Canada before 1972 are imprecise and incomplete. In 1972 the federal Department of Fisheries and Oceans assumed responsibility for compiling information on white whale catches (Kemper, 1980; Usher and Wenzel, 1987). Before then, the compilation of such data was idiosyncratic or unreliable. The pre-1972 data (e.g. as reported in *International Whaling Statistics* – see Reeves and Mitchell, 1987b; Strong, 1989) should be discounted or interpreted cautiously, particularly in evaluating year-to-year variability or trends through time. Although a more systematic effort has been made since 1972 to document the white whale harvest (Table 11; Strong, 1989), the problem of incomplete reporting of landed catches remains in some areas (Usher and Wenzel, 1987).

Before Canada's withdrawal from the IWC, catches of white whales and other whales were reported and published annually in the Canadian progress reports. Although a progress report has continued to be compiled and submitted annually to the IWC (Department of Fisheries and Oceans, 1990b) the most recent published report was in 1984 (Goodman, 1984). Catches are included in the Tables of reported catches worldwide published each year as part of the report of the sub-committee on small cetaceans (e.g. IWC, 1989).

Alaska (USA)

The quality and regularity of Alaskan catch statistics have improved over the past 15 years (see Seaman and Burns, 1981; Feldman, 1986; Hazard, 1988; Lowry *et al.*, 1989). K.J. Frost (*in litt.* to Reeves, 1 April 1991) reports good cooperation with hunters in obtaining accurate catch statistics for recent years (Table 12). Because of the improved reporting, comparisons of catch levels through time should be made with caution.

USSR

Catch figures provided by the USSR are difficult to interpret because little information is available concerning the hunting methods, effort, product utilisation etc. The official catch totals (e.g., Ivashin and Mineev, 1981; IWC progress reports e.g. Ivashin, 1986) presumably reflect mostly or entirely commercial catches. The totals given by Ivashin and Mineev (1981) are separated into a vessel catch in the western areas and a shore-based catch in all areas. Catches by aborigines and others for subsistence, if they occur (cf. Ivashin and Shevlyagin, 1987), may be under-reported or unreported. Burns and Seaman (1985) referred to a report received in 1985 that 25–30 white whales were taken annually at Sireniki, on the southeast coast of Chukotka. The same source confirmed that although white whales are occasionally hunted at other localities in the Bering and Chukchi seas, the average number taken is very low. The opportunistic hunt at a *savssat* in the Bering Strait region in winter 1984–85 resulted in a catch of 506 whales and an estimated 500 more dead due to 'hunger, lack of air and injuries' (Ivashin and Shevlyagin, 1987). After reviewing available information, Burns and Seaman (1985) concluded that the Soviet harvest in the Bering and Chukchi seas was on the order of 60 white whales per year in the mid-1980s. They considered it likely that 60% of the whales killed were lost (see below), indicating a total kill of about 150 per year.

Berzin (1981) implied that commercial hunting for white whales ended in the Soviet Bering and Okhotsk seas in 1963. However, the table of catches published by Ivashin and Mineev (1981) shows no catch for the Bering Sea from 1960 to 1972, then a total catch of 160 between 1973 and 1980. For the Okhotsk Sea, it shows no catch from 1960 to 1963, then a total catch of 293 between 1964 and 1969 and no catch from 1970 to 1980. Commercial catching apparently continued in the White and Kara seas through the mid 1980s (Table 13). Yablokov's (1979) summary of annual catches in Soviet waters, apparently referring to the

Table 11

Reported catches of white whales in Canada, 1974-87. See note for communities included within each statistical area.

	Year													
Area	74	75	76	77	78	79	80	81	82	83	84	85	86	87
W Arctic[1] (Beaufort Sea/ Mackenzie Delta)	128	154	154	148	129	144	85	155	126	86	142	129	157	144
E High Arctic[1]	144	60	58	61	48	86	16	158	101	106	123	121	75	58
SE Baffin[1]	200	80	171	204	93	107	74	105	66	44	51	72	65	110
Hudson Strait[2]	277	327-429	229	314	158	153	195	158	216	228	170	142	74	
Ungava[2]	92	130-163	184	194	37-38	78	60	79	58	43-45	29	32	42-44	
E Hudson Bay[2]	119	126-139	143	181	118-124	211	220	61	73	69	97	62	32-33	
W+N Hudson Bay[1]	164	94	152	191	112	105	137	211	158	196	324	263	238	238

Note: W Arctic - Aklavik, Inuvik, Tuktoyaktuk, Paulatuk, Holman; E High Arctic - Clyde River, Coppermine, Pond Inlet, Arctic Bay, Grise Fiord, Resolute, Creswell Bay, Spence Bay, Hall Beach, Igloolik, Pelly Bay; SE Baffin - Pangnirtung, Iqaluit, Lake Harbour, Broughton Island; Hudson Strait - Cape Dorset, Ivujivik, Salluit, Kangiqsujuaq, Quaqtaq; Ungava - Kangirsuk, Aupaluk, Tasiujaq, Kuujjuaq, Kangirsualujjuaq, Killiniq; E Hudson Bay - Sanikiluaq, Kuujjuarapik, Umiujaq, Inukjuak, Povungnituk, Akulivik; W and N Hudson Bay - Churchill, Eskimo Point, Whale Cove, Rankin Inlet, Chesterfield Inlet, Repulse Bay, Coral Harbour.

[1]Strong (1989), [2]Reeves and Mitchell (1989b)

1970s, indicated: 100–300 along Kanin Peninsula in trap nets; 10–15 in Onega Bay and other parts of the White and Barents seas by rifle; 200–400 in trap and gillnets and 20–50 by rifle in the Kara and Barents Seas (Yenisey and Pyasina bays); 100 or less in the Laptev, East Siberian and Chukchi seas by rifle; 20–50 in the Bering Sea by rifle; and 100 or less in the Sea of Okhotsk in seines. The total annual catch in all areas of the USSR, according to Yablokov (1979), was 550–1,015.

According to Ivashin and Mineev (1981), the commercial exploitation of white whales is regulated by catch limits, although for unstated reasons the quotas have almost always been higher than the actual catches.

Table 12

Recent landed catches of white whales in Alaska (AIBWC via K.J. Frost, in litt. to Reeves, 1 April 1991). For data from earlier years, see Seaman and Burns (1981) and Lowry *et al.* (1989). Frost (in litt. to Reeves, 1 April 1991) considers the data for 1987-90 the most complete ever available for Alaska.

Year	Beaufort[1]	E Chukchi	Norton Sd/ Yukon Del.	Kusko-kwim Del.[2]	Bristol Bay	Cook Inlet
1987	31-52	78	60-68	3-5	6	8-10
1988	67	69	200-223	13-20	5-10	12-13
1989	26-30	48-53	141-169	12	6	11-13
1990	34-35	99	85-101	0	4	10-12
4/yr ave.:	40-46	74-75	122-140	7-9	5-7	10-12

[1]Taken from the same stock as those reported for Canadian Western Arctic (Table 11).
[2]Could belong to either Norton Sound/Yukon Delta or Bristol Bay stock.

Table 13

Reported white whale catches in the USSR, 1960-88, from Ivashin and Mineev (1981) and IWC USSR progress reports. WBK - White, Barents and Kara Seas (vessel fishery); Yen - Yenisey Gulf (Kara Sea); White - White Sea; Bar - Barents Sea; Ch - Chukchi Sea; Bering - Bering Sea; Okhotsk - Okhotsk Sea; B + K - Barents and Kara Seas; Kara - Kara Sea.

	Area								
Year	WBK	Yen	White	Ch	Bering	Okhotsk	Bar	B+K	Totals
1960	2,382	324	840						3,546
1961	1,732	319	18						2,069
1962	1,143	314	21						1,478
1963	1,030	254	223						1,507
1964	2,322	253	662			94			3,331
1965	1,510	929	297			6			2,742
1966	905	35	609			35			1,584
1967		608	166						774
1968		56	30			101			187
1969		43	167			57			267
1970		67	850						917
1971		53	458						511
1972		36	518						554
1973		42	155	4	15		197		413
1974		24	146	2	17		9		198
1975		74	91						165
1976		170	302		21		38		531
1977	457	64	215		29				765
1978		19			32				51
1979		74	179		26				279
1980	60	81	75		20				236
1981									-
1982			139		53		13	73 *	278
1983			24		12		2	183 *	221
1984					33		1	300 *	334
1985			110		506	29		74 **	719
1986			172		3		3		178
1987			27		3		4		34
1988			3		5				8
	11,541	3,839	6,497	6	775	322	267	640	23,877

* Barents + Kara; ** Kara only.

Hunting loss in all areas

Estimated loss rates for white whale hunting in Greenland ranged from 14 – 19% in West Greenland south of Thule and were less than 10% for the Thule district (IWC, 1980c:appendix 4). Set nets used in Upernavik for catching white whales (Kapel, 1985) presumably cause few losses. Communal hunts using boats to drive whales or trap them in shallow water before killing them with rifles (as described by Oldendow [1935] and Dahl [1990] for the Disko Bay area and by Heide-Jørgensen [1990] for Upernavik district) also may result in relatively small losses. On the other hand, the winter and spring hunting over deep water (at *savssats* or along an ice edge) results in substantial hunting loss (Kapel, 1977). 'As a preliminary figure an overall loss rate of 25% seems reasonable for white whales' (Heide-Jørgensen, 1990).

Seaman and Burns (1981; also see IWC, 1980c, Appendix 5) reported much higher losses for white whales killed in deep water, such as when they are hunted by seal or bowhead hunters during spring, than for those killed in shallow coastal water during open-water hunts. They estimated loss rates of 60% for deep-water hunting and 20% for shallow water hunting. Their estimated total kills were based on the assumption that for all parts of Alaska, one-fourth to one-third of the white whales are taken in deep water and two-thirds to three-fourths in shallow water. Lowry *et al.* (1989) provided estimates of loss rates on a finer scale than that of Seaman and Burns (1981). They considered losses in nets (some set deliberately to catch white whales, others intended mainly to catch fish, with white whales being caught incidentally) to be negligible. Also, they estimated the loss rate for open-water hunting from boats in areas with deep, muddy water (e.g., the Yukon-Kuskokwim Delta and Bristol Bay) to be 40%. In estimating catches throughout Alaska, Lowry *et al.* (1989) applied appropriate loss rates to each harvesting situation. However, it should be noted that the loss rates applied by Burns and Seaman (1981) and Lowry *et al.* (1989) were somewhat subjective.

According to K.J. Frost (*in litt.* to Reeves, 1 May 1991) the loss rate of 20% for shallow-water hunting in parts of the eastern Chukchi Sea and Northern Sound is probably too high, particularly since small aeroplanes have been used in recent years to search these areas after the hunt to find any animals that were killed but not secured. She suggests 10% as a more appropriate estimate.

For the Mackenzie Delta, Fraker (1980) reported estimates by hunters of loss rates (percentage of killed whales that were not secured) of 32% (1973) and 27% (1977). Fraker suggested that Hunt's (1979) estimate of a 40% loss rate in the Mackenzie Delta hunt included an allowance for injured animals that escaped but eventually died from their wounds (c.f. Brodie, 1981). Fraker considered a loss rate of 33% appropriate for correcting catch statistics for this area. More recent monitoring of the Mackenzie Delta hunt has resulted in loss rate estimates of 20 to 38% of the landed catch (Strong, 1990; Weaver, 1991). Weaver (1991) attempted to account for orphaned calves by noting the number of lactating females taken, then counting their calves part of hunting mortality. The

Fisheries Joint Management Committee has funded systematic collection of data on harvest and loss in recent years. For 1985–89 the average catch was 123 (116–133) and the average number struck and lost was 28 (17–38); this would suggest 1 whale lost for every 4 landed (Alaska and Inuvialuit Beluga Whale Committee, via K.J. Frost, *in litt.* to Reeves, 1 May 1991).

For the SE Baffin region, during hunts monitored both in and outside Clearwater Fiord, the main hunting area, in 1982–84, only one instance was reported of a white whale being killed but lost (by sinking) (Orr and Richard, 1985). Most killed whales floated and thus were relatively easy to secure (c.f. Brodie, 1981). Burns and Seaman (1985) queried Orr and Richard's conclusion, noting

> 'In our experience, whales that sink before being harpooned or speared, would not be seen unless they were subsequently grappled, or floated to the surface, usually a day or more after death.'

Richard and Orr (1986) noted that losses were higher in hunts conducted in and near Cumberland Sound outside Clearwater Fiord. The overall loss rate for this stock may be in the order of 10–30% of the total kill (Richard, 1991a).

No data are available for the USSR. In areas where trap and gillnets have been used to capture white whales (e.g., White, Barents, and Kara seas – Yablokov, 1974; 1979; Mitchell, 1975a), the loss rate presumably has been low. However, in those areas where the whales are hunted with rifles, hunting loss must be significant (cf. Burns and Seaman, 1985; see above).

POPULATION ESTIMATES

Greenland

No independent estimate of population size for white whales in Greenlandic waters is available. Heide-Jørgensen (1990) considered the estimate by Smith *et al.* (1985) for the Canadian High Arctic stock as applicable to West and North Greenland, on the still unproven assumption that the whales found as far west as Peel Sound and Barrow Strait in summer migrate east and south in the fall to winter off West Greenland. McLaren and Davis (1981; 1982) surveyed a large area of northern Davis Strait and southern Baffin Bay in March 1981. They estimated that about 2,400 white whales were present in waters south of 70°N, north of 66°N and east of 55°30′W; their estimate made no allowance for animals that were submerged or under the ice. Surveys in 1990 and 1991 of the same area using similar methods revealed an approximately 40% decline in the number of white whales present (M.P. Heide-Jørgensen, pers. comm. to Reeves, 30 April 1991).

Canada

The stock summering in the Mackenzie Delta and eastern Beaufort Sea has been estimated recently at 11,500 (Davis and Evans, 1982).

A detailed reconstruction of the catch history in western Hudson Bay and Foxe Basin revealed no pattern of intensive exploitation and depletion that could be used for a cumulative catch estimate (Reeves and Mitchell, 1989a). The highest documented kill for any decade before 1949, when the commercial white whale processing plant at Churchill began operations, was somewhat less than 1,600 whales taken at York and Churchill, combined, in the 1880s. Richard *et al.* (1990) estimated the white whale population in western Hudson Bay as more than 23,000 in 1987. They also estimated summering populations in northern Hudson Bay of more than 700 and southern Hudson Bay of more than 1,300. These three areas have been treated as a single stock area in Table 9.

Cumulative catches indicate a minimum population in southeastern Hudson Bay (mainly summering in the Great Whale and Little Whale river estuaries) of 6,600 in the 1850s (Reeves and Mitchell, 1987c). Aerial surveys in summer 1985 produced current estimates of 1,123 (95% confidence limits 740–1,970) in James Bay and 1,124–1,904 (offshore estimate plus estuarine count) in eastern Hudson Bay south of 59°N (Smith and Hammill, 1986). The totals for southeastern Hudson Bay and James Bay are combined for an estimate of the East Hudson Bay – James Bay stock (Table 9).

At least 800–1,000 white whales summered in southern Ungava Bay during the 1870s (Reeves and Mitchell, 1987a). Systematic and coastal reconnaissance aerial surveys of Ungava Bay in the late 1970s and early 1980s suggested a remnant population of less than 50 (Finley *et al.*, 1982; Smith and Hammill, 1986).

At least 5,000 white whales summered in Cumberland Sound (SE Baffin stock) in the early 20th century, judging by the catches made in this area (Reeves and Mitchell, 1981). The most recent estimate of population size, based on aerial photographic surveys in 1985–86, is less than 500 (Richard *et al.*, 1990).

Alaska (USA)

Population estimates for all Alaskan coastal stocks were provided by Hazard (1988) and Lowry *et al.* (1989) (see Table 9). Additional surveys summarised by Frost and Lowry (1990) and Frost *et al.* (1991) gave no reason to change the earlier estimates. Surveys planned for 1991 should provide additional data for Cook Inlet and the eastern Chukchi Sea. It should be noted that there is no recent basis for the Norton Sound/Yukon Delta stock estimate; this area has never been properly surveyed for white whales (K.J. Frost, *in litt.* to Reeves, 1 May 1991).

USSR

Yablokov (1979) stated that there were no good census data from Soviet Arctic waters. He guessed that some 1,000–2,000 white whales summered in the East Siberian and western Chukchi Seas and some 2,000–3,000 in the Soviet Bering Sea. Burns (1984) assumed that at least 3,000–4,000 white whales were present in summer in offshore waters of the western Beaufort, northern Chukchi and East Siberian seas and that another 6,000-8,000 were present in coastal waters along the Asian sides of the Chukchi Sea, Bering Strait and Bering Sea, including Wrangel Island (Burns and Seaman, 1985). Gaev *et al.* (1987), as summarised by Ivashin (1990) claimed that white whales were rare in coastal waters around Wrangel Island, although Berzin (1981) cited reports of migrating herds of up to 500 white whales seen southeast of Wrangel Island in October 1960. An estimated 2,500–3,000 white whales became trapped in ice in Senjavin Strait along the eastern coast of Chukotka in December 1984 (Ivashin and Shevlyagin, 1987)

Results of aerial surveys in 1987 suggested a Sakhalin-Amur population of not more than 7,000–10,000 white whales (Popov, 1990). In addition, it was estimated that there were 3,000–5,000 white whales in the Shantar Islands area in 1987 and roughly 15,000 in the northern Sea of Okhotsk. Thus, the total estimated current population in the Okhotsk Sea is 25,000–30,000. However, the reliability of this estimate is uncertain.

Ognetov and Potelov (1984) referred to observations of a few hundred to several thousand white whales in different areas of the Kara Sea at different times, but they gave no recent population estimate for the Kara Sea stock. Judging by the large commercial catches summarised by Kleinenberg *et al.* (1968) for the Kara Sea in the 1930s (1,922 in Yenisei and Pyasina bays from 1930 to 1936; 2,092 in the Gulf of Ob from 1931 to 1935) and 1950s (743 near Dickson Island from 1953 to 1958), the Kara and Barents seas combined in the 1950s (3,664 from 1953 to 1959 by vessels of the Arkhangel'sk and Tyumen Sovnarkhozes) and near Svalbard by Norwegian vessels after World War II (3,407 from 1945 to 1960 [Lønø and Øynes, 1961]), the West Siberian stock must have been very large historically. Yablokov (1979) estimated current stock sizes of 500–1,000 for the White Sea and 7,000–10,000 for the Barents-Kara-Laptev Seas.

ASSESSMENT AND STATUS

In general, white whale stocks can be assigned to five categories: (A) large (3,000+) and lightly or sustainably exploited; (B) large and exploited at rates that give cause for concern; (C) medium (500–3,000) and lightly or sustainably exploited; (D) medium and exploited at rates that give cause for concern; (E) small (500 or less) and vulnerable to hunting or habitat deterioration. Of the 16 stocks tentatively identified (Table 9), at least 3 are in category A, 1 in B, 2 in C, 2 in D and 4 in E.

Greenland

Using annual estimates of 875–1,500 whales killed from a population of 6,300–18,600 whales (Smith *et al.*, 1985), and citing estimates of permissible exploitation rates of 2% for white whales (IWC, 1984b) and 3–4% for narwhals (Kingsley, 1989), Heide-Jørgensen (1990) concluded that the Canadian High Arctic-West Greenland white whale population is being exploited at a level above sustainable yield. White whales have virtually disappeared from the southern districts of West Greenland where large catches were made in the 19th and early 20th centuries (Kapel *in* Reeves and Mitchell, 1987b). Catches listed for South and Southwest Greenland in recent years (Table 10) indicate mainly catches made by hunters who travelled to the more northern districts for hunting (M.P. Heide-Jørgensen, pers. comm. to Reeves, 30 April 1991).

Three factors that may cause white whale catches in Greenland to increase are: the high and increasing price of muktuk, the improved technology for hunting white whales and transporting muktuk, and the expansion of freezer facilities allowing preservation of muktuk in most settlements (M.P. Heide-Jørgensen, pers. comm. to Reeves, 30 April 1991).

Alaska

Major reviews of the status of white whales in Alaskan waters have been published recently (Seaman and Burns, 1981; Hazard, 1988; Lowry *et al.*, 1989; Frost and Lowry, 1990). The Beaufort Sea/Mackenzie Delta stock shared with Canada is not considered to be in jeopardy at present (see below). Of the other four provisional stocks in Alaska, the Norton Sound-Yukon Delta stock is of greatest concern because there is no reliable stock estimate and there are substantial removals. For the other three, the stock estimates are far more current and reliable and harvest levels have been relatively stable in recent years (Lowry *et al.*, 1989; Frost and Lowry, 1990)

Aerial survey results, hunter information and reduced catch levels have been interpreted to indicate a decline in the use of southeastern Kotzebue Sound by white whales (eastern Chukchi Sea stock) (Lowry *et al.*, 1989; Frost and Lowry, 1990). Local informants have suggested that boat traffic, noise and other disturbances (Burns and Seaman, 1985; Frost and Lowry, 1990) have contributed to this decline in local availability of white whales. When this migratory stock has been surveyed farther north off Point Lay, there has been no indication of a substantial change in numbers between 1979 and 1990 (Frost and Lowry, 1990; Frost *et al.*, 1991).

Frost and Lowry (1990) concluded that the Bristol Bay stock is stable at or near its historical size. The Cook Inlet stock has been small (a few hundred) for a considerable time (at least 25 years) (Hazard, 1988).

The Alaska and Inuvialuit Beluga Whale Committee (AIBWC) was established in 1988 with the objectives of conserving white whales and their habitat and preserving traditional white whale hunting in Alaska and the western Canadian Arctic. A draft management plan has been published (Anonymous, 1990b). This plan includes provisions for ensuring full reporting of catches (including struck but lost whales), reduction of hunting loss and monitoring of populations. Harvest levels are to be based on 'the number of animals in the populations and cultural and nutritional needs.'

Canada

Exploitation of the Beaufort Sea stock within Canadian waters is managed under the Inuvialuit Final Agreement of 1984, which entrenches the preferential rights of the Inuvialuit to harvest white whales and to sell or barter the products of the harvest to other beneficiaries of the claim, and commits the Canadian federal government to a process of joint management with the Inuvialuit (Anonymous, 1984). The Inuvialuit are also represented in the AIBWC (see above). Recent reviews have concluded that this stock is large and healthy and that its rate of exploitation is within sustainable limits (Fraker, 1980; Finley *et al.*, 1987; Lowry *et al.*, 1989).

The relatively large Canadian High Arctic population is thought to be shared with Greenland (see Greenland section above). It is expected that problems associated with the management of this stock's exploitation will be a principal concern of the Greenland-Canada Joint Commission on Conservation and Management of Narwhal and Beluga (Lemche, 1991).

A scientific advisory committee within the Canadian Department of Fisheries and Oceans (DFO) stated in its prognosis for the SE Baffin stock:

> 'Pre-exploited' stock size is irrelevant to the current management decisions because unknown ecosystem changes may have altered carrying capacity, and 'historical' levels may no longer be attainable (Cosens *et al.*, 1990).

Rather than using a target level related explicitly to the minimum estimated pre-exploitation population size of 5,000, the committee recommended a target level of 'a few thousand (e.g. 3,000), to provide an adequate buffer from ... natural hazards.' To achieve the objective of allowing this limited recovery, the committee recommended complete closure of the white whale hunt in Pangnirtung and Iqaluit and a closed season from June to October in Lake Harbour. In addition, it recommended that the stock not be allowed to fall below its current level of 400–500 in the late 1980s. Richard (1991a) has predicted that continued hunting could extirpate the stock in less than a

decade. However, the expected decline in the population due to hunting removals of around 100 per year during the 1980s apparently did not occur. Results of aerial photographic surveys in August 1990 were similar to those of surveys conducted in 1979–82 (Richard and Orr, 1986; P. Richard, pers. comm., 22 April 1991). In 1990, following a decision of the Nunavut Wildlife Management Board, DFO introduced annual quotas of 5 white whales each for Iqaluit and Lake Harbour and reduced the quota for Pangnirtung from 40 to 5 whales (Department of Fisheries and Oceans, 1990a; Richard, 1991a). This change provoked much controversy (e.g., Amagoalik, 1990; Anonymous, 1990b; Tinling, 1990), and the hunters in Iqaluit claimed to have taken about 60 and those in Pangnirtung more than 40 white whales in the 1990 season (Smellie, 1990a; b). The matter of SE Baffin white whale stock assessment has been referred within Canada to an independent committee for re-evaluation.

The Ungava Bay stock is severely depleted, and its conservation and recovery are a high priority (Anonymous, 1987a; Reeves and Mitchell, 1989b). Exploitation has continued in recent years (Table 11; Department of Fisheries and Oceans, 1990b), regulated at least to some degree by an informal cooperative agreement between the responsible federal agency and local or regional Inuit groups (Osherenko, 1988). It is unclear whether the community quotas and hunting ban for the Mucalic River (S. Ungava Bay) agreed in 1987 have been effective in reducing the hunting pressure on this stock.

The Eastern Hudson Bay stock is listed as 'threatened' by the Committee on the Status of Endangered Wildlife in Canada (Campbell, 1989; Reeves and Mitchell, 1989b). It continues to be hunted at levels that may exceed replacement yield (Anonymous, 1987a). An important further concern is that major hydroelectric damming and diversion projects are planned for several of the rivers used by white whales in summer (e.g. Great Whale and Nastapoka), and other large-scale industrial developments, including the impoundment of James Bay to supply fresh water to southern states and provinces, is being considered.

With respect to the Western, Northern and Southern Hudson Bay 'stocks'; the question of whether more than one stock should be recognised for the western half of Hudson Bay remains open (Richard *et al.*, 1990). If the whales summering from the Southampton Island area in the north to James Bay in the south are treated as a single population, they comprise a stock of more than 25,000. Approximately 185 white whales were taken per year by hunters in western and northern Hudson Bay (average for 1974–87 – Table 3). Whales from these areas are also hunted in Hudson Strait during autumn, winter and spring (possibly also in Foxe Basin). Arbitrarily attributing 60% of the reported or estimated catch in Hudson Strait to this stock increases the yearly average (1974–86 – Table 11) to 302–07. Applying a loss rate of 30% of the total kill, annual hunting removals in the order of 431 from this 'stock' are suggested. These calculations are necessarily very crude, but it seems safe to conclude that this stock (or these stocks) are in relatively good shape.

USSR

Without better information on population sizes and recent removals, it is impossible to make useful assessments of stocks in the Eurasian Arctic. However, despite considerable variation in the population estimates for the Sea of Okhotsk, the stock or stocks there apparently remain large (certainly in thousands or low tens of thousands). If commercial exploitation has stopped and the subsistence catch is low as implied by available information, there should be no acute conservation problem for white whales in the USSR.

RECOMMENDATIONS

The Scientific Committee (IWC, 1980a) reviewed the status of white whale stocks in 1979 and made the following recommendations as a result.

(1) That the Cumberland Sound (=SE Baffin) stock be given complete protection, that it be censused regularly to estimate population size and gross recruitment, that its relations with 'stocks' in Hudson Strait be examined and that any whales taken (should there be a hunt) be examined and sampled. As demonstrated by the work cited above, considerable effort has been devoted to stock assessment since 1979, and the catch limit has been reduced.

(2) That Canada initiate research on the stock identity and size of white whale populations hunted along the Quebec coasts of Hudson Strait and northeast Hudson Bay. Finley *et al.* (1982), Smith and Hammill (1986), Helbig *et al.* (1989) and Doidge (1990) have reported some of the relevant work conducted since 1979.

(3) That the Canadian High Arctic (summer) and West Greenland (winter) populations of white whales be provisionally managed as one stock and that Canada and Denmark (Greenland) initiate a joint research programme on this stock. Particularly, the Committee called for censuses of white whales summering in Melville Bay-Thule district and Canadian and Greenland waters of Smith Sound and Kane Basin and for analysis of the stock affinities of these whales. The Greenland-Canada Joint Commission on Conservation and Management of Narwhal and Beluga has initiated a research programme on this stock. However, no census of the specified areas has been made.

(4) That more accurate estimates be made of struck-but-lost rates in the white whale hunts of Greenland and Canada. No new data on loss rates in Greenland are available. For Canada, considerable effort has been directed at estimating loss rates in the Mackenzie Delta (Strong, 1990; Weaver, 1991; K. Frost, *in litt.* to Reeves, 1 May 1991).

(5) That the USSR provide all available data on the white whales in the Barents, White, Kara and Laptev Seas and include 'a study of the components of the Barents Sea wintering group and an assessment of the stock or stocks involved.' Some information has become available since 1979 (e.g. Berzin, 1981; Ivashin and Mineev, 1981; Ognetov and Potelov, 1982; 1984; Berzin and Vladimirov, 1986).

(6) That national research programmes on the white whales thought to winter in the Bering Sea be expanded and that a cooperative research programme be instituted by the USA, USSR and Canada. It was expected that such programmes would include documentation of catch statistics, loss rates and characteristics of the hunt and collection of biological samples for determination of vital parameters. Also, 'the temporal and spatial components of the populations should be determined, the populations censused and the inter-relationships among them identified.' No cooperative programme has been

established with the USSR to date. Several cooperative efforts between Canada and Alaska have been initiated and include sharing of harvest information, collection of samples for stock identification and vital parameters and planning further census efforts. Surveys will be conducted of the Cook Inlet and eastern Chukchi Sea stocks in 1991.

(7) That the white whale be defined as a 'whale' and listed in the IWC schedule 'so that appropriate management procedures may be discussed and implemented in the future.' No action has been taken with respect to the later part of this recommendation.

(8) That Canada provide complete catch statistics for Manitoba, Ontario and Quebec. Reporting for Quebec (mainly East Hudson Bay – James Bay, West-South-North Hudson Bay and Ungava Bay stocks) and Manitoba (West-South-North Hudson Bay stock(s)) has improved substantially over the past decade (e.g., Boulva, 1981; Gamble, 1987a; b; Reeves and Mitchell, 1989b; Strong, 1990). The white whale harvest in Ontario (southern Hudson Bay and James Bay) is negligible.

The substance of these same recommendations was reiterated in 1980 (IWC, 1981). It was noted with reference to No. 1 that a catch limit of 40 had been introduced for the Cumberland Sound stock. However, the Committee recommended that this be reduced to zero. It was noted with reference to No. 3 that the current rate of removals from the Canadian High Arctic-West Greenland stock could be 'too high for the overall population,' and this demonstrated the need for better data on population size, stock relations and removals. With reference to No. 5, it was noted that either the reported catch levels for white whales in the Barents, White, Kara and Laptev Seas (c.f. Ivashin and Mineev, 1981) were substantially above annual gross production or the current population estimates were too low. This problem highlighted the need for abundance estimates for this area.

The Scientific Committee carried out another review of white whale stocks in 1981 (IWC, 1982a, pp. 60, 121–2). The 'responsive and considerable expansion' of studies in Greenland and Canada was noted, and both governments were encouraged to continue this work, giving particular attention to stock identity, migration, abundance, calf production, collection of complete and accurate catch statistics and full collection of age and reproductive samples from the catch. Noting the 'seriously depleted status' of the Cumberland Sound, Ungava Bay and eastern Hudson Bay stocks (Finley *et al.*, 1982) and the importance to the species of 'estuarine calf–rearing grounds', the Committee recommended that all three stocks and their critical habitat be fully protected. The USA and USSR were again urged to initiate field studies to evaluate the stock structure, abundance and status of white whales summering in their waters. With respect to No. 7, the question of adding the white whale to the IWC Schedule, the Committee report noted that most members supported the earlier recommendation.

In 1982, the Scientific Committee noted that the research recommendations made in previous years had been acted upon by the USSR and Canada and that the results of research on population size, productivity and exploitation in the USSR and population size, discreteness, exploitation history and loss rates in Quebec, Hudson Strait, northeast Hudson Bay, the Canadian High Arctic and West Greenland had been reported in progress reports and the SM series (IWC, 1983a, p.161). The Committee reiterated its recommendation that the summer populations in Cumberland Sound, eastern Hudson Bay and Ungava Bay be completely protected. It also called for catch statistics and population assessment from the USA and more nearly complete catch statistics from Canada.

The Scientific Committee made three recommendations in 1982 (IWC, 1983a, p.61):

(1) that white whale catches in Alaska be 'minimised' until the uncertainty about stock identity, stock size, net recruitment and removal rates was removed;
(2) that the three depleted stocks in eastern Canada be given complete protection;
(3) that the USSR make available catch information for its white whale fishery.

In 1984, it was recommended again that the USA collect and report data on catches and loss rates (IWC, 1985, p.136). The AIBWC has been doing this since 1988 and the data are improving each year (K.J. Frost, *in litt.* to Reeves, 2 May 1991). The Alaska Department of Fish and Game reported catch figures for 1980–86 (Lowry *et al.*, 1989).

The sub-committee makes the following new **recommendations**:

(1) that the USA obtain more accurate estimates of stock size for white whales in Alaska, particularly the Norton Sound/Yukon Delta stock for which there is no reliable estimate;
(2) that more accurate and complete information be obtained on struck-and-lost rates for all areas where white whales are hunted and that methods for reducing the number of whales that are struck-but-lost be developed and implemented;
(3) that the USA, USSR, Canada and Greenland conduct genetic studies to determine the stock identity of white whales;
(4) that Greenland conduct an assessment of white whale stocks to serve as a basis for management, and that Greenland report data on white whale catches and loss rates.

The sub-committee welcomed the formation of the Canada-Greenland Joint Commission on Conservation and Management of Narwhal and Beluga and of the Alaska and Inuvialiut Beluga Whale Committee as bilateral initiatives that promise to provide intensified and coordinated research and management of shared stocks.

The sub-committee noted its continuing concern about white whale stocks in Canada that are harvested at rates above their estimated sustainable yield levels.

5.1.2.2 *Monodon monoceros*[3]

COMMON NAMES

Narwhal, *narhval* (Denmark), *killalugaq* (Inuktitut, Baffin Island), *tugalik* (Inuktitut, West Greenland), *qilaluaq qernertaq* (Greenlandic).

DISTRIBUTION

The narwhal's distribution is circumpolar north of about 65°N, but it occurs in much higher densities in Arctic waters adjoining the North Atlantic basin than in those adjoining the North Pacific. Three high-density summering areas have been identified in the eastern Canadian Arctic and off northwest Greenland: Repulse Bay and Frozen Strait, the Lancaster Sound region, and Inglefield Bay (Born, 1986; Strong, 1988). Small groups of narwhals

[3] Initial draft from R. Reeves dissertation in preparation.

summer in many other areas, including Jones Sound, Smith Sound, Melville Bay, western Baffin Bay and Davis Strait, and northern Foxe Basin. Narwhals winter mainly in the open and close pack ice of Baffin Bay and Davis Strait as far south as *ca* 64°N and in the Labrador Sea and Hudson Strait (Kapel, 1977; McLaren and Davis, 1981; 1982; Mitchell and Reeves, 1981; Turl, 1987; Richard, 1991). They rarely occur in the main body of Hudson Bay south of Southampton Island. There are few definite records from eastern Hudson Bay, but narwhals are killed occasionally on the west side of the bay as far south as Whale Cove (*ca* 62°N).

Narwhals occur in many fiords along the east coast of Greenland north from Ammassalik (Dietz *et al.*, 1985). Two offshore areas have been identified in the Greenland Sea where 19th-century whalers consistently observed narwhals, on some occasions in large numbers. These areas are centred west of Spitsbergen at 78–81°N, 05°W-10°E, and off the Greenland coast between latitudes 72–76°N (Dietz *et al.*, 1985). A possible third concentration area was identified off the northeast coast of Greenland at 79–81°N. There is no direct evidence that the narwhals in the Greenland Sea belong to a separate stock from those in Davis Strait, Baffin Bay and Smith Sound.

PROBLEMS AND CATCH STATISTICS

Greenland Sea

The narwhals in the Greenland, Barents and Kara Seas, and in the Arctic basin north of these, were exploited to some degree by European commercial whalers during the bowhead whaling era and by the Inuit of east Greenland. However, this exploitation is believed to have been light in terms of the numbers of animals killed relative to the population size.

Tomilin (1957) estimated the annual catch in Scoresby Sound as 20. Incomplete statistics for east Greenland from 1954–75 indicate annual catches ranging from 2 to 65, with a mean of about 21 (Kapel, 1977). The total reported catch in Ammassalik district during the 1970s was 141 (Dietz *et al.*, 1985). Reported catches increased during the 1980s, averaging 87 per year for Scoresbysund and Ammassalik districts, combined, from 1980 to 1987 (Table 14).

West and North Greenland

Catch statistics are provided through the Greenland Hunters' Lists of Game (Kapel, 1977; 1978; Born and Olesen, 1986; Table 14). Participation in the reporting scheme has declined during recent decades, and this has meant that a higher proportion of the reported catch is estimated rather than being an actual count (E.W. Born, *in litt.* to Reeves, 3 October 1985; Heide-Jørgensen,MP, 1990). An important shortcoming of the statistics has been the lack of reporting for Thule district (North Greenland) and in recent years the entire system of reporting catch statistics for small cetaceans in Greenland has deteriorated. Thule provided reliable estimates of the narwhal catch for only three years in the early 1960s (M.P. Heide-Jørgensen, pers. comm. to Reeves, 30 April 1991). Heide-Jørgensen (1990) estimated the recent annual catch for all of West Greenland, including Thule district, as 200–600. The Greenland Fisheries Research Institute estimated the total catch for West Greenland as 600 in 1989 and 1,200 in 1990.

Canada

Narwhal catches in Canada are underreported for a number of reasons (Finley *et al.*, 1980; Finley and Miller, 1982; IWC, 1982a; Gamble, 1987a). The tag system used to implement the national quota is most effective for monitoring the number of large, unbroken tusks that are sold. It is considerably less effective for ensuring that kills of untusked whales (females, calves and juveniles) and whales with short or significantly damaged tusks are reported. Reported catches during the 1970s and 1980s show no clear trend of increase or decrease (Table 15). The total reported catch in all years has been below the total national quota of 525 (Strong, 1989). The catch in Arctic Bay (as observed by and reported to fisheries field personnel) is strongly biased toward males (Roberge and Dunn, 1990). This bias appears to be less consistent and strong at Pond Inlet (Weaver and Walker, 1988). Discussion of the trade in tusks and other products is given in Appendix 3.

Loss rates

Acknowledging that there are no data for estimating the loss rate directly in Greenland south of Thule district, Born and Olesen (1986) assumed that it was *ca* 20%, similar to the open-water loss rate in Canada. [Born and Olesen cited as their source for the 20% figure an unpublished report by Strong *et al.* (1985) which was published in abbreviated form as Strong (1988).] Most of the hunting south of Thule is done in open water, by shooting first and then

Table 14

Narwhal catches reported in IWC Denmark progress reports. For previous years, see Kapel (1977). Note that figures listed for 1983-85 are estimates which include an allowance for unreported catches (but not for hunting loss).

	Year												
Area[1]	75	76	77	78	79	80	81	82	83	84	85	86	87
West Greenland													
N Greenland	-		150/yr[2]	-	110	120	130	118	164	135	274	115	150/yr[2]
NW Greenland	65	49	175	239	154	207	223	221	236	325	73	178	479
CWe Greenland	0	12	6	100	36	10	10	19	10	10	0	?	?
CWw Greenland	44	45	47	162	64	110	239	57	58	56	67	23	25
SW + S Greenland	7	0	9	1	3	5	19	0	0	1	1	36	1
Total	266	256	387	612	377	462	609	461	439	666	256	387	655
East Greenland													
Ammassalik	10	8	17	1	8	48	128	84	12	15	21	140	42
Scoresbysund	2	16	4	2	10	10	15	15	41	50	28	28	16
Total	12	24	21	3	18	58	143	99	53	65	49	168	58

[1] For communities assigned to each area, see Kapel (1977).
[2] Annual estimate - Kapel (1983).

Table 15

Reported narwhal catches (uncorrected for under-reporting and hunting loss) in Canada, 1974-87 (from Strong, 1989). See note for communities included within each statistical area.

	Year													
Area	74	75	76	77	78	79	80	81	82*	83	84	85	86*	87*
High Arctic	152	266	281	217	233	260	256	272	283	310	189	231	218	110
SE Baffin	-	5	16	38	28	28	68	94	99	23	69	67	38	47
N Hudson Bay/ Hudson Strait	-	-	8	-	6	31	26	40	22	11	27	16	7	24
Totals	152	271	305	255	267	319	350	406	404	344	285	314	263	181

*Strong (1989) considered the data for these years complete.

Note: High Arctic - Clyde River, Pond Inlet, Arctic Bay, Grise Fiord, Resolute, Creswell Bay, Spence Bay, Gjoa Haven, Hall Beach, Igloolik, Pelly Bay; SE Baffin - Broughton Island, Pangnirtung, Iqaluit; N Hudson Bay/Hudson Strait - Lake Harbour, Cape Dorset, Whale Cove, Rankin Inlet, Repulse Bay, Coral Harbour.

harpooning. Losses are low in Thule district, where most of the hunting is done from kayaks in open water, using a harpoon first and then killing with a rifle shot. Approximately 1 whale is lost for 20 landed in the summer hunt in Thule district (IWC, 1980b). Loss rates for hunting at *savssats* are much higher, on the order of 1 whale lost for every 2 landed (IWC, 1980b). Winter-spring hunting in Greenland generally is assumed to involve the loss of approximately 1 whale for every 4 landed (IWC, 1980b).

Nets are set for narwhals in Thule district beginning on 1 September each year. This net fishery apparently began about nine years ago after hunters noted that narwhals frequently entangled in seal nets (M.-P. Heide-Jørgensen, pers. comm. to Reeves, August 1990). The number of narwhals that are netted is unknown, except that it is small, probably less than 20 per year; the loss rate from netting is probably close to nil.

Direct observations of narwhal hunting in Canada have revealed significant hunting loss (Land, 1977; Finley *et al.*, 1980; Finley and Miller, 1982; Weaver and Walker, 1988; Roberge and Dunn, 1990). Cosens *et al.* (1990) cited a range in estimated loss rates (percentage lost of total killed) of 42–56%; thus, the estimated total of removals by hunting would be 1.72–2.27 times the landed catch. The range of 42–56% apparently is based mainly or entirely on data from Pond Inlet, which may not be representative for all catch areas. For example, at Arctic Bay, the estimated loss rates for five years with data (1983, 1986–89) ranged from 20% to 34% (Weaver and Walker, 1988). The secured catch at Arctic Bay is often as high as or higher than that at Pond Inlet (Strong, 1989). In the absence of data on loss rates from other settlements that hunt narwhals, it is impossible to decide which of the two ranges of estimates is more representative. In general, losses are highest during the ice-edge and ice-crack phases of the hunt and lowest during the open-water phase.

MANAGEMENT

In Greenland, the hunting of narwhals is regulated mainly by local legislation (Born, 1986; Qujaakitsoq, 1990).

In Canada, narwhal hunting is regulated under the Narwhal Protection Regulations (Fisheries Act) introduced in 1971 (Strong, 1988). In addition to specifying that females with calves not be hunted, waste be minimised and only high-power ammunition be used, these regulations include a national quota, allocated by community primarily on the basis of historic catch levels. The total quota is 525.

The Canada-Greenland Joint Commission on Conservation and Management of Narwhal and Beluga met for the first time in January 1991 (Lemche, 1991). This commission was established under the terms of a Memorandum of Understanding between the responsible Canadian and Greenlandic government agencies. No decisions on management were made at this session. A Scientific Working Group was charged with reviewing information on potentially shared stocks and providing advice on research and management needs. It was specified in the report that the scientific advisory group should consider knowledge from hunters in the development of its advice to the Joint Commission.

POPULATION SIZE

Greenland Sea

The only estimate is for a small part of the summer range. Larsen (1930) estimated that there were at least 176 narwhals in Scoresby Sound in September 1983, based on an aerial line-transect survey. No correction was made for animals below the surface.

Inglefield Bay

In mid-August 1984, Born (1986) counted 4,043 narwhals passing a clifftop observation site at the head of Inglefield Bay. This provides a minimum estimate for the number of narwhals summering off northwest Greenland. Additional animals apparently summer in Melville Bay (Meldgaard and Kapel, 1981) and in Smith Sound and other areas north of Inglefield Bay (Vibe, 1950).

Baffin Bay and Davis Strait

McLaren and Davis (1981; 1982) estimated that a minimum of 5,000 narwhals were present in the pack ice of northern Davis Strait and southern Baffin Bay in March 1981. This was considered an underestimate because many animals were thought to be submerged or under the ice and missed by the surveys. These wintering narwhals are considered part of the Inglefield Bay and/or the Canadian High Arctic stocks (see below).

Canadian High Arctic Stock

Smith *et al.* (1985) estimated that 13,200–18,000 narwhals summered in Lancaster Sound and adjoining waterways in 1981. This estimate was based on the results of a stratified strip-transect survey of Lancaster Sound, Barrow Strait and Prince Regent Inlet in August, and it included estimates of 2,000 and 2,117 to account for whales in two

unsurveyed areas (Peel Sound and Admiralty Inlet, respectively; the former based on Smith *et al.*'s own observation of 2,022 in July 1980, the latter on Fallis *et al.* [1983]). No allowance was made for whales summering in the Pond Inlet-Eclipse Sound-Navy Board Inlet complex or along the east coast of Baffin Island. Smith *et al.* (1985) considered the estimate by Davis *et al.* (1978) of 20,000 to 30,000 narwhals in the Lancaster Sound region in 1976 to be an overestimate caused by 'the inappropriate combination of shorebased counts (Greendale and Brousseau-Greendale, 1976) with their aerial surveys.' Aerial photographic surveys of Eclipse Sound, Admiralty Inlet, Prince Regent Inlet and Peel Sound in August 1984 resulted in an estimate of 17,900 narwhals, uncorrected to account for submerged animals or for those in unsurveyed areas (Strong, 1988). Confidence limits for this estimate are 13,100–21,400 (Cosens *et al.*, 1990). It should be noted that Born (1986) and Born and Olesen (1986), citing an earlier unpublished report by Strong *et al.*, referred to an estimate of 23,700 (95% CI 18,100–29,500) for the Canadian High Arctic stock. Combining his own count with the estimate from Strong et al., Born (1986) suggested a combined Canada–Greenland High Arctic population size of at least 28,000, with confidence limits of about 22,000 to 33,500. According to J.T. Strong (pers. comm. to Reeves, 15 April 1991), the high estimate of 23,700 for the Canadian sector was released prematurely and should be ignored. A reanalysis of the 1984 aerial photographic survey data is planned (J.T. Strong, pers. comm. to Reeves, 15 April 1991).

Northern Hudson Bay Stock

Systematic photographic surveys centred in Repulse Bay and Frozen Strait in July 1982, 1983 and 1984 provided estimates ranging between 1,038 and 1,517 narwhals, with varying degrees of precision (Richard, 1991). Richard (1991) suggested that the narwhals in this area be managed as an isolated stock of about 1,300 animals.

ASSESSMENT AND STATUS

Table 16 summarises the current status of the world's narwhal stocks.

Barents and Kara Seas

The comments by Tomilin (1957) about narwhal abundance in the areas around Franz Josef Land and Novaya Zemlya are problematical. His account suggests a significant decrease in abundance post-1930, but no basis for this impression is offered nor is any possible reason given for such a decrease. Yablokov and Bel'kovich (1974) claimed that chronicles and the discovery of bones on beaches 'testify to the former greater distribution of narwhal in the seas of the European North (White and Kara seas).' However, they did not elaborate. The statement that the narwhal 'is thought to have disappeared from the northeastern part of its range (Novaya Zemlya and Franz Josef Land), presumably because of hunting' (Anonymous, 1978) apparently is based on the reports cited above. Yablokov (1979) indicated that observations of narwhals in Soviet waters were 'rare' but speculated that there could be several thousand animals in two populations in the Soviet High Arctic. Apart from occasional kills by commercial whalers hunting bowheads in the Barents Sea during the 19th century and kills by aborigines along the Yamal Peninsula during at least the 17th century (MacRitchie, 1909), no regular hunt for narwhals in the Eurasian Arctic is documented. Their offshore, high-latitude distribution in this sector may explain, at least partially, the absence of a more detailed record. The continuing presence of small numbers of narwhals in the Barents and Kara seas (as well as in the western part of the East Siberian Sea) was noted by Belikov *et al.* (1990).

Table 16

Status of world narwhal stocks (modified from Braham, 1984).

Centre of summer distribution	Est. abundance	Est. annual kill	Removal rate (% stock size)	Refs
Barents & Kara Seas (Arctic Basin)	no estimate	none known	-	-
Greenland Sea	no estimate[1]	89[2]	unknown	-
Canadian High Arctic (Lancaster Sound region)	17,900[3]	397-568[4]	2.2-3.2	1,2
NW Greenland (Inglefield Bay)	4,043+[5]	616[6]	15[7]	-
N Hudson Bay	1,300	29-41[8]	2.2-3.2	3

[1]Larsen (1985) gave conservative estimate of 176 in Scoresby Sound, September 1983.
[2]Based on average reported catch 1978-87 (Table 1), corrected assuming 1 whale killed and lost for 4 secured (see text).
[3]The data from the 1984 survey are being reanalysed.
[4] Secured catch 290/yr (average 1976-87; Cosens *et al.*, 1990), corrected using loss rates from pooled Pond Inlet data 1982-3 (Weaver and Walker, 1988), 49%, and from pooled Arctic Bay data 1983, 1986-89 (Roberge and Dunn, 1990), 27%, as a range.
[5]Number counted in one day from a shore observation site in Inglefield Bay (Born, 1986).
[6]Based on average reported catch 1978-87 (Table 1), corrected assuming 1 whale killed and lost for 4 secured (see text).
[7]Probably an overestimate since the population estimate is an underestimate of the stock(s) hunted.
[8]Based on average reported catch 1978-87 (Table 1), corrected using the same procedures as described in footnote 3 for Canadian High Arctic stock. Note that the catches included are those from Hudson Bay and Hudson Strait only; Foxe Basin catches are assumed to be from the High Arctic stock.

References: (1) Strong, 1988; (2) Cosens *et al.*, 1990; (3) Richard, 1991.

Greenland Sea

The basis for the statement that this stock was historically much larger and more widely distributed than currently (Anonymous, 1990c, p.136) is uncertain. Too little information is available about the past or present population size for narwhals in this region. Substantial recent catches, particularly in Ammassalik district (Table 14), demonstrate the need for better information on the stock(s) off east Greenland.

Canadian High Arctic

Although Cosens *et al.* (1990) indicated in their Introduction that there was no evidence of Canadian narwhal stocks being harvested at levels that could not be sustained, they concluded in their assessment of the High Arctic stock that harvests have exceeded the estimated net recruitment rate of 2–3% and that if the stock size is 17,900 as estimated, the population must be declining. Strong (1988), using similar estimates of population size and calf production, but a lower estimate of the annual kill rate, concluded that the stock was stable and that the current level of harvest could be sustained. Better information is needed about stock relations and removal rates.

Cosens *et al.* (1990) apparently did not include the two Foxe Basin communities' harvests (Igloolik and Hall Beach) in their assessment of removals from the High Arctic stock. Neither Smith *et al.* (1985) nor Richard (1991) covered Foxe Basin in their population assessment surveys. The stock affinities of narwhals hunted in northern Foxe Basin are unknown, but there is circumstantial evidence from local people suggesting that they come from the High Arctic, passing through Gulf of Boothia and Fury and Hecla Strait in late summer (P. Richard, pers. comm. to Reeves, 1 May 1991).

West and North Greenland

Annual catches of about 450 (the 1975–87 average from Table 14) would represent more than 10% of an estimated minimum stock size of 4043. However, both the catch level (incomplete reporting, no allowance for hunting loss) and the population size (based on a one-day count at a fixed location in Inglefield Bay – Born, 1986) are likely underestimates. Without improved census data and better information on stock relations of narwhals hunted in the Canadian Arctic and West Greenland, it is impossible to make a useful assessment. However, the available data are sufficient to warrant concern about the status of the stock.

Northern Hudson Bay

The combined quotas for communities in northern Hudson Bay (summering area) and Hudson Strait (wintering area) is 70, or 5.4% of the estimated stock size. Reported landed catches in most communities have been below the quota in most years (Strong, 1989), but since reporting is incomplete (Gamble, 1987a) and the quotas make no allowance for struck whales that are not secured, there is reason for concern about the impact of hunting on this stock.

RECOMMENDATIONS

The IWC Scientific Committee has made few recommendations concerning narwhals, apart from calling for their inclusion in the IWC Schedule (IWC, 1980b, p.124). In 1981, Canada and Denmark were encouraged to continue and expand research on stock identity, migration, abundance and calf production; to collect complete and accurate catch statistics; and to sample catches fully for studies of age estimation and reproduction (IWC, 1982a, p.121). Some effort toward achieving these objectives has been made by Denmark and Greenland (e.g. Born, 1986). In Canada, comprehensive research programmes have been implemented to address many of these concerns (e.g. Smith *et al.*, 1985; Gamble, 1987a; Strong, 1988; Weaver and Walker, 1988; Kingsley, 1989; Roberge and Dunn, 1990; Richard, 1991).

The sub-committee remains concerned about catch levels and loss rates in the Canadian and Greenlandic fisheries. It **recommends** particularly that more effort be made to assess stock size and removal rates for the narwhal population in the High Arctic, Baffin Bay and Davis Strait. In this regard, the sub-committee welcomes the formation of the Greenland-Canada Joint Commission on Conservation and Management of Narwhal and white whale, which is expected to implement a joint programme of research and management. The sub-committee notes with concern that the system for reporting catch statistics in Greenland has deteriorated, and recommends that such record keeping and reporting be made a high priority. In view of the substantial catches in some years in east Greenland, the sub-committee also recommends that some attention be given to stock assessment in the Greenland Sea.

(Low, 1906; Bruemmer, 1966; Hansen, 1970; Hay and Sergeant, 1976; Riewe, 1977; Treude, 1977; Durham, 1978; Kapel, 1983; Anonymous, 1985b; Ivashin, 1988; Sergeant and Hoek, 1988)

5.1.3 Direct fisheries for Globicephala melas, *in the North Atlantic*[4]

COMMON NAMES

Long finned pilot whale. Faroe Islands: *grindahvalur*; *nydingur* (large pilot whale); *leiftur* (newborn). Iceland: *marsvín*. Greenland: *nisarnaq*. Newfoundland: pilot whale; blackfish; pothead; roundhead. Norway: *grindehval*. Shetland Isles: pilot whale; blackfish; caa'ing whale. Britain: long-finned pilot whale. Sweden: *grindval*. Finland: *pallopää*; *grindvalas*. Denmark: *grindehval*. Holland and Belgium: *griend*. Germany: *grindwal*. France: *globicéphale noir*; *dauphin pilote*. Spain: *calderòn*; *caldeirò* (Galician); *cap d'olla* (Catalan). Portugal: *boca de panela*. Italy: *globicefalo*. Greece: *mavrodelphini*.

DISTRIBUTION

In the North Atlantic, the long-finned pilot whale lives in cold temperate and subarctic waters. Its general distribution is from Northwest Africa, including the Mediterranean, to the Norwegian-Barents Sea in the east and from Bermuda and Cape Hatteras at the coast of North Carolina to central parts of Greenland in the west. The North Atlantic Sightings Surveys (NASS) in 1987 and 1989 have improved our knowledge of the abundance inside the northeast Atlantic distribution area. Concentrations of pilot whales were observed especially from 2–40°W and 45–65°N, (Lens *et al.*, 1989; Bloch *et al.*, 1989; Buckland *et al.*, 1993). There is some overlap in distribution of the northerly range of the short-finned pilot whale, *Globicephala macrorhynchus*, and southerly limit of the long-finned pilot whale.

Although the pilot whale occurs north to the Barents Sea (Mitchell, 1975b), the only record from the Norwegian coast from NASS surveys was a single observation off southwestern Norway (Øritsland *et al.*, 1989; Bloch *et al.*, 1989), although they occasionally beach on the Norwegian coast (Griffiths and Øen, 1990). Elsewhere the pilot whale is commonly distributed in the western basin of the Mediterranean (Gannier and Gannier, 1990), in the Gibraltar Strait (Hashmi, 1990) and off Spain (Lens *et al.*, 1989).

Pilot whales appear to move into coastal areas following their squid prey in the summer and are more concentrated offshore in deep waters in winter (Evans, 1987). Brown's (1961) summary of observations made from ocean weather ships, merchant vessels and other ships, provides information on the oceanic range of this species as far south as 45°N in the central area of the North Atlantic, suggesting occurrence throughout the year in oceanic waters between 45°N and 50°N and probably in all longitudes from the Bay of Biscay to Newfoundland. Observations during the NASS studies tend to confirm this, indicating a greater abundance of whales, including pilot whales, in the central parts of the North Atlantic.

[4] Initial draft by D. Bloch and C. Lockyer

PROBLEMS AND CATCH STATISTICS

There is not enough information to separate North Atlantic pilot whales into discrete stocks. Previously, pilot whales were taken in the old Norse areas, including Norway, Iceland, Shetland, Orkney and Hebrides (Williamson, 1970; Joensen, 1976). Until 1972, the pilot whale was still taken in Newfoundland and until 1973 in Norway. Today, the pilot whale is only taken in the Faroe Islands and Greenland.

Between 1975 and 1987, a total catch of 487 pilot whales has been taken by small type whalers off Greenland (Table 17). The largest catch was 136 in 1977.

In the Faroe Islands, the fishery (*grind*) is opportunistic. Whales are observed either from land or from boat, and are driven on shore and killed, with entire schools taken usually. Between 1986 and 1988, 47 sightings of pods occurred (one third from land), followed by landings of 43 pods. The distance from the school to the shore ranged between 0.1 to 3.3 n.miles (Bloch *et al.*, 1990a). Traditional Faroese fishing boats are used (specialised boats or whalers have never been used). The whales are driven into suitable bays. Since November 1989, the Faroe Islands Government has restricted the use to 21 bays only.

The whales are hunted communally for food and are utilised non-commercially – the catch is shared free among the local inhabitants. Complex laws and regulations exist for the control of the catch and its utilisation. The first regulations, covering the total course of events from the initial sighting of a pod until the animals have been flensed and the beach cleaned, appeared in 1832. These have been updated several times, but the original regulations still form the backbone of today's laws (Bjørk, 1956–63).

Pilot whales have been harvested in the Faroe Islands since the Norse settlement in the 9th Century (Thorsteinsson, 1986). Hunting statistics exist back to 1584, and unbroken records exist from 1709 to the present (Joensen and Zachariassen, 1982; Bloch *et al.*, 1990b). During the period 1709–1990, 1,646 pods (235,630 whales) were harvested. The statistics show a peak periodical occurrence of whales every 110–120 years (Joensen, 1962; Joensen and Zachariassen, 1982).

In the period 1709–1990, a range of 0–4,360 whales (0–23 pods) per year were harvested, averaging 990 (6.9 pods). The maximum harvest occurred in 1941 (23 pods and 4,325 whales). In three years, 1844, 1939 and 1941, the harvest exceeded 3,000 whales; in 25 years, more than 2,000 whales were landed, while in over 95 years (a third of the time period), the annual catch exceeded 1,000 whales.

By contrast, the period 1750–1795 showed poor harvests with a total of only 13 pods comprising 2,459 whales, averaging 55 whales per year. During the years around 1900, there were occasional years with no pods landed (1890–1, 1901, 1924 and 1927). Although pods were seen during those years, attempts to beach them met with no success. In all, there were 44 years when no pods were taken (Bloch *et al.*, 1990b).

The fishery has never been managed by quota limitation. However, since 1982, a district or a whaling bay can be closed by an executive order issued by the Faroe Islands Government whenever the area in question is considered to already have an adequate supply of meat. Between 1986–1988, restrictions occurred in 4 (1986), 5 (1987) and 3 (1988) districts out of 9, and lasted for 0.5–3.5 months. So long as the pilot whale meat and blubber is used non-commercially, and only by Faroese people for local consumption, there will be an upper limit on the catch, regulated by demand.

In recent years, the Faroese Government has made limitations of the use of the gaff and spear in the fishery, in response to international concerns.

The complete pilot whale catch information is held at the Faroese Museum of Natural History in Tórshavn. There are other species taken by drive fisheries in the Faroes, including *Lagenorhynchus acutus* in some years. Catch statistics for some species are available for the past five years.

POPULATION ESTIMATE

The NASS-87 (June-August) survey of the Faroese-Icelandic area covered an area bounded by Spitzbergen and the Barents Sea in the north, the Spanish coast in the south, West Greenland in the west and the Norwegian coast in the east (Sigurjónsson *et al.*, 1989). A total of 109 sightings of approximately 4,413 animals were made onboard the four survey vessels. The sightings were concentrated southwest and west of the Faroe Islands, off the southeast coast of Iceland and in deep waters southwest and west of Iceland in the Denmark Strait; although some sightings were made west of the British Isles and Ireland, and along the East Greenland coast.

The resultant population estimates were 72,000 (CV 0.4) for the area covered by the Faroese vessel; partial population estimates for closing and passing mode are 18,950 (CV 0.5) and 12,945 (CV 0.25) whales respectively, for the areas covered by the Icelandic vessels. This gives a total 'best' estimate of close to 100,000 animals; it does not include a correction for submerged animals and assumes that all schools close to the trackline were sighted (Bloch *et al.*, 1989). When reviewing these estimates, the sub-committee discussed several factors that could bias the estimates, and noted that due to these factors, there was a greater uncertainty in the estimate than indicated by the calculated CVs (IWC, 1990b).

The area between 50–65°N and 06–45°W was covered by Iceland and the Faroe Islands during the NASS-89 survey, and a similar number of sightings of pilot whales was recorded but the data are still not fully analysed. There are no updated estimates from the other areas in the North Atlantic. However, there is an estimate of about 60,000 whales as the initial population in Newfoundland waters (Mercer, 1975), and about 13,000 whales from an aerial line-transect of a portion of the Newfoundland-Labrador area (Hay, 1982).

ASSESSMENT AND STATUS

There is no detectable evidence that the stock size of pilot whales appearing in the Faroese area has been affected by the drive fishery. The observed periodicity in the

Table 17

Catches of pilot whales in Greenland 1975-87 (Total=487). Data from Danish Progress Reports.

Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Catch	106	51	136	101	50	6	1	1	-	-	26	9	-

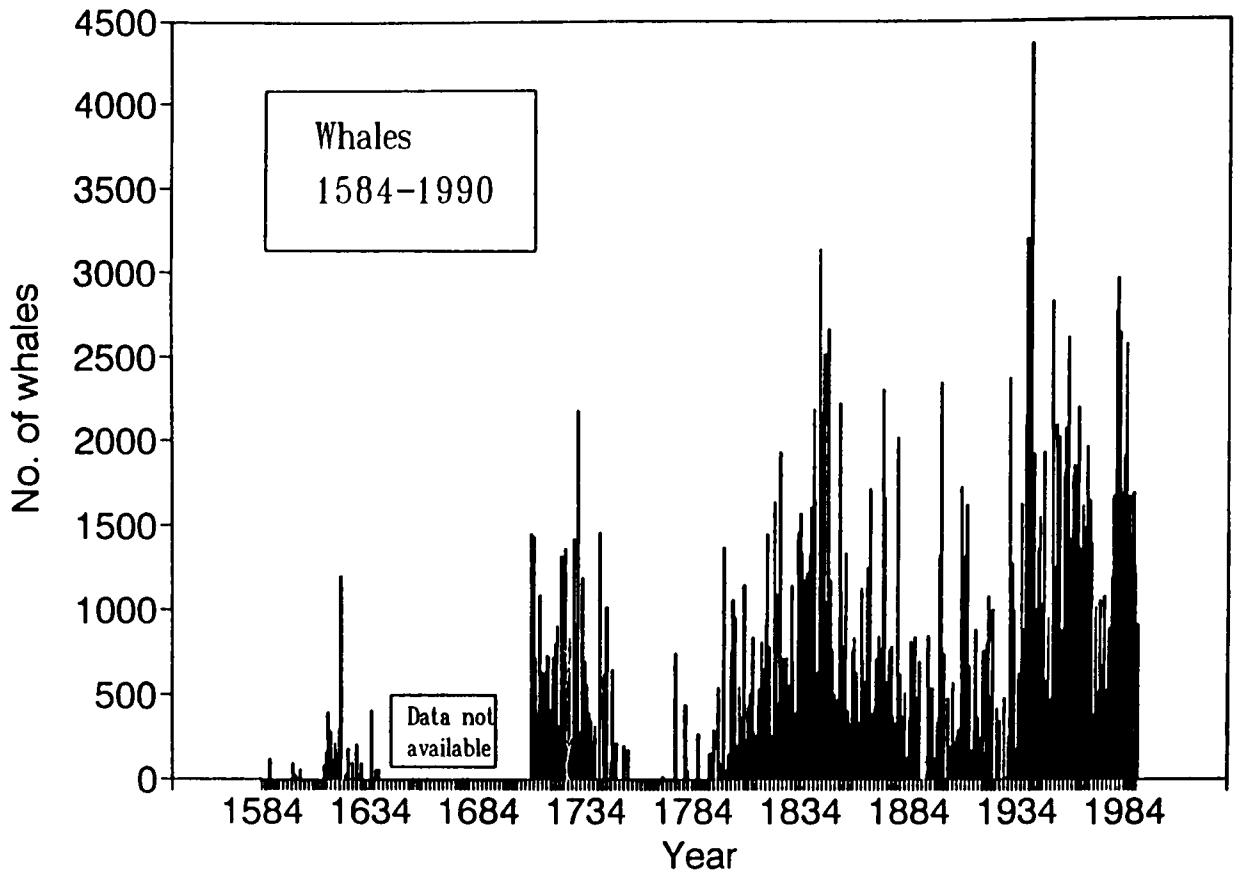

Fig. 2. Catches of pilot whales at the Faroe Islands.

occurrence of whales in the Faroese area (Fig. 2) is significantly correlated with the occurrence of the squid prey, *Todarodes sagittatus*, the presence of which is also correlated with the periodicity in the sea surface temperature (Hoydal, 1986). Any connection between the pilot whales occurring around Newfoundland in summertime and the all year round occurrence in the Faroes (Sergeant, 1986) is still not proven.

RECOMMENDATIONS

In 1985, the Scientific Committee recommended the funding of a proposal to examine the ecology of Faroese pilot whales (IWC, 1986a, p.52). Although IWC funding was not forthcoming, between July 1986 and July 1988, a comprehensive examination was undertaken of the ecology and status of the pilot whale in the Faroe Islands, under the auspices of the IWC and the United Nations Environment Programme (UNEP). The content of these examinations is outlined by Desportes (1990), and most of the results are published in Donovan *et al.* (1993).

In 1987 (IWC, 1988, p.51), the Scientific Committee noted that material being collected from the Faroese pilot whale fishery was particularly valuable for investigating the factors which determined the concentrations of organochlorine pollutants in whale tissue. These compounds are known to affect reproduction in other marine mammals. It therefore recommended that this opportunity should be brought to the attention of laboratories capable of performing standardised analyses for organochlorines and particularly for individual PCB congenors. Studies on these matters were instigated and the results are published in Donovan *et al.* (1993).

In 1989 (IWC, 1990a), the Scientific Committee made several recommendations. Concerns about past fisheries and by-catches were expressed, and in view of the fact that in the western North Atlantic the by-catch of pilot whales by foreign flag mackerel vessels in the US EEZ jumped sharply in 1988 to 140 and may have been larger in earlier years when the then larger mackerel fishery was unmonitored, it was recommended that the historical data for this fishery be examined to estimate earlier removals of pilot whales.

The existence of a past Icelandic drive fishery was confirmed (Anonymous, 1990c) and the Committee recommended that the historical data for that fishery and for strandings be obtained and reported.

Information on these matters was published in Donovan *et al.* (1993).

Several recommendations specific to the Faroese drive fishery were also made. At that time, no new information was available on population dynamics, but it was recommended that attention be given to research on this topic using the Faroese frequency-at-age data. Extensive demographic information which has been, and will be, generated by the Faroese research programme could form the basis for a valuable mathematical model of the population dynamics of pilot whales, and possibly other odontocetes. The Committee therefore recommended that such an integrated model should be developed.

The Committee recommended that stock identity be addressed by genetic comparisons being carried out between pilot whales from the Faroes and from other regions in the North Atlantic using both analyses of isoenzyme allelic frequencies and appropriate analyses of DNA. Results of such studies were presented in Donovan *et al.* (1993).

Because of the importance of information about migration to questions of stock identity and status and because the pilot whale is a species particularly suitable for radio-telemetry studies, the Committee recommended that the proposed project using satellite-linked transmitters at the Faroes to study movements, described at an earlier meeting two years previously be undertaken. This particular project, while attempted, has not met with success. No further attempts have been made or are planned.

In teeth and hard tissues, depositional anomalies may be related to stress or other external factors and it was recommended that incidence of marker lines and other anomalies in teeth of pilot whales be examined in more

detail to determine possible links with oceanographic conditions, food availability and life history events. Research on this matter is continuing.

5.1.4 The Black Sea dolphin and porpoise fishery[5]

Three species of small cetacean were killed by fishermen from the four countries surrounding the Black Sea between 1870 and 1983. The common dolphin (*Delphinus delphis*) was historically the species caught in the largest numbers by the USSR, and although the limited catch statistics have generally been reported for all three species combined, it appears that the harbour porpoise (*Phocoena phocoena*) became the numerically dominant species in the catch from 1964 to the time the fishery ended in 1966 (except Turkey). The bottlenose dolphin (*Tursiops truncatus*) was of intermediate importance in the harvest. The Turkish catch reportedly consisted of 80% *Phocoena*, 15–16% *Delphinus* and 2–3% *Tursiops* in the early 1980s (Klinowska, 1991). No information is available on the composition of the earlier Turkish catches or on the Bulgarian and Romanian catches for any period. The abundance of all three species was greatly reduced by the fisheries (Zemsky and Yablokov, 1974; Smith, 1982).

DISTRIBUTION

The three species involved in the Black Sea fisheries are distributed widely, in disjunct populations, in temperate regions of the Northern Hemisphere (*Phocoena*) or the world (*Delphinus* and *Tursiops*). They are found throughout the Black Sea, reportedly moving seasonally to follow concentrations of various small pelagic fishes. For example, in the autumn they follow such prey fishes northward along the eastern Black Sea. The cetaceans formerly entered the Azov Sea, in the northeast corner of the Black Sea, along with the prey species. However, they no longer occur in that shallow sea, reportedly because it has become heavily polluted. The common dolphin historically occurred primarily in the central Black Sea, harbour porpoises and bottlenose dolphins primarily in the more coastal regions. However, sightings data suggest that there were shifts in ranges of the species in later years as the numbers of common dolphins declined. The animals in the Black Sea could move into the Mediterranean Sea, and bottlenose dolphins have been reported moving through the Bosphorous Straits. The extent of such movement is unknown, however. Tomilin (1957) presented evidence that all three cetacean species in the Black Sea differ morphologically from those elsewhere. Harbour porpoises do not occur in the eastern Mediterranean Sea at present, so those in the Black Sea are definitely an isolated stock. There is no information on the existence of separate breeding stocks within the Black Sea for any of the species. The genetics of the Black Sea dolphins and porpoise have not been studied. However, DNA-sequence comparisons with samples from other regions are presently being carried out for the common dolphin and the harbour porpoise (W. Perrin, pers. comm.).

PROBLEMS AND CATCH STATISTICS

Although the three species were harvested for many years at high levels, catch statistics are sketchy, being reported only irregularly and in total weight of the catch for all three species combined, as summarised up to 1974 by Smith (1982). The USSR catches apparently reached their maximum of 135,000 to 140,000 animals in 1938, after which they declined. The average reported catches before World War II were roughly double those for later years, despite increasing fishing effort including the use of spotting aeroplanes. During the entire fishery, catches were made by both netting (mainly USSR) and shooting (mainly Turkey), with unknown loss rates in the latter. Smith reported that during a June 1981 joint USSR-US dolphin sighting survey, there was a decreasing rate of encounter of floating harbour porpoise carcasses with increasing distance from the Turkish coast (IWC, 1983b), suggesting the continuation of a harvest by shooting in the early 1980s and an apparently high struck-and-lost rate. The decline in catches of all three species to a few thousand per year by 1964–66 prompted first seasonal restriction, then a total moratorium in the USSR, Bulgaria and Romania from 1966. Little information has been reported for years since 1974 although it is known that the harvest continued in Turkey until it was banned in 1983.

Çelikkale *et al.* (1989) and Çelikkale (1990) described recent developments in the fishery, noting especially concern within Turkey that the dolphins and porpoises posed a serious threat to the continued success of local net fisheries for the European anchovy.

Recently, illegal takes of at least two of the three species have been reported in Turkey. The causes are not known but are variously described in newspaper accounts in March and April 1991 as incidental entanglement in net fisheries, directed take to reduce competition for the European anchovy, directed take to reduce the damage to fishing nets, utilisation of an incidental catch, and directed takes for commercial marketing of fertiliser, animal feed, and oil, perhaps for cosmetics. Catches are reportedly being made in 'turbot nets', and carcasses seen on the docks are being processed by boiling in vats. There have been no official estimates of the magnitude of this recent harvest, and no confirmation of their purpose; given the lack of systematic reporting in the years before the harvesting became illegal and the illegal nature of present harvests, accurate statistical reporting should not be expected.

POPULATION ESTIMATES

Following the 1966 moratorium on industrial Black Sea dolphin/porpoise hunting in the USSR, Bulgaria and Romania, a series of aerial sighting surveys was begun by the USSR, continuing at least through the early 1980s. The methods and some of the resulting data are described in Zemsky and Yablokov (1974), and analyses of the annual variability of estimates based on these data through 1973 are presented in Smith (1982). The abundance of all three species together was estimated to be 1.5 to 2.0 million animals in the 1930s, but only 250,000 over the period 1967 to 1974. There was no apparent trend in abundance in the latter period, but variability in the estimates between years was far greater than anything reasonably compatible with the biology of the species. The largest estimates in the later period were for the common dolphin (average roughly 150,000), while the smallest estimates were for harbour porpoise (average roughly 22,000), with bottlenose dolphins intermediate (averaging roughly 85,000). These estimates are based on expanding the numbers of animals sighted assuming an effective track width of three km in which 50% of the animals present were seen. The survey tracks covered most of the Black Sea, although certain areas were missed, including that within 12 miles of the Turkish coast.

[5] Initial draft by T.D. Smith.

New surveys were conducted by Turkey in April and July of 1987 using standard line transect methods aboard four ships (Çelikkale *et al.*, 1989), and estimates for the three species combined of more than 450,000 animals obtained. The surveys were conducted seaward to 60 km, over roughly 1/6th the total area of the Black Sea, primarily along the southern coastlines. The estimates are based on assuming an effective track width of 5 km (2.5 km on each side of the vessel) and that the animals are distributed over the unsurveyed areas of the Black Sea at the same density as observed in the surveyed areas. Buckland *et al.* (1992) reviewed the statistical basis of these estimates, however, and suggested that they may be seriously biased by the use of the 'maximum effective sighting distance' as the 'effective search width', by size-biased sampling because the school sizes varied between several tens and several thousands of animals, and by extrapolating to unsurveyed areas. For example, they suggest that an estimate of just the surveyed area would be on the order of 76,000 animals, and that 'the true abundance might be substantially below the estimate of 454,440 animals, and may be well below half that estimate'. New estimates of 96,000 ±30,000, 10,000 ±3,000 and 7,000 ±3,000 for common dolphins, harbour porpoise and bottlenose dolphin, respectively, were reported in SC/43/Prog Rep USSR, but these estimates were not reviewed by the sub-committee.

ASSESSMENT AND STATUS

The populations of the three species in the Black Sea had clearly been greatly reduced by the time the fisheries closed between 1966 and 1983. While all three species continue to exist in the Black Sea, the degree of their recovery from previous depletion is not known with any precision. Based on the generally low rates of increase of cetacean populations, however, it is unlikely that they have increased to any substantial fraction of their pre-exploitation abundance in the few years that they have been protected. Further, given the reported declines in the fishery for at least one of their prey items, the recovery of the cetaceans may have been inhibited by reduced food resources. The reported Turkish takes, therefore, are of great concern, whatever their purpose.

RECOMMENDATIONS

The Scientific Committee made five recommendations concerning Black Sea dolphins in 1982 (IWC, 1983a, p.60):

(1) that better information on catch levels and species composition be made available;
(2) that the data from aerial surveys by the USSR be made available for analysis and evaluation;
(3) that a Turkish scientist familiar with the fishery be invited to participate in the next meeting;
(4) that the history of the anchovy fisheries in the Black Sea be reviewed; and
(5) that Turkey and FAO be approached concerning the sampling of the Turkish fishery to obtain biological data of various sorts.

The Scientific Committee reviewed the above recommendations in 1983 (IWC, 1984a, pp.58–9) and noted that a general FAO fishery mission to Turkey had obtained some new data on the harvest of small cetaceans. However, the requested USSR sightings data had not been obtained, nor was the invitation for a Turkish scientist to attend the Scientific Committee meeting accepted. In view of the ban on the hunting of dolphins and porpoises announced by the Turkish Government, effective mid-April 1983, the recommended sampling programme was no longer required. The Scientific Committee re-stated recommendations 2, 3 and 4.

No new data were available in 1984, and the Scientific Committee requested information from IUCN and UNEP and again expressed the desire to have a Turkish scientist attend the Scientific Committee meeting (IWC, 1985, p.53).

The paper on the anchovy fishery provided to the 1990 Scientific Committee meeting (Çelikkale, 1990) was welcomed as a partial response to recommendation 4, as was the participation of Çelikkale.

The Committee in 1990 recommended (1) that the current abundance estimates not be used as a basis for management and that they be reviewed independently; (2) that further population surveys be carried out, preferably involving at least the four nations bordering the Black Sea, and (3) that, because of the perception by fishermen in Turkey of competition by dolphins for fish, studies of feeding ecology of the small cetaceans be carried out.

The sub-committee makes two further **recommendations** below.

(1) An evaluation of alternate possible causes for the declines in the anchovy fishery in Turkey should be made, including fishery resource surveys to monitor abundance and collection of specific catch and fishing effort statistics. The seasonal distribution of the anchovy population and the small cetaceans should be more fully described. Because the fish populations migrate throughout the Black Sea, similar information should be obtained in all countries surrounding the Black Sea, including information on possible incidental take or directed take of cetaceans.
(2) The actual reasons for the reported takes of dolphins and porpoises in Turkey should be determined, and accurate statistics should be collected. Steps should be taken to ensure that these takes are reduced given the poor present understanding of the status of these populations. If the takes are motivated by perceived threats to the anchovy fishery, these threats should be further evaluated. If the takes are motivated by the commercial value of the products, these markets should be documented, and the existence of alternate sources of raw materials investigated. If the takes are incidental to commercial fishing operations, the causes of the entanglements should be determined, and steps taken to reduce the incidental take through education and possible changes to gear and fishing practices. Bulgaria, Romania and the USSR should also be encouraged to provide similar information.

5.1.5 The Peruvian small cetacean fishery[6]

Several species of small cetacean are taken by a variety of artisanal fisheries in Peruvian coastal waters and used for human consumption (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a). In Peru, the distinction between directed and incidental catches is blurred because small cetaceans possess commercial value, so all catches of dolphins and porpoises have been retained. Three species are commonly taken by these fisheries: dusky dolphin (*Lagenorhynchus obscurus*), Burmeister's porpoise (*Phocoena spinipinnis*), and common dolphin (*Delphinus delphis*).

[6] Initial draft by A. Read.

DISTRIBUTION

The dusky dolphin occurs in cold-temperate waters along both coasts of South America and in presumably separate populations off southern Africa and New Zealand. On the Pacific coast of south America, it is distributed in coastal waters from Huacho, Peru (11°S) to southern Chile (Gaskin *et al.*, 1987). Burmeister's porpoises also occur in the cool waters of the coastal upwelling zone in Peru, extending from Paita (5°S) to the Beagle Channel in Chile and in the coastal waters of the Atlantic into southern Brazil (IWC, 1991c). Their entire range appears to be limited to coastal waters of South America. Common dolphins are widely distributed in pelagic and coastal waters throughout the world oceans, extending south in the Pacific to at least 40°S (Aguayo, 1975). Nothing is known about seasonal movements or stock structure of these three species in Peruvian waters.

PROBLEMS AND CATCH STATISTICS

Two sets of catch statistics describe the numbers of dolphins and porpoises captured in Peruvian waters. Official government statistics, compiled by the Ministerio de Pesqueria (MIPE), report the weight of all small cetaceans landed annually in Peruvian ports from 1966 to the present. Reported landings were at fairly low levels until the early 1970s, when catches rose dramatically (Read *et al.*, 1988). Recent annual landings have decreased from a peak of 1,408 tonnes in 1979 to 426 tonnes in 1989 (Van Waerebeek and Reyes, 1990b). Unfortunately these data are not collected on a species-by-species basis, so it is difficult to estimate the total number of individuals taken.

Estimates have also been made of the actual number of small cetaceans landed at several ports in central Peru since 1985 (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a; b). In the small port of Pucusana (12°S), the estimated total kill of small cetaceans has increased from 175 in 1985 to 2,320 in 1989 (Van Waerebeek and Reyes, 1990b). The majority of this catch is comprised of dusky dolphins, captured intentionally in a drift net fishery during the winter months (Read *et al.*, 1988). Comparison of these estimates with the published statistics show that the MIPE data are accurate for Pucusana, where small cetacean carcasses are weighed, but highly inaccurate for other ports where weights are estimated by port officials (Van Waerebeek and Reyes, 1990b).

Read *et al.* (1988) estimated the total number of dolphins and porpoises captured in Peruvian waters by combining official MIPE statistics on landed weights with data on species composition and mean weight of each species collected at Pucusana. These authors reported an approximate catch of 10,000 dolphins and porpoises during 1985, although they cautioned that this estimate depended on the accuracy of MIPE records and the extrapolation of species composition from central Peru to the remainder of the coastline.

A particularly troubling aspect of the situation in Peru is the recent development of the directed fishery for small cetaceans. Early reports of utilisation of small cetaceans in Peru (Mitchell, 1975a) indicated that the capture of these animals occurred incidentally to other fishing operations. In recent years, the majority of landed dolphins and porpoises have been deliberately captured, mostly in the directed net fishery for dusky dolphins (Read *et al.*, 1988), although a large catch of common dolphins was taken by harpoon in 1987 (Van Waerebeek and Reyes, 1990b). It has been suggested that this direct exploitation was initiated in the early 1970s following the collapse of the industrial anchoveta fishery in 1972 (Read *et al.*, 1988). The commercial value of incidentally captured dolphins and porpoises presumably stimulated deliberate catches of these animals, particularly after the demise of the lucrative anchoveta fishery.

POPULATION ESTIMATES

There are no population estimates for any species of small cetacean in Peruvian waters.

ASSESSMENT AND STATUS

It is not possible to assess the status of small cetaceans in Peru, because estimates of total kill and abundance are lacking. The catch of dusky dolphins is known to be large, however, numbering in the thousands, and is thus cause for concern. In 1990, the IWC Workshop on Mortality of Cetaceans in Passive Fishing Nets and Traps expressed concern for this population of dusky dolphins (IWC, 1994). Notwithstanding the increase in catches at Pucusana, Van Waerebeek and Reyes (1990b) noted a negative trend in MIPE national landing statistics between 1979 and 1990, and suggested that this reduction in catches might indicate an unsustainable exploitation of declining populations. The Peruvian government reportedly closed the directed fishery for small cetaceans in November 1990, but the Scientific Committee had no detailed information about this closure and its effects.

RECOMMENDATIONS

Research is required to provide reliable estimates of total fishing mortality for each species in Peruvian waters. The sub-committee **recommends** that this be achieved by modifying existing MIPE data collection procedures to record the number of individuals of each species landed rather than total weight. Estimates of abundance of affected species and elucidation of stock structure are also urgently required to assess the impact of directed and incidental takes on affected populations, and the sub-committee **recommends** such studies to be undertaken.

The IWC Workshop (IWC, 1994) recommended that the Government of Peru collect and report catches of cetaceans at all ports, by species and number as well as weight. It also recommended that alternative fishing methods be sought to reduce marine mammal mortality without affecting fishery yields and that technological programmes to this end be established. If the incidental and directed kills continue, it is vital that an effort be made to assess the dolphin population(s), to at least obtain a minimum estimate of abundance.

5.1.6 The Sri Lankan small cetacean fishery[7]

Large catches of small cetaceans have been reported around Sri Lanka. Although some dolphins may have been harpooned by Sri Lankan fishermen at least as long ago as the late nineteenth century (Leatherwood and Reeves, 1989), the current situation appears to have developed along with the rapid expansion of use of synthetic gillnets, which were introduced in the 1950s and are now the fishing method of choice in most fishing areas of the country. Initially, incidentally gillnetted cetaceans may have been discarded by most fishermen, or retained for personal use by only a few. However, as uses were identified and markets established for flesh of small cetaceans, those animals incidentally caught began to be retained and practices were gradually expanded to include deliberate

[7] Initial draft by R. Reeves.

taking (Leatherwood and Reeves, 1989). These developments may well have been fuelled by rapidly increasing human populations and declining availability of some other traditionally sought marine resources (Amarisiri and Joseph, 1985; Joseph, 1985). At present, dolphins are taken mostly in gillnets and by hand harpoons and are used for human consumption and as bait in longline fisheries. The taking of dolphins in Sri Lanka is now widespread and apparently growing (Leatherwood and Reeves, 1989).

SPECIES INVOLVED

The following species of small cetaceans, in approximately descending order of importance (i.e. numbers landed), have been identified in Sri Lanka since 1982: *Stenella longirostris*, *Grampus griseus*, *S. attenuata*, *S. coeruleoalba*, *Tursiops truncatus*, *Kogia simus*, *Feresa attenuata*, *Pseudorca crassidens*, *Globicephala macrorhynchus*, *Peponocehala electra*, *Lagenodelphis hosei*, *K. breviceps*, *Steno bredanensis*, *Orcinus orca*, *Mesoplodon sp.*, *Delphinus delphis* and *Ziphius cavirostris* (Leatherwood and Reeves, 1989). Catches also include a few large cetaceans (*Physeter catodon, Balaenoptera physalus and Megaptera novaeangliae)* and dugongs (*Dugong dugon*) (Leatherwood and Reeves, 1989). Most of the species involved in the Sri Lankan fisheries have pantropical or cosmopolitan distributions.

ESTIMATED CATCHES

The Sri Lankan National Aquatic Resources Agency (NARA) recently estimated that approximately 12,950 small cetaceans are caught in gillnets and others (no estimate) are harpooned annually in Sri Lanka (Dayaratne and de Silva, 1990). Methods used to estimate mortality were not presented in sufficient detail to warrant critical evaluation. Leatherwood (1994) reexamined data on fishing effort and dolphin catches in Sri Lanka from 1984–1986 originally presented in Leatherwood and Reeves (1989), and estimated that at least 8,042–11,821 small cetaceans were taken annually, depending on the assumptions used; he regarded even the highest of these figures as a substantial underestimate. In fact, data do show clearly that takes of small cetaceans are very large in Sri Lanka but are inadequate to permit calculation of reliable estimates with appropriate measures of confidence. With the kind and quality of data currently available

'All attempts to estimate mortality of cetaceans in Sri Lankan fisheries ... are compromised in significant ways ... The best (one) could do was to calculate a series of estimates using conservative assumptions and present the basis and details for those estimates in sufficient detail that they can be recalculated as more information becomes available' (Leatherwood and Reeves, 1989,p.47).

POPULATION STATUS

Although small-scale aerial and vessel surveys have helped describe distribution, relative abundance and behaviour of cetaceans in some areas of Sri Lanka (e.g. Alling, 1986; Leatherwood and Reeves, 1989), there is virtually no information available on stock identity, size or status for any species. Even if there were, data on fishing effort and catches of small cetaceans are inadequate to reliably define any trends in catches of small cetaceans. Therefore, it is not possible to assess effects of removals on the populations involved.

RECOMMENDATIONS

A well-established system for collecting statistics on fish catches exists in Sri Lanka. Observers in fish-landing sites record fishing effort and catches daily or weekly; these data are regularly compiled for each of the 14 fish-landing districts and reported to a national data centre. Catches of cetaceans are not routinely included in catch reports; they are available for only a few sites regularly visited by officials. By training local fisheries officers in identification of cetaceans and making reporting of cetacean catches a routine part of their duties, Sri Lankan authorities could use the existing fisheries reporting system to assess magnitude of catches. Biological studies of caught specimens, as have been initiated by NARA, combined with extensive surveys of the fishing grounds and adjacent EEZ, are then needed to assess effects of catches on affected populations.

It is already illegal to take cetaceans in Sri Lanka (Leatherwood and Reeves, 1989). However, pressures from increasing human populations and economic problems in the country are defining government policies favouring expansion of resource harvesting. As favoured status, and thus full protection, for cetaceans is unlikely, a conservative management programme is needed. To succeed, this programme must educate fishermen and field workers about differences between reproductive potentials of fishes and marine mammals, and thus consequences of overfishing the latter, and provide for careful monitoring and regulation of takes.

The IWC Workshop (IWC, 1994), in addition to a variety of recommendations applicable to Sri Lanka as one of many nations with large cetacean by-catches, recommended that new fisheries not be initiated and that existing fisheries not be expanded until after evaluation of their effects on non-target species.

5.1.7 Platanista minor[8]

COMMON NAMES

Indus susu, Indus river dolphin, *bhulan* (Pakistan)

DISTRIBUTION

This dolphin formerly inhabited the Indus River system, from upstream as far as Attock to downstream below Hyderabad. The historic distribution included the major tributaries of the main channel: Ravi, Sutlej, Chenab and Jhelum (Reeves, 1991). The present distribution is much less extensive (Fig. 3). A few dolphins may survive upstream of Chashma Barrage and below Sukkur Barrage, but most of the population is downstream of Chashma Barrage and upstream of Sukkur Barrage. They are now absent from the tributaries above Panjnad Barrage (Khan and Niazi, 1989).

Upstream movement through barrages is very unlikely to occur, and downstream movement, while possible, is probably only sporadic (Reeves *et al.*, 1991). The extant population is divided into five isolated subpopulations (Khan and Niazi, 1989).

PROBLEMS AND CATCH STATISTICS

No official statistics of any kind appear ever to have been kept on dolphin catches in the Indus system. Information about takes is limited to what can be learned from the literature on scientific collections and live captures, totalling at least 6 and 11, respectively, since 1968 (Herald *et al.*, 1969; Pilleri, 1970a; b; 1972; Pilleri *et al.*, 1976).

[8] Initial draft by R.R. Reeves and R.L. Brownell, Jr.

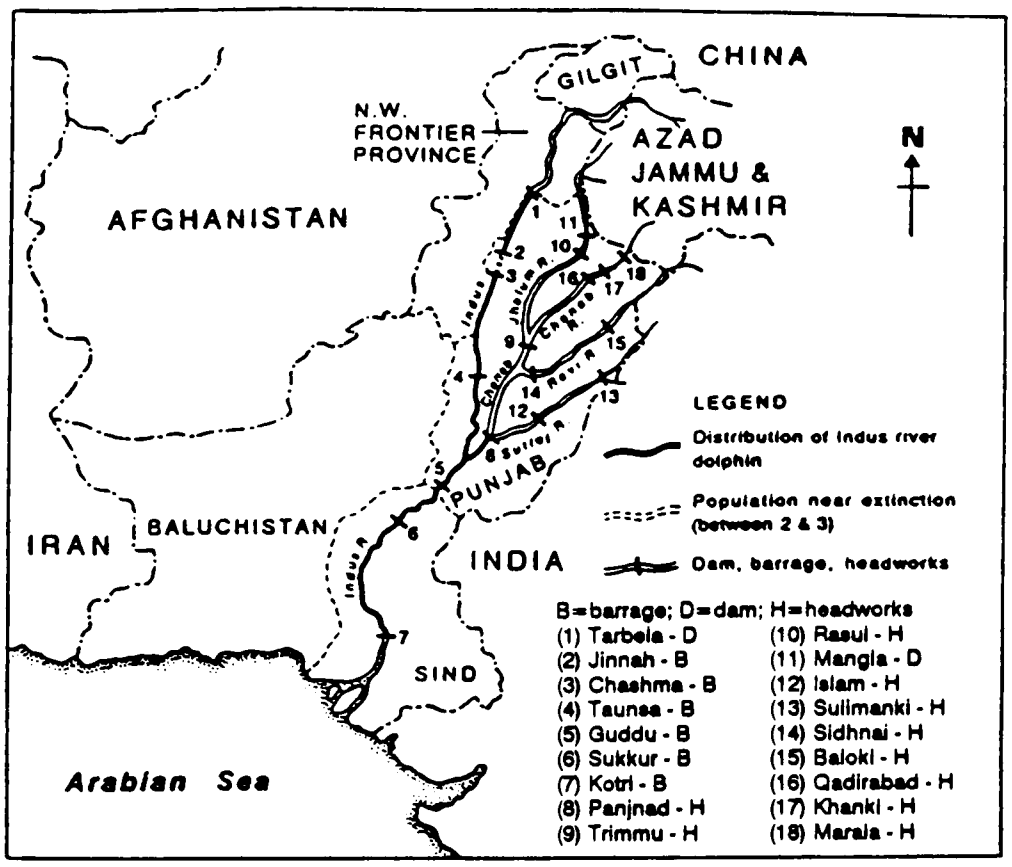

Fig. 3. Distribution of the Indus river dolphin.

Although the river dolphin has been legally protected in Sind province since 1972, the Punjab province since 1974 and the Northwest Frontier province since 1975 (Atkins, 1989), there have been reports of continued killing (Pilleri and Zbinden, 1974; Pilleri and Bhatti, 1978; Reeves, 1991). There is no reported regular incidental mortality in fishing gear or from boat collisions. However, fishing with gillnets, throw nets and various other gears takes place, and some motor traffic occurs, throughout much of the area inhabited by the dolphins.

The most serious conservation problem for this species is the loss of suitable habitat, including the partitioning of the metapopulation by barrages. All the barrages are being considered for retrofitting to produce hydroelectric power. The pressure is strong in Pakistan for intensified agricultural and industrial development, and the demand for water will certainly continue to grow.

POPULATION ESTIMATE

Counts of dolphins in the Sind Dolphin Reserve between Sukkur and Guddu barrages, carried out by the Sind Wild Life Management Board since the late 1970s, suggest a stable or increasing subpopulation there (Khan and Niazi, 1989). The most recent counts suggest a population size on the order of 400–450 dolphins. Because the details of survey methodology are unavailable, however, it is difficult to judge the validity of this estimate.

In the Punjab, counts by the Punjab Wildlife Research Centre between 1987 and 1990 indicate a subpopulation of about 100–110 in waters below Taunsa and Panjnad barrages and above Guddu Barrage (Chaudhry and Chaudhry, 1988; Chaudhry and Khalid, 1989; A.A. Chaudhry and U. Khalid, pers. comm. to Reeves, May 1990). The subpopulations in the Punjab and Northwest Frontier province upstream of Chashma Barrage and in Sind downstream of Sukkur Barrage range from a few to 10–20 individuals (Khan and Niazi, 1989; Chaudhry and Khalid, In press). Although the counts for the Punjab reported by Chaudhry and colleagues are substantially higher than those reported by Khan and Niazi (1989), there is no reason to suppose that the population has increased. Khan and Niazi's counts were made in discrete portions of the area (see Niazi and Azam, 1988), whereas Chaudhry *et al.* attempted 100% coverage.

ASSESSMENT AND STATUS

The Indus River dolphin is critically endangered because of its restricted distribution and low population size. The subpopulation between Sukkur and Guddu barrages receives some protection, and its distribution and population size are monitored regularly by the Sind wildlife authorities. The same is true of the subpopulation between Taunsa, Panjnad and Guddu barrages, although since this area lacks explicit status as a dolphin reserve, policing efforts may be less effective. Even if protection from direct exploitation were complete, which it probably is not (Reeves, 1991), the deterioration of habitat is likely to continue.

RECOMMENDATIONS

International support is urgently needed for developing a programme of field research that addresses immediate management problems. Research should include (1) continued regular monitoring of population size and distribution, (2) noninvasive efforts to identify and track the movements and activities of individual dolphins, (3) estimating calf production and calf mortality, (4) identifying limiting habitat parameters, (5) precisely mapping and monitoring existing utilised and vacant habitat along the full length of the river, (6) determining and quantifying the cause(s) of mortality generally, determining whether the subpopulations are increasing or decreasing and projecting future trends in the subpopulations. Potential reserve areas need to be surveyed and appropriate reports and recommendations prepared. The advisability and feasibility of creating ways to allow mixing of the artificial subpopulations should be studied, perhaps as a component of the hydroelectric development work being supported with foreign capital (Reeves *et al.*, 1991).

Enforcement and strengthening of existing protective laws and creation of additional reserves should be high priorities. International support may be needed to ensure

adequate staffing, training and equipping of wardens. Further withdrawals of water from the main river channels for irrigation, power plant cooling or any other domestic or industrial use should be minimised. The Government of Pakistan and the international aid agencies involved in supporting development projects in the Indus basin should be made aware of the river dolphin's precarious status, required to assess the likely impact of the projects on dolphins and dolphin habitat, and encouraged to make every effort to reduce or eliminate any deleterious effects.

5.2 Incidental catches

5.2.1 Phocoena sinus[9]

COMMON NAMES

Vaquita, Gulf of California harbour porpoise

DISTRIBUTION

This porpoise is endemic to the warm-temperate waters of the upper Gulf of California. It has the smallest geographic range of any marine cetacean. A few sightings from farther south in the Gulf have not been confirmed. (Silber, 1990; Vidal, In press).

PROBLEMS AND CATCH STATISTICS

The vaquita has been incidentally caught in the gillnet fishery for totoaba (the large sciaenid fish *Totoaba macdonaldi*) since the mid-1920s (Vidal, In press). The fishery peaked in the 1940s and declined as the totoaba was depleted. The totoaba became fully protected in 1975, but the fishery has continued at lower levels, both as a legal experimental fishery and illegally. In addition, the vaquita is taken incidentally in gillnets in a growing shark fishery and a fishery for sierra (*Scomberomorus* sp.) and in shrimp trawls. The historical levels of incidental catches are impossible to reconstruct because of lack of information on fishing effort and vaquita catch rates. Records are available for 85 vaquitas taken incidentally since 1985 (Vidal, In press). This undoubtedly represents a very small proportion of the total mortality from fishing operations. The available information suggests that 30–40 vaquitas are killed each year (IWC, 1991c). Most recently, 13 vaquitas have been caught in the totoaba fishery during February and March this year (O. Vidal, pers. comm., 1991; not included in Vidal, In press).

POPULATION ESTIMATE

The size and status of the vaquita population are unknown. Extensive surveys by Silber (1990) and co-workers 1986–89 resulted in sightings of only 110 individuals in all surveys combined. Considering the scarcity of sightings relative to survey effort, the few individuals per sighting, and the very limited geographic range of the species, there can be no doubt that the population is very small, perhaps in the low hundreds (IWC, 1991c).

ASSESSMENT AND STATUS

The vaquita is the most endangered marine cetacean. The relatively high incidental catches and the difficulties and costs of enforcing long-term conservation measures quickly lead to the conclusion that the vaquita is in immediate danger of extinction (IWC, 1991c).

RECOMMENDATIONS

Because of the precarious status of the single population of this species, the Scientific Committee in 1990 (IWC, 1991b) recommended that further action be taken to stop the major cause of entanglement by fully enforcing the closure of the totoaba fishery and reconsidering the issuance of future permits for experimental totoaba fishing, that immediate action be taken to stop the illegal shipment of totoaba (also and endangered species) across the US border, and that a management plan for the long-term protection of this species and its habitat be developed and implemented. The plan should include: (1) an evaluation of other fisheries that take or may take vaquitas; (2) investigation and implementation of alternative methods of fishing or other economically viable activities to prevent further incidental mortality; (3) education of the local fishermen and general public to increase awareness of the vaquita's dangerous situation; (4) monitoring of the status of the population of vaquitas; and (5) studies of the population biology of the species.

5.2.2 Lipotes vexillifer[10]

COMMON NAMES

Baiji, Chinese river dolphin

DISTRIBUTION

The species is presently restricted to the lower and middle Yangtze River, from the mouth to Yichang below the Three Gorges, where it occurs in small scattered groups over a distance of more than 1,000 km (Ridgway, 1966). It formerly occurred in other rivers and in the lakes feeding into the Yangtze.

PROBLEMS AND CATCH STATISTICS

The decline of the baiji is due to several causes: (1) habitat degradation (through depletion of fish stocks, development for water conservation and irrigation, and riverbank development, including explosion during construction), (2) increased river traffic resulting in deaths due to collisions with vessels, and (3) harmful fishing practices (Peixun and Yuanyu, 1989). The harmful fishing practices include the use of illegal bottom snaglines ('rolling hooks') and electrofishing. In 1984, in the section of the river from Honghu to Wuhu, 7 baiji were killed in explosions, 10 in illegal fisheries and one in electrofishing. Incidental kill data are not available for the entire length of the range of the species or for more recent years.

POPULATION ESTIMATE

The total number of baiji is estimated at 300 (Peixun and Yuanyu, 1989). This estimate is based on surveys conducted in 1985 and 1986. The density of dolphins per km of river searched ranged from 0.09 to 0.39. Further population surveys are planned.

ASSESSMENT AND STATUS

There is no estimate of original population size, but the range has contracted in historical times. The decline is thought to have been particularly steep during the last 35 years, as the Yangtze Valley has become industrialised and the river itself more heavily used (Perrin and Brownell, 1989).

RECOMMENDATIONS

The Workshop on Biology and Conservation of the Platanistoid Dolphins at Wuhan, People's Republic of China, in 1986 made a series of recommendations concerning conservation and management (Perrin and Brownell, 1989).

[9] Initial draft by W.F. Perrin.

[10] Initial draft by W.F. Perrin.

(1) Further efforts should be made to eliminate or reduce the use of the 'rolling hook' fishing gear in the regions of high dolphin density.
(2) Procedures should be developed to ensure that dolphins are absent or removed from the area before explosives are used in river-bank construction.
(3) All the proposed and additional natural reserve areas should be established along the river, with commitment of sufficient resources for effective enforcement of protective regulations.
(4) The two proposed semi-natural reserves at Shishou and Tongling should be constructed and the health of the captured dolphins placed in them monitored closely. Hydrologic surveys of the probable effects of high-dam construction on both sites should be carried out. Before dolphins are placed in the reserves, thorough studies of levels of contaminants in the water, bottom sediments and food fish should be completed. Seasonal change in the quantity and nutritive quality of the food fish should also be analysed. Finless porpoise should not be placed in the reserves; they may compete with the baiji for food in the situation of decreased species diversity of food fishes.

Since the workshop, several of these recommendations have been acted on. A patrol vessel has been put in service to enforce the ban on the use of 'rolling hooks'. An additional natural reserve has been established, and construction of the semi-natural reserve at Tangling has nearly been completed. An environmental study of the site of the proposed semi-natural reserve at Shishou has been carried out.

In addition the sub-committee **recommends** that monitoring of the population status should be continued.

5.2.3 Tursiops truncatus *on the Natal South Coast of South Africa*

COMMON NAMES

Bottlenose dolphin, *stumpneusdolfyn* (Afrikaans)

DISTRIBUTION

The bottlenose dolphin is found in tropical and temperate coastal waters around the world and in offshore waters in some regions (e. g. the eastern tropical Pacific: Scott and Chivers, 1990). In South African waters, the South Natal Coast population is apparently resident in a range approximately 30–40 km long (Ross *et al.*, 1989). Roughly 80–90% of dolphins seen in aerial surveys were within one km of the shore.

PROBLEMS AND CATCH STATISTICS

Approximately 20 dolphins die annually in anti-shark gillnets (Cockcroft, 1990; IWC, 1994). Most of the kill is made up of lactating females and their calves.

POPULATION ESTIMATE

Ross *et al.* (1989) estimated the population at 219–249, although some assumptions and factors in the assessment probably cause this to be an underestimate. They suggested a need for offshore aerial surveys, more detailed data on home range and daily movement patterns to assist in assessing the reliability of the aerial survey estimates, a means for estimating percentage of schools missed on the trackline, and mark-resighting studies of individual schools. Some of these problems were addressed in a series of surveys flown along the north coast of Natal in 1989 (Cockcroft *et al.*, 1991), from which it was estimated that the probability of seeing a dolphin group was 0.31 (approximate confidence limits 0.15, 0.46).

ASSESSMENT AND STATUS

The population may have been under pressure from the shark nets since 1952 (Ross *et al.*, 1989). The original size of the population is unknown. Although population size has been estimated as 219–249, the results of Cockcroft *et al.* (1991) suggest that this might be a substantial underestimate. Even so, the annual take of about 20 may be more than can be sustained, and it is likely that the population is declining (IWC, 1994).

RECOMMENDATIONS

Research needed to improve the population estimate is described above. The IWC Workshop (IWC, 1994) recommended that the killing of bottlenose dolphins in Natal waters be reduced immediately and that an immediate reassessment of deployment of the anti-shark nets be carried out. Information is also needed on relationships among contiguous stocks or herds of bottlenose dolphins.

5.2.4 Stenella coeruleoalba *in the Mediterranean Sea*[11]

COMMON NAMES

Striped dolphin (English), *delfin listado* (Spanish), *dauphin bleu et blanc* (French).

DISTRIBUTION

The striped dolphin is found in tropical and temperate waters worldwide. It is one of the most abundant cetacean species in Mediterranean waters. Its distribution extends over both the eastern and the western basins, although it appears to reach higher densities in the latter. It prefers deep waters and is usually found beyond at least 5–10 miles of the coast with the highest densities being probably reached in open waters.

PROBLEMS AND CATCH STATISTICS

Because of their pelagic habits, striped dolphins do not usually interact with coastal and artisanal fisheries. The major problems appear to be pollution, incidental catches in offshore drift nets.

(i) Pollution

This is probably the most acute long term problem for the population. Western Mediterranean striped dolphins are amongst those mammals in which the highest concentrations of organochlorine pollutants have ever been detected. The blubber of specimens stranded on the Mediterranean coast of France showed concentrations averaging 267 ppm for PCBs and 344 ppm for DDTs (Alzieu and Duguy, 1979) and free-ranging striped dolphins off Spain carried levels averaging 326 ppm of PCBs and 165 ppm of DDTs (Aguilar and Perrin, 1988). Concentrations of heavy metals, especially mercury, are also known to be extremely high (Viale, 1978; 1981; Sanpera *et al.*, unpub. data). Although no studies to establish the impact of these pollutant levels on the population have been carried out, it is well documented that some pollutants, especially organochlorines, depress reproductive rates, produce alterations in skeletal development, and depress the immune system of mammals (Luster and Faith, 1979; Nicholson and Moore, 1979).

[11] Initial draft by A. Aguilar.

In 1990 an epizootic process broke out in the western Mediterranean and produced thousands of deaths of striped dolphins. The ultimate cause was found to be a morbillivirus infection, although levels of PCBs in diseased dolphins were found to be higher than in the healthy population, suggesting that individuals carrying high pollution loads were more susceptible to the disease. Also, abnormal weather conditions that decreased water productivity in the region (and subsequent lack of food for the dolphins) may have also played a role by weakening the dolphins and facilitating the infection and spreading of the disease (Aguilar and Raga, 1990).

(ii) Catches

The striped dolphin is seldom caught in coastal gillnets, bottom trawlers or long-line fishing (Duguy *et al.*, 1983). However, the recent development of pelagic gillnet fisheries in Italian, Spanish and African Mediterranean waters produced considerable by-catches of this species in the late 1980s (Magnaghi and Podesta, 1987; di Natale, 1990; di Natale and di Sciara, 1990). Large-scale drift nets were temporarily banned in 1990 in Italy and strictly regulated in Spain in 1991. However, some limited drift net operations by foreign flag vessels in the southern Mediterranean still remain totally unregulated. The Government of Italy is reportedly considering whether the temporary ban instituted last year will be continued. Very recent, and as yet unconfirmed, information indicates that Italian vessels may be permitted to restart driftnetting in 1991 [*The ban was lifted – Ed*]. Reliable quantification of past and current incidental kills of striped dolphins in the Mediterranean is not available. Illegal directed kills of striped dolphins also occur in France, Italy, southern Spain and northern Morocco at least (Duguy *et al.*, 1983; Aguilar, unpub. data; di Natale, 1990).

POPULATION ESTIMATE

The Mediterranean population of striped dolphins appears to be independent of that inhabiting North Atlantic waters, although some limited mixing through the Gibraltar Straits probably exists (Aguilar and Perrin, 1988). No reliable population estimate for the Mediterranean population of striped dolphins is available. In the western basin it has been suggested that the species may have expanded in the last decades to occupy the ecological niche of the common dolphin, a species in clear recession (due to unknown causes), at least in the northern fringe of the western Mediterranean (Viale, 1985).

ASSESSMENT AND STATUS

Because of lack of reliable information of population abundance, population trends and biological parameters, the status of the species in the Mediterranean can not be assessed. However, the pressure of human activities, especially through pollution, incidental catches and decrease of prey abundance is undoubtedly adversely affecting the population.

RECOMMENDATIONS

IWC (1994) recommended that actions similar to the ban instituted by Italy should be encouraged elsewhere in the Mediterranean, and that international co-operation and action by the General Fisheries Council for the Mediterranean (GFCM) are required to ensure that large scale driftnet fisheries do not restart from other nations, or that reflagging for the purpose of continuing the fishery does not occur. A second recommendation was that wherever possible the consequences of banning drift nets for the fishermen involved should be studied, the economic impacts on the fishing community appraised and the subsequent development of alternative fishing methods monitored.

The sub-committee **recommends** that research efforts should be devoted to:

(i) monitoring pollutant levels, especially organochlorines and heavy metals, and assessing their effect on population parameters such as reproductive rates, body and skeletal growth, and immunological strength;
(ii) monitoring incidental and direct catches and identifying the fishing gear and areas in which the highest mortality occur;
(iii) determining population size, structure and stock identity, and estimating local abundance, especially in the regions affected by the 1990 epizootic;
(iv) monitoring fishing and anomalous natural mortality through examination of stranded animals. This will also permit continued monitoring of the health status of the population through necropsy.

The sub-committee also **recommends** that management measures should be adopted to ensure the enforcement of existing laws to restrict harmful fishing operations, and the reduction of pollutant shedding into Mediterranean waters.

5.2.5 Phocoena phocoena *in the western North Atlantic*[12]

COMMON NAMES

Harbour porpoise, common porpoise, *marsouin commun, pourcil*, (French); puffin' pig.

DISTRIBUTION

Distributed primarily in temperate and subarctic waters of the Northern Hemisphere, in the western North Atlantic, the distributional limits of this species are Upernavik (72°N) and northern Florida (28°N) (Gaskin, 1984; Polacheck *et al.*, In press). The vast majority of sightings have been made over the continental shelf, although harbour porpoises are occasionally found in deep waters further offshore (Stenson and Reddin, 1990). Gaskin (1984) suggested the existence of four stocks in the western North Atlantic based on indirect evidence from patterns of distribution and seasonal movements. From north to south, these proposed stocks are: (1) western Greenland, (2) eastern Newfoundland and Labrador, (3) Gulf of St. Lawrence, and (4) Bay of Fundy, Gulf of Maine and southwestern Scotian Shelf. Porpoises in all four stocks exhibit seasonal migrations and are common in inshore waters only during the summer months (Gaskin, 1984).

PROBLEMS AND CATCH STATISTICS

Harbour porpoises have been subjected to both directed hunting and incidental catches in commercial fisheries throughout their range. Aboriginal hunters in western Greenland took between 400 and 900 porpoises per year between 1900–50 and between 600 and 1,200 from 1950–87 except for the period 1968–71 when the catch was between

[12] Initial draft by A. Read.

1,300 and 1,500 (Kapel, 1977 and Danish Progress Reports to the IWC). It should be noted, however, that the reliability of the Greenlandic hunting statistics has been deteriorating during recent years. Harbour porpoises were also hunted in the Gulf of St. Lawrence (Laurin, 1976) and Bay of Fundy (Leighton, 1937; Prescott and Fiorelli, 1980) until recently (Gaskin, 1984). There are no reliable records of direct exploitation of this species in the waters of Newfoundland and Labrador.

Large numbers of harbour porpoises have been killed in salmon gillnets off the western coast of Greenland for several decades (Lear and Christensen, 1975). Foreign vessels were estimated to have taken approximately 1,500 porpoises in 1972 (Lear and Christensen, 1975) and the catch of the domestic fleet may have been almost as large (Kapel, 1977). No recent data exist on the numbers of porpoises killed in this fishery, although foreign vessels have been excluded since 1976 (Kapel, 1977). There is, however, reason to believe that the number of porpoises killed in this fishery has decreased since 1975 as the salmon quota has gone down from 2,000 tonnes in 1972 to around 800 tonnes in the most recent years (Lear and Christensen, 1975; Larsen, pers. comm.).

In Newfoundland and Labrador, harbour porpoises are killed in salmon gillnets, cod traps and groundfish gillnets. In 1980, 100 fishermen in Newfoundland reported taking 243 harbour porpoises in gillnets (Lien *et al.*, 1987). It is not possible to extrapolate a total catch from these data, because sampling was not proportional to fishing effort and no estimates of total effort are available. Nevertheless, the total annual incidental catch of harbour porpoises in this region probably numbers in the low thousands (Lien *et al.*, 1987).

Fontaine *et al.* (1992) sent questionnaires to 968 coastal fishermen in the Gulf of St. Lawrence and asked them how many porpoises they encountered in their nets during 1988. One-third of the fishermen responded, reporting that they caught 623 porpoises, mostly in groundfish gillnets. It is not known whether or not the respondents were representative of the entire fishing community, but it is clear that the incidental catch of harbour porpoises in the Gulf of St. Lawrence is substantial.

Harbour porpoises are also captured by bottom tending gillnets and herring weirs in the Bay of Fundy and Gulf of Maine (Smith *et al.*, 1983; Read and Gaskin, 1988). The largest incidental catches in this area are recorded by the groundfish gillnet fisheries. Reported kills by fishermen from the western Bay of Fundy and data on observed kill rates in the Gulf of Maine, combined with information on gillnet effort, suggest that the incidental catches are substantial, and it is has been suggested that recent takes are on the order of 300 to 800 animals per year (IWC, In press). However it is not currently possible to extrapolate observed kill rates for the Gulf of Maine to obtain an accurate estimate of total takes for this area because of the non-representative sample of vessels from which kill rate data were obtained and problems with spatial/temporal resolution in the gill net effort data (Smith *et al.*, 1990). In addition, no information is available on possible kills in the eastern Bay of Fundy and the western Scotian Shelf. There are a few confirmed reports of incidental catches from fixed gear in waters south of Cape Cod during winter months (Polacheck *et al.*, In press). Current efforts by the US National Marine Fisheries Services (NMFS) are directed at improving estimates of incidental catches by placing observers aboard gillnet vessels in the Gulf of Maine (Payne *et al.*, In press).

POPULATION ESTIMATES

No reliable population estimates are available for harbour porpoise stocks in Greenland, Newfoundland and Labrador, or the Gulf of St. Lawrence. Aerial surveys in the Gulf of Maine resulted in a minimum abundance estimate of 3,541 ±1,486 (Winn, 1982). Kraus *et al.* (1983b) performed a shipboard survey of the inshore waters of the Gulf of Maine and estimated harbour porpoise abundance at 7,956 ±1,327. The results of an experiment on census techniques indicated that aerial and shipboard surveys both under-estimate actual harbour porpoise density because only a small proportion of individuals are at the surface when the survey vessel passes (Kraus *et al.*, 1983a). Application of *ad hoc* correction factors derived from this experiment suggests that actual abundance was at least 15,000 when these surveys were performed. It was noted that these surveys may have missed a substantial proportion of the range of the population in this area, so that this may still be a considerable underestimate of the true population size (IWC, 1991c). A comprehensive census of harbour porpoises in the Bay of Fundy and Gulf of Maine is planned by NMFS during the summer of 1991.

ASSESSMENT AND STATUS

A lack of accurate data on the magnitude of directed and incidental mortality prevents definitive assessments of the status of harbour porpoises in Greenland, Newfoundland and Labrador, and the Gulf of St. Lawrence. Preliminary evidence, however, suggests that incidental catches are large in these areas and are thus cause for concern. Two recent reviews (IWC, 1991c; 1994) have concluded that the incidental catch of harbour porpoises in the Bay of Fundy and Gulf of Maine is unlikely to be sustainable. These reviews both recommended that steps be taken immediately to reduce the incidental mortality of harbour porpoises in this region. At the present time, harbour porpoises are listed as 'threatened' in eastern Canada by the Committee on the Status of Endangered Wildlife in Canada (Gaskin, 1989). A status review of this species in the United States is currently being performed by NMFS.

RECOMMENDATIONS

In 1990, the Scientific Committee (IWC, 1991c) recommended that research be undertaken to (1) improve understanding of harbour porpoise stock identity, (2) estimate abundance for all stocks, and (3) refine estimates of the magnitude of directed catches and incidental mortality for all stocks. Also to, (4) conduct a joint US-Canada comprehensive sighting survey in the Bay of Fundy, Gulf of Maine and adjacent waters. Each of these research initiatives will require a substantial investment of time and resources. In addition, research should address degradation of the coastal habitat of this species and the effects of contaminants on the condition of particular stocks. Research is underway for these recommendations in the Bay of Fundy and Gulf of Maine. Further, more general, recommendations on harbour porpoise research were made by the Scientific Committee in 1990. These are summarised in Item 5.2.7 below.

The large kills of harbour porpoises in commercial fisheries, combined with substantial uncertainty regarding many aspects of the biology of this species, led the Scientific Committee to recommend that levels of incidental mortality be reduced throughout the range of the species.

5.2.6 Phocoena phocoena *in the eastern North Atlantic*[13]

COMMON NAMES

Harbour porpoise (English), *bruinvis* (Dutch), *Schweinswal* (German), *marsvin* (Danish), *tumlare* (Swedish), *nise* (Norwegian and Faroese), *muc mhara* (Irish), *Marsouin* (French), *Marsopa* (Spanish).

DISTRIBUTION

Although recent surveys show an offshore, oceanic occurrence of the harbour porpoise, this species is primarily distributed in coastal waters of the temperate and subarctic zone throughout the Northern Hemisphere, with a population occurring as far south as Senegal in the East Atlantic (IWC, 1991c). The extensive shallow waters of the North Sea are probably the most important habitat for harbour porpoises in the Northeast Atlantic.

PROBLEMS AND CATCH STATISTICS

The sub-committee on small cetaceans expressed concern for the status of the stock when it reviewed available information in 1990, and listed incidental catches, depletion of prey populations, pollution and human disturbances as possible threats to porpoise populations in these areas (IWC, 1991c).

Most countries in the region have legislation protecting the harbour porpoise. The only reported directed catches of harbour porpoises are small takes in the Faroe Islands, and these takes are likely to have a negligible effect on the stock. Habitat degradation and incidental catches in fishing gear have been proposed as more significant threats to harbour porpoises in this region.

The seasonal migration of porpoises through the Danish Belt Seas into the Baltic is well known (Möhl-Hansen, 1954). This migration through shallow and narrow waters gave rise to the long history of the Danish harvest of porpoises. This historical hunt is described by Kinze (in prep), who mentions six major catching sites. The most important site was the northern Little Belt, which was operative in the period from 1357 to 1892 and in the years 1916–19 and 1941–44. The overall annual take for this site may have been about 1,000 animals, with a minimum total take of 47,432 animals from 1827 to 1892. According to Kinze, this hunt continued for about five centuries. However, in the 1880s the annual catches increased and may have initiated the decline of the 'Baltic population' of porpoises. The relative importance of these takes compared with other negative influences on the Baltic population is unknown.

Clausen and Andersen (1988) collected 149 porpoises mainly from coastal gillnet fisheries in Danish waters during 1980 and 1981. They also noted the existence of further catches in wreck nets worked further offshore in the southern North Sea. They proposed a total catch of several thousand by Danish vessels in the North Sea. Kinze (1990a) reported the capture of 152 porpoises in Danish fisheries, mainly in the Skagerrak, between 1986 and 1989. One vessel, from a fleet of 15 similar vessels at Hantsholm, was monitored individually in 1988 and 1989. An annual catch rate of 30 porpoises was recorded, which lead Kinze to speculate that this fleet may take around 450 per year. Further catches are reported in gillnets in Danish waters.

Further incidental takes in the order of tens to a few hundreds are reported from most other countries in the region (e.g. Northridge, 1988; Kremer and Schulze, 1990; Northridge and Lankester, 1990; Benke *et al.*, 1991). About 100 porpoises were recorded incidentally caught in a six-week period in 1988 by a drift net fishery for salmon in Norwegian coastal waters. The use of salmon drift nets was prohibited in Norway after the 1988 fishing season. Other Norwegian gillnet fisheries are known to catch porpoises, but less so than the former drift net fishery for salmon (Bjørge and Øien, 1990). Since the summer of 1988, a systematic scheme for collecting incidentally caught porpoises in Sweden has resulted in the collection of 178 individuals to December 1990, most of which came from gillnets in the Kattegat and Skagerrak (Lindstedt, 1990).

POPULATION ESTIMATES

The only estimates of population size based on survey results, are those of Bjørge and Øien (1990), who reported an estimated abundance of harbour porpoises in the Lofoten-Barents Sea area of 10,994 (CV 0.2381), and in the northern North Sea of 82,619 (CV 0.2165). There is little information on population trends in this area. In the Baltic Sea it is clear that harbour porpoise abundance has declined during this century (Andersen, 1982; Skora *et al.*, 1988; Määttänen, 1990). In the North Sea the situation is far from clear. The relatively large number of porpoises found in the central and northwestern North Sea gives no reason to neglect the possibility of a depletion of porpoise populations in neighbouring areas. Evans (1990) has reported declines in porpoise abundance in three separate areas in the Shetland Islands on the basis of boat surveys carried out locally in the early and late 1980s. Such results are difficult to interpret when so little is known of population distribution.

The stock identity of porpoises in the eastern North Atlantic is not well understood. A non-metric analysis of a large series of harbour porpoise skulls suggested the existence of several population units in this region (Kinze, 1990b), and a study based on isoenzyme electrophoresis indicated distinct Dutch and North Sea populations (Andersen, 1990).

ASSESSMENT AND STATUS

Although no single fishery is known to have a dramatically high incidental catch of porpoises (except for the possible large take in some Danish fisheries reported by Clausen and Andersen (1988)), the species is taken incidentally throughout the region, and there is a fear that the overall incidental catches could be above the sustainable level for the total population in the area. Although no reliable information is available at present on the population structure in the North and Baltic Seas, indications of distinct sub-populations exist. Taking into account the uneven distribution of fisheries, the impact of bycatches on any distinct sub-population may be more significant than overall takes on the total population in the northeast Atlantic region.

RECOMMENDATIONS

At its 1990 meeting, the Scientific Committee recommended, as a high priority, that incidental kills of harbour porpoises in gillnets should be reduced throughout their range (IWC, 1991c). Possible ways to reduce incidental kills include gear modifications, gear conversions, area or season closures and other restrictions in the fisheries.

The importance of determining harbour porpoise stock identities was also highlighted by the Scientific Committee in 1990 and it recommended that studies on stock identity should be undertaken through an integrated approach that

[13] Initial draft by A. Bjørge.

includes a combination of pollutant levels, calving areas, non-metric variation, DNA allozymes and other types of research that may contribute to stock discrimination.

The Committee also recommended:

(1) that the methodology for these different approaches be standardised so that results are comparable;
(2) that where distribution extends beyond the boundaries of a single country, available samples and data should be pooled from as many potential sub-populations as possible, across national boundaries, and be analysed together;
(3) that for the northeastern Atlantic the information on potential stocks, distribution, and other relevant data be synthesised in an attempt to produce a clearer picture of the stock identities in that region;
(4) that abundance be estimated for populations where no such estimates exist, and especially for those for which there is or may be a large incidental kill;
(5) that such studies consider the possibility that apparent declines in abundance may result from geographic shifts in distribution. Trends in abundance should be monitored on the basis of systematic surveys;
(6) that dedicated sightings surveys should be conducted in the North and Baltic Seas;
(7) that attention should be given to estimating g(0) for harbour porpoise surveys;
(8) that behavioural studies of free ranging harbour porpoises should be made to gain knowledge of habitat requirements in order to provide a framework for establishing management plans for the species and its habitat;
(9) that tissues of stranded and incidentally killed harbour porpoises should be collected and analysed in order to monitor their contaminant levels;
(10) that monitoring of pollutants be integrated with research on reproductive biology and other population parameters to increase the understanding of the possible effects of contaminant loads on the condition of the populations (this was considered especially important in the northeast Atlantic region);
(11) that a high priority be given to monitoring, as well as reducing, levels of incidental mortality in all fisheries;
(12) that when questionnaire and interview methodology is used to investigate or monitor incidental catches, studies of reliability and scaling of reported take estimates should also be included.

An additional recommendation is that all countries of the northeast Atlantic region should implement a recording scheme for incidental captures of harbour porpoises in their waters.

5.2.7 High Seas driftnet fisheries

5.2.7.1 *North Pacific*

Driftnet fisheries in the North Pacific Ocean include the following: (1) Japanese salmon drift gillnet fishery, (2) Japanese, Taiwanese and Korean drift squid gillnet fishery and (3) Japanese and Taiwanese large mesh drift gillnet fishery for tunas and billfishes. The major small cetaceans taken in these fisheries are the northern right whale dolphin, *Lissodelphis borealis*, Pacific white-sided dolphin, *Lagenorhynchus obliquidens* and Dall's porpoise *Phocoenoides dalli*. Other small cetaceans that are known or likely to be taken included common dolphin, *Delphinus delphis*, striped dolphin, *Stenella coeruleoalba*, bottlenose dolphin, *Tursiops truncatus*, Risso's dolphin, *Grampus griseus*, spotted dolphin, *Stenella attenuata*, pygmy killer whale, *Feresa attenuata*, pygmy sperm whale, *Kogia* spp. and ziphiids. The three major species are reviewed in turn below.

Lissodelphis borealis[14]

COMMON NAMES

Northern right whale dolphin; *semi-iruka* (Japanese); *severnyi kitovidnyi del'fin* (Russian).

DISTRIBUTION

The northern right whale dolphin is a cold-temperate water species endemic to the North Pacific Ocean. In the eastern North Pacific, it has been sighted from about 32° to 58°N (Fig. 4; Leatherwood and Walker, 1979; Kajimura and Loughlin, 1988). In the western North Pacific, the southern limit is as far south as 35°N from September to June (Kasuya, 1971) and about 40°N in the remainder of the year (Fig. 4); the northern limit is the southern Kurile Islands (Sleptsov, 1952; Klumov, 1959). The southern boundary in the central North Pacific is about 35°N (Fig. 4). Their temperature range is about 8° to 24°C, although the majority of the sightings have been in temperatures of 11°to 17°C (Fig. 4; Dohl *et al.*, 1983). Based on sightings

[14] Initial draft by L.L. Jones and E. Miller.

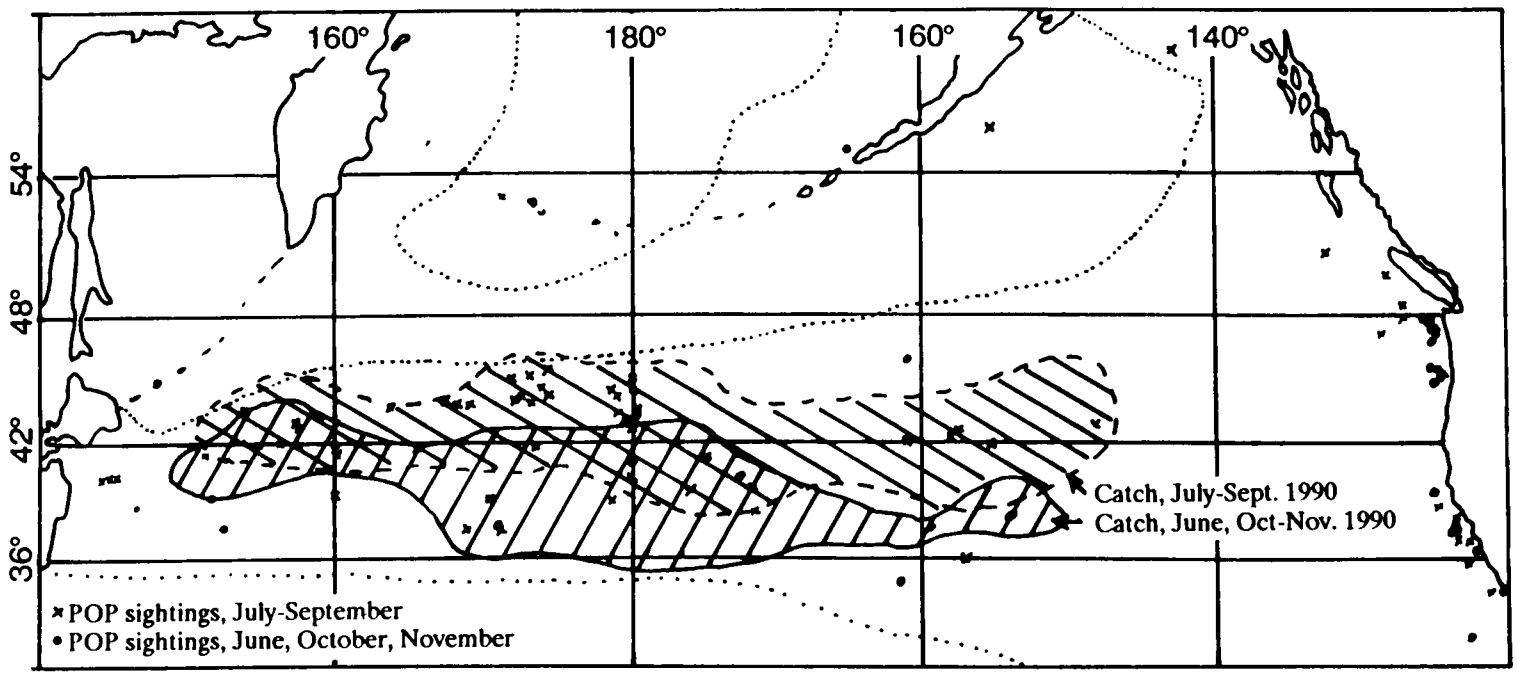

Fig. 4. Sightings of *Lissodelphis borealis* (1958–89) and high seas driftnet catch areas in 1990.

and bycatch data, off the Pacific coast of Japan and in the central North Pacific, seasonal movements appear to be related to the seasonal movements of the waters of the North Pacific Transition Zone.

Although this species occurs predominately in offshore waters, it does occur seasonally over the continental shelf in winter and spring off California (Leatherwood and Walker, 1979). Off Oregon and Washington it is also sighted more frequently nearer to shore in the colder water months (November to June; Fig. 4).

No colour morphs have been reported, although colour variants have (Nishiwaki, 1972; Leatherwood and Walker, 1979). Nishiwaki (1972) proposed two subspecies based on differences in colour pattern and dental formulae. However, Leatherwood and Walker (1979) examined these characteristics from animals from the eastern North Pacific and concluded there was not sufficient evidence for two subspecies.

PROBLEMS AND CATCH STATISTICS

Large numbers of northern right whale dolphins are currently taken incidentally in several high seas driftnet fisheries. Seven driftnet fisheries operate in the high seas in the North Pacific: Japanese squid, salmon mothership (now called the non-traditional landbased), salmon (traditional) landbased, and large-mesh for tuna and billfishes; Korean squid; and Taiwanese squid and large-mesh for tuna and billfishes. The northern right whale dolphin is probably taken in all except the salmon fisheries.

The largest known incidental take of northern right whale dolphins is in the Japanese high seas squid driftnet fishery which began in 1978. This fishery expanded rapidly, to a peak of 534 boats in 1981. In 1990, there were 457 vessels in the Japanese fleet which conducted 23,588 driftnet operations, deploying about 1,200,000 km of net (data from the Fisheries Agency of Japan).

Using a simple ratio estimator with the observed catch rate from June to September 1989, and reported fishing effort for the entire fishing season (33,646 operations, June-December 1989), nearly 11,000 northern right whale dolphins are estimated to have been incidentally taken by the Japanese high seas squid fishery in 1989. This estimate is based on a pilot observer programme in which 1,402 out of 33,646 driftnet operations (about 4%) were observed. The majority of the dolphins caught were dead but some (2%) were released alive. The survival rate of dolphins released is unknown.

In 1990, the scientific observer programmes were expanded in all the high seas driftnet fisheries in the North Pacific to increase observer coverage substantially and to cover all fishing seasons and grounds. These data are currently being analysed to provide more accurate estimates of the annual incidental take in these fisheries over the fishing areas and seasons. Summaries of the catch data from these fisheries will be available in June 1991.

Catch rates of northern right whale dolphins in other high seas driftnet fisheries may be lower than that of the Japanese squid fishery. Although the general fishing methods are similar, the driftnet fisheries use different mesh sizes, different amounts of net, and fish in different areas at different times of the year (Jones *et al.*, 1990). For example, the fishing grounds occupied by Korean squid driftnet vessels overlap with those occupied by Japanese squid driftnet vessels less than one-third of the season, mainly in June. The remainder of the season the Korean vessels fish further west than do Japanese vessels. Taiwanese vessels also tend to operate further west than the Japanese squid vessels. Therefore, applying take rates from one fishery to another may result in inaccurate estimates of the total incidental take for a species.

Two previous calculations for incidental take of northern right whale dolphins in high seas driftnet fisheries have been reported. Northridge (In press) provided a crude estimate of some 19,000 northern right whale dolphins taken in the three squid fisheries in 1989. This estimate was based on the gross catch rate observed in the Japanese squid driftnet fishery (Gjernes *et al.*, 1990) and an assumed total fishing effort of 3,000,000 km of netting set. This latter figure was based on the reported numbers of vessels operating in 1988 in each of the three fleets, with some allowance for differences in the average amounts of netting deployed by vessels from each of the three fleets. The actual fishing effort may have been lower than this in 1989, as the number of vessels and catch by the Republic of Korea which were recently reported by the Korean Government were lower than assumed by Northridge.

Beamish *et al.* (1989) stated that 50,718 northern right whale dolphins were caught each year in high seas squid driftnet fisheries. Their calculation was based on a total of 63 retrieval observations collected in 1986 and 1988, and the reported Japanese squid fishing effort in 1987. They also assumed the same kill rate for all fisheries and estimated the fishing effort for the Korean and Taiwanese fisheries as a proration of the Japanese fishing effort, based on the number of vessels in each fishery.

These two estimates of total kills demonstrate the problems inherent in extrapolating estimates of kill rates to entire fleets when adequate data on all parts of the fleet are not available.

In addition to these catches in driftnet fisheries, the northern right whale dolphin has been hunted in Japan historically (Gilmore, 1951; Wilke *et al.*, 1953; Mitchell, 1975a). Ohsumi (1972) reported that harpoon fishermen took northern right whale dolphins when billfish and tuna catch was low. From 1976 to 1982, a total of 252 northern right whale dolphins were reported caught by the harpoon fishery for Dall's porpoise (*Phocoenoides dalli*) off Sanriku in northern Honshu (Miyazaki, 1983). This species currently is also incidentally taken by Japanese coastal driftnets. The reported catch in 1988 was 268 (Anonymous, 1990d). Small numbers are also taken in gillnet fisheries in California (IWC, 1994).

POPULATIONS AND ESTIMATES

The northern right whale dolphin is reported to be an abundant species in temperate waters. Nishiwaki (1972) provided an unrealistic low abundance estimate of 10,000 northern right whale dolphins in the North Pacific Ocean. Subsequently, Leatherwood and Walker (1979) estimated the population in the Southern California Bight in winter, when density is known to be highest, to be about 17,800 (no variance given). Japan has conducted sightings surveys in offshore areas, including the area of the driftnet fishery. Results from these surveys will be presented in the near future. US sightings data are also currently being analysed to provide abundance estimates for the offshore area of the North Pacific.

ASSESSMENT AND STATUS

The number of stocks which the fisheries affect is not known, but probably includes more than one stock. Lacking population estimates and information on stocks, and with only a preliminary estimate of incidental take in one fishery, status of the northern right whale dolphin is

unknown. However, large incidental catches for more than ten years raise concern for possible impacts by these fisheries, and the Scientific Committee (IWC, 1994) considered that the large catches of northern right whale dolphins were potentially not sustainable.

ADDITIONAL INFORMATION NEEDS

Incidental take in the high seas driftnet fisheries will continue to be monitored under international agreements at levels that will provide reliable estimates of incidental take in 1991 and early 1992 . Biological samples are being collected to determine age structure, reproductive parameters, food habits and stocks. Sighting data are being collected on commercial and research vessels to provide estimates of abundance. However, the survey effort will be low over much of the species range. The USA and Japan will both conduct sighting surveys in July and August 1991 to obtain estimates of abundance on the fishing grounds during the peak of the fishing season, and to relate cetacean distribution to Japanese fishing effort data and oceanographic features.

Lagenorhynchus obliquidens[15]

COMMON NAMES

Pacific white-sided dolphin, *kama iruka* (Japanese)

DISTRIBUTION

This species is found only in the North Pacific Ocean. In the western North Pacific it is found as far south as Taiwan, in the eastern North Pacific to southern Baja California, Mexico, and across the temperate waters of the North Pacific (Leatherwood *et al.*, 1984; Miyashita, 1989). Two stocks may occur within the coastal waters of both the western and eastern Pacific (Walker *et al.*, 1986; Miyazaki and Shikano, 1989).

PROBLEMS AND CATCH STATISTICS

Pacific white-sided dolphins are the second most frequently caught small cetacean in the high seas Japanese squid driftnet fishery in the central North Pacific. Northridge (In press) has provided a rough estimate of the number killed in 1989 at around 11,000 (see method used and caveat under *Lissodelphis borealis* section above). Additional Pacific white-sided dolphins may also be killed in the Japanese and Taiwanese large-mesh high seas driftnet fisheries that target tunas and billfishes (Watanabe, 1994). These dolphins are also known to be caught incidentally in the Japanese fisheries.

Small numbers of Pacific white-sided dolphins are killed each year in Japanese waters for human consumption. Larger numbers of these dolphins were taken in cull programmes during the 1970s and 1980s. Additionally, small numbers of Pacific white-sided dolphins are incidentally killed in various coastal fisheries on both sides of the North Pacific (e.g. Anonymous, 1987b; Barlow *et al.*, 1992).

POPULATION ESTIMATES

The total size of the populations throughout the range of this species is unknown.

ASSESSMENT AND STATUS

The number of stocks affected by high seas driftnet fisheries is unknown but probably more than one stock is taken. The Scientific Committee (IWC, 1994) considered that the large kills of Pacific white-sided dolphins were potentially not sustainable. Large incidental catches have occurred for more than ten years (since the start of the high seas squid driftnet fishery) and the total population size is unknown. Therefore, concern is noted over the status of the stocks taken in high-seas driftnet fisheries.

Dall's porpoise, Phocoenoides dalli *(True, 1885)*[16]

COMMON NAMES

Dall's porpoise, *ishi iruka* (Japanese).

DISTRIBUTION

The distribution of this species is described above in Item 5.1.1. The main stock of concern is that south of the Aleutian Islands.

PROBLEMS AND CATCH STATISTICS

This species has been taken in all four of the major driftnet fisheries of the North Pacific. In the past, incidental kills of 10,000 to 20,000 Dall's porpoises per year were considered possible in the Japanese high seas salmon driftnet mothership fishery (Mizue and Yoshida, 1965) which started in 1952. This fishery operated within the US 200 mile limit between 1978 and 1988. Eleven motherships and 368 catchers operated in this fishery during the 1960s, compared to only 4 motherships and 172 catchers in 1978. The estimated annual incidental catch of Dall's porpoises in the fishery between 1981 and 1987 within the US EEZ ranged from a low of 741 in 1987 to a high of 4,187 in 1982 (IWC, 1991c). In the western North Pacific, these porpoises are also taken in the Japanese land-based salmon gillnet fishery. Between 1981 and 1986 the estimated annual catch averaged 1,645 (Ito, 1986).

Incidental catches of Dall's porpoise have also been reported in the driftnet fishery for squid, operated by Japanese, Taiwanese and Korean vessels. An extensive observer scheme in the Japanese fishery in 1989 revealed catches of around 1.98 Dall's porpoises per 1,000km of netting set. Northridge (in press) suggested a possible total of around 3,000,000 km of netting set in these fisheries, which might suggest a total catch of about 6,000 animals. Jones and Miller (*Lissodelphis* section above) thought that total effort was less than this, and that this estimate might be therefore high because of variation in take rates between fisheries. Catch rates vary from year to year and fleet to fleet, so any estimate of total catch is necessarily very crude at this stage.

POPULATION ESTIMATE

There is no population estimate for the Dall's porpoise stock south of the Aleutian Islands, but (Turnock, 1987) gave an estimate of 741,000 porpoises for the western and central North Pacific region (see 5.1.1.).

ASSESSMENT AND STATUS

The pelagic squid drift net fishery may have taken around 6,000 porpoises in 1989 from a wide area across the North Pacific from more than one stock. The pelagic squid fishery was started by Japan in 1978. It does not exploit the same stocks as are taken in the hand harpoon fishery. Additional Dall's porpoises are killed in smaller numbers in the large-mesh drift net fishery off Japan for tunas and billfishes (L.L. Jones, pers. comm.). The total take from these populations is, therefore, somewhat less than 1% of the

[15] Initial draft by R.L. Brownell, Jr.

[16] Initial draft by R.L. Brownell, Jr. and T. Kasuya.

population estimate (741,000) for the western and central North Pacific. Impact on the 'South of Aleutian' stock is uncertain.

RECOMMENDATIONS

In line with the UN Resolution, it is recommended that all large scale pelagic high seas driftnet fishing in the North Pacific, as elsewhere, should be suspended by 30 June 1992, with the understanding that such a measure will not be imposed, or if implemented, can be lifted, should effective conservation and management measures be taken based upon statistically sound analysis to be jointly made by concerned parties of the international community with an interest in the fishery resources of the region, to prevent unacceptable impact of such fishing practices on the region, and to ensure the conservation of the living marine resources of the region.

The IWC Workshop (IWC, 1994) also recommended that should the North Pacific high seas driftnet fisheries continue, the observer programme should continue to collect statistically adequate data, and that the data collected on mammals taken in the squid driftnet and large mesh driftnet fisheries be analysed as soon as possible.

5.2.7.2 *South Pacific*

Two species of dolphins (common dolphin, *Delphinus delphis;* striped dolphin, *Stenella coeruleoalba)*, were taken in considerable numbers by large-scale pelagic driftnet fisheries in the South Pacific region in the 1988/89 and 1989/90 seasons. At least three other cetacean species (southern bottlenose whale, *Hyperoodon planifrons;* short-finned pilot whale, *Globicephala macrorhynchus;* and Risso's dolphin, *Grampus griseus)* were also reported to have been taken incidental to fishing operations.

DISTRIBUTION

Striped and common dolphins are found in tropical and temperate waters worldwide; Risso's dolphin and the short-finned pilot whale are recorded from tropical and warm temperate waters; the southern bottlenose whale occurs throughout the Southern Ocean, and north to about 30°S (Klinowska, 1991).

PROBLEMS AND CATCH STATISTICS

A small number of Japanese vessels operated an experimental large-mesh driftnet fishery for several species of tuna in the Tasman Sea and the waters to the east and south-east of New Zealand from 1983–1988 (IWC, 1994). During the austral summer of 1988–89 there was a rapid increase in the number of vessels involved in the fishery. 64 Japanese vessels fished in the Tasman Sea, and between 60–130 Taiwanese driftnet vessels operated in the Sub-Tropical Convergence Zone (STCZ), south of the Cook Islands and French Polynesia. One driftnet research vessel from the Republic of Korea also operated in the region during part of the 1988/89 season.

No data are available for the numbers of small cetaceans incidentally taken during the course of the 1988/89 season, but estimates can be made from observations of the operations of the driftnet fleet during the 1989/90 season. An observer aboard a Japanese driftnet research vessel in the Tasman Sea in November/December 1989 observed 22 sets and reported an average catch rate of 0.64 common and striped dolphins per 10 km of net set (Sharples *et al.*, 1989). The proportion of common dolphins incidentally taken to striped dolphins was 4.5:1.

Surveys were also carried out on approximately 126 km of driftnet set by Japanese vessels in the Tasman Sea during January 1990 (Coffey and Grace, 1990). An incidental rate of capture of 0.54 striped and common dolphins was reported per 10 km of net set.

No data were provided by the Taiwanese driftnet fleet which operated in the Sub-Tropical Convergence Zone during the 1988/89, 1989/90 and 1990/91 seasons, and no observers were placed aboard the fleet. The Taiwanese Government announced a reduction in the fleet size from between 60 and 130 vessels in 1988/89, to 11 vessels in 1989/90 and 11 vessels in 1990/91.

Estimates of the likely catch rates can be derived from the report of the observer aboard the *Shin-Hoyo Maru* driftnet research vessel, which carried out trials in the STCZ in February/March 1990 (Shaples *et al.*, 1989). Cetacean catch rates of 0.17 per 10km of net were reported in the STCZ, and comprised mainly common dolphins, with one capture of a Risso's dolphin.

It is clear that thousands of dolphins may have been killed in these fisheries.

POPULATION ESTIMATES

No population estimates in the South Pacific region are available for any of the species subjected to incidental catch in driftnets.

ASSESSMENT AND STATUS

Because of the lack of reliable information on population abundance and biological parameters, the impact of large-scale pelagic driftnet fisheries on the small cetaceans of the South Pacific region cannot be reliably assessed.

Concern over the conservation of both tuna and non-target species gave rise to the Tarawa Declaration adopted by the South Pacific Forum in July 1989. The Declaration resolved to prevent and discourage the practice of large-scale pelagic driftnet fishing in the region. In addition, the UN Resolution (UNGA 44/225) on 'large-scale pelagic driftnet fishing and its impact on the living marine resources of the world's oceans and seas', paragraph 4b, called for 'immediate action should be taken to reduce progressively large-scale pelagic driftnet fishing activities in the South Pacific region with a view to the cessation of such activities by 1 July 1991, as an interim measure, until appropriate conservation and management arrangements for South Pacific albacore-tuna resources are entered into by the parties concerned'.

The Japanese Government suspended any further operations of driftnet vessels in the South Pacific in July 1990, pending the conclusion of negotiations to establish a management regime for albacore tuna in the region. This was one year before the onset of the moratorium agreed to under the UN resolution. The Republic of Korea suspended driftnet operations in the South Pacific from the end of the 1988/89 season. The Taiwanese Government has informed the Forum Fisheries Agency that there will be no further deployments of Taiwanese driftnet vessels in the region.

RECOMMENDATIONS

Nations of the South Pacific region should be encouraged to carry out surveys of cetacean abundance and distribution, especially for pelagic small cetaceans. The South Pacific Regional Environment Programme may be an appropriate vehicle to encourage and promote such research.

5.2.7.3 *Indian Ocean*

There are known to be about 140 Taiwanese driftnet vessels operating in the Indian Ocean targeting albacore, other tunas and sharks. The fishery operates in the Arabian Sea and in southerly latitudes between about 20°S and 40°S (Hsu and Liu, 1990). There is no information on catches of cetaceans, but this is the largest driftnet fishery currently operating outside of the North Pacific, and large numbers of cetaceans might be expected to be caught. This fact is of particular concern to the sub-committee in view of the status of the Indian Ocean region as a whale sanctuary, and in view of the almost complete lack of information on cetacean catches and the apparent inaction of the Indian Ocean Fisheries Commission in this regard.

RECOMMENDATIONS

The IWC Workshop (IWC, 1994) noted that fleets from Taiwan, China (with inadequate data for operations) operate in the Indian Ocean and recommended that, while such activities continue, data on all distant-water fleets must be collected by the flag nations and nations servicing these fleets, and independent observers placed on board vessels. The by-catches must be reported and evaluated and appropriate management actions taken before further fishing takes place.

5.2.7.4 *Atlantic and Mediterranean*

Taiwanese large-mesh fisheries for tunas and other species are known to operate in both the South and North Atlantic. In the South Atlantic, recent reports indicate a previously unknown driftnet fishery for albacore around Tristan da Cunha. As many as 160 Taiwanese vessels may operate in this fishery and reports indicate incidental catches of unknown species of small whales and dolphins (Ryan and Cooper, 1991). Observations from a South African deckhand have been used to produce a speculative estimate of some 7,500–10,000 dolphins, and 1,000–1,500 small whales killed in this fishery (IWC, 1994). In the North Atlantic a smaller fleet of about 20 Taiwanese vessels is thought to be operating and entanglements of cetaceans have also been reported, but in unknown numbers (Northridge, In Press).

In the Mediterranean Sea there are no 200 mile EEZs, and as a consequence much of the area is classified as high seas. Driftnets for tuna and swordfish are used by several nations, but until July 1990 the great majority of vessels, some 700 or more, were Italian. The Italian fishery was suspended in 1990, but recent unconfirmed information suggests a part of this fishery may be resumed. Striped dolphins are the most commonly taken species (see Item 5.2.4).

There is an expanding fishery for albacore operating in the Northeast Atlantic both inside and outside European EEZs. This fishery was initiated by the French in 1986, and 37 French vessels participated in 1989. Two Irish vessels joined this fleet in 1990 (Wray, 1990) and four English vessels have indicated an intention to join the fishery in 1991 (Anonymous, 1991). Cetacean species known to be taken include striped and common dolphins, but other species are also likely to be taken. The total dolphin catch by the French fleet was estimated as 131 in 1989 and 420–460 in 1990.

DISTRIBUTION OF SPECIES

Species taken in the Taiwanese fisheries are unknown. Common and striped dolphins have a worldwide distribution in tropical and temperate waters.

ASSESSMENT AND STATUS

The IWC's Workshop (IWC, 1994) proposed that catches of striped dolphins in the swordfish driftnet fishery in the Mediterranean were not sustainable (see also Section 5.2.4). Nothing is known of the stock size or status of any other species or population likely to be impacted by these fisheries.

RECOMMENDATIONS

(1) The IWC Workshop (IWC, 1994) noted that fleets from Taiwan, China, and other nations continue to operate without documentation in the Atlantic and recommended (as for the Indian Ocean) that, while such activities continue, data on all distant water fleets must be collected by the flag nation, and nations servicing these fleets, and independent observers placed on board vessels. The incidental catches must be reported and evaluated and appropriate management actions taken before further fishing is authorised.

(2) The United Nations resolution 44/225 recommended to member states 'that further expansion of large scale pelagic driftnet fishing on the high seas of the North Pacific and all other areas outside the Pacific Ocean should cease immediately'.

In view of the unanimously passed resolution, the Scientific Committee strongly **recommends** that member nations take immediate steps to curtail the expansion of driftnet fisheries in the Mediterranean and Northeast Atlantic into high seas areas, and in any event **recommends** that such fisheries should be terminated by June 1992 in accordance with paragraph 4a of the UN resolution 44/225.

(3) Paragraph 4a of the UN resolution 44/225 called upon member nations to impose moratoria on all large-scale pelagic high-seas driftnet fishing by 30 June 1992, with the understanding that such a measure will not be imposed in an area, or if implemented, can be lifted, should effective conservation and management measures be taken based upon statistically sound analysis to be jointly made by concerned parties of the international community with an interest in the fishery resources of the region, to prevent unacceptable impact of such fishing practices on that region, and to ensure the conservation of the living marine resources of that region.

In view of the absence of any relevant data on the status of cetacean stocks impacted by high seas driftnet fisheries in this area, the sub-committee **recommends** that research priority should be given by the EC and its member states to assessing the status of all cetacean stocks impacted by the European high seas driftnet fisheries. Such an action is required by the UN Resolution for any continued fishing.

5.3 Deliberate incidental catches in Eastern Tropical Pacific[17]

Since the late 1950s, large numbers of dolphins, perhaps as many as seven million have been killed incidental to purse seine fishing operations for yellowfin (and skipjack) tuna in the eastern tropical Pacific. Over 80% of the incidental kill involved just two stocks: the northern offshore form of spotted dolphin, *Stenella attentuata*, (62%) and the eastern form of spinner dolphin, *Stenella longirostris*, (22%). Also involved are common dolphins (*Delphinus delphis*) and striped dolphins (*Stenella coeruleoalba*). Incidental catch levels have been significantly reduced from the levels of the 1960s but have continued to average over 85,000 for the last 5 years. The total kill in 1990 was 53,000 dolphins.

[17] Initial draft by DeMaster, Wade and Sisson.

Some stocks were likely significantly reduced in the early years of the fishery. Information from recent analysis of trends suggests that no major changes in abundance have taken place in recent years. Insufficient information exists to compare reliably current abundance estimates of these dolphin stocks with their population levels prior to the commencement of purse-seine fishing operations in the ETP.

5.3.1 Stenella attenuata

COMMON NAMES

Spotted dolphin; spotted porpoise; *delfínmanchado* (Spanish).

DISTRIBUTION

Three stocks of spotted dolphins are recognised: northern offshore, southern offshore, and coastal. (Perrin *et al.*, 1985). Recent information on seasonal movement patterns (Reilly, 1990) and patterns of morphological variation (Perrin *et al.*, 1985) suggests that spotted dolphins move between the western and southern portions of their range, and the stock delineations are being re-examined.

PROBLEMS AND CATCH STATISTICS

Estimates of incidental mortality are reported in Smith (1983) for years 1959–1978, the IATTC Annual Report (Anonymous, 1989, for years 1979–1988), Hall and Boyer (1990) for 1989, and Hall and Boyer (1991) for 1990. These data are summarised in Table 18. Quotas for the US fleet have been set for the northern offshore, southern offshore, and coastal stocks (20,500, 5,697, and 250 respectively). Mortality estimates for the coastal stock are considered unreliable because of the difficulty in separating the offshore and coastal forms and because of the low level of effort in near-shore waters. Estimates of mortality between 1959–1972 and 1979–1985 are imprecise because of inadequate observer coverage. Since 1986, observer coverage of US and international fleets has yielded much more reliable estimates of mortality.

POPULATION ESTIMATES

Wade and Gerrodette (1992) analysed data from five years of research vessel surveys and produced estimates of relative abundance. The sub-committee believes that these are the best available estimates of absolute abundance of the stocks. The northern offshore spotted dolphin population size ranged between 658,300 and 2,205,500 (average 1,514,800) with CVs between 29 and 36 %. The southern stock size was estimated to be between 85,800 and 475,800 (average 267,400) with CVs between 48 and 86 %.

In addition to these estimates, Anganuzzi *et al.* (1992) reported estimated trends in relative abundance for the northern and southern stocks based on sightings data from observers aboard tuna vessels.

ASSESSMENT AND STATUS

At this time, the only reliable information on trends in abundance is based on sightings data collected aboard tuna vessels, because too few annual data points have been obtained from the research vessel surveys and the available history data have not yet been suitably analysed. Estimated trends (Anganuzzi *et al.*, 1992) suggest that there was a significant decline in the northern stock in the late 1970s, followed be a period of relative stability (and perhaps some increase) in the 1980s. For the southern stock, there is indication of a decline during the early 1980s. Recent high estimates suggest the possibility of exchange with the northern stock, so reported trends for the southern stock should be treated with caution. The tuna vessel estimates of Anganuzzi and Buckland (1989) were used by Edwards and Glick (1991) to test for linear trend over 10-year windows. Significant declines were only found for the northern stock in years 1975–1984 and 1976–1985. A power analysis with type 1 and type 2 error levels set at 0.1 indicated that significant trends would have had to be on the order of 6–7% per year over the 10 year period to be detected. It is currently thought that these populations under conditions of no incidental mortality should be increasing at approximately 2–6% per year (Reilly and Barlow, 1986). For the northern offshore stock, the current level of incidental mortality (Table 18) is at a level similar to the expected rate of increase, therefore, it is not surprising that no significant trends in abundance have been detected in recent years. Table 18 indicates that the take has been of the order of 2.1% to 4.5% of the northern stock and 0.6% to 1.9% of the southern stock annually since 1986.

Table 18

Estimates of population size, mortality and percent mortality from 1986 - 1990 of the three major dolphin species killed in the Eastern Tropical Pacific (ETP) purse seine fishery.

	Average abundance[1]	1986		1987		1988		1989		1990	
	1986-90	kill	% kill	kill	%kill	kill	%kill	kill	%kill	kill	%kill
Spotted											
N. offshore	1,514.8	68.0	4.5	51.7	3.4	36.1	2.4	52.1	3.4	32.3	2.1
S. offshore	267.4	5.1	1.9	3.3	1.2	2.2	0.8	3.9	1.5	1.6	0.6
Spinner											
Eastern	588.5	19.5	3.3	10.4	1.8	18.8	3.2	15.2	2.6	5.4	0.9
Whitebelly	993.7	11.0	1.1	6.0	0.6	3.5	0.4	8.3	0.8	7.0	0.7
Common											
Northern	467.4	13.3	2.8	8.2	1.8	4.8	1.0	1.1	0.2	0.7	0.1
Central	594.3	10.9	1.8	9.7	1.6	7.1	1.2	12.7	2.1	4.1	0.7
Common	2,117.5	0.1	0.0	6.8	0.3	4.2	0.2	0.6	0.0	0.3	0.0
Total		127.9		96.1		76.7		93.9		51.4	

[1] From Gerrodette and Wade (SC/43/SM13).

5.3.2 Stenella longirostris

COMMON NAMES

Spinner dolphin, spinner porpoise; *tornillo* (Spanish).

DISTRIBUTION

There are four recognised stocks of spinner dolphins in the ETP (northern whitebelly, southern whitebelly, eastern and Central American [formerly Costa Rican]. The last two have been recognised as subspecies (Perrin, 1990). Recent analyses by Perrin *et al.* (1991) suggest that the northern and southern whitebelly stocks should be combined into a single management unit. Subsequent references to whitebelly spinner dolphins here will follow this recommendation.

PROBLEMS AND CATCH STATISTICS

Incidental mortality estimates for the eastern stock have varied between a maximum of 133,000 in 1960 and a low of 745 in 1983 (Table 19). For the whitebelly stock, absolute mortality and % mortality has been much lower than for the eastern stock.

POPULATION ESTIMATES

Wade and Gerrodette (1992) estimated the eastern spinner abundance based on five years of research vessel surveys (1986–1990) to be between 391,200 and 754,200 (average 588,500) with CVs between 37 and 42 %. Abundance estimates for the whitebelly stock ranged from 363,300 to 1,398,400 (average 993,700) with CVs between 38 and 64%. Anganuzzi and Buckland (1989) reported abundance estimates of 584,000 (CV=18%) and 384,000 (CV=23%) for the eastern spinner in 1986 and 1987, respectively.

No significant trends in eastern spinner numbers during 1975/90 was detected by Anganuzzi *et al.* (1992). Eastern spinners may have had a similar pattern of decline to the offshore spotted dolphin, although estimated relative abundance in the late 1980s is roughly equal to that of the mid-1970s, so reduction between 1975 and 1983 may have been less than for northern offshore spotted dolphin.

The estimated trend for the whitebelly spinners is similar to that for northern offshore spotted, indicating a stable situation in recent years.

ASSESSMENT AND STATUS

Back calculation estimates of historic abundance of eastern spinner dolphins, based on recent estimates of population size, but with all other input parameters from Smith (1983), were performed by Wade (1991). He found that over the range of parameter estimates explored, the selection of the initial population size (defined as the current abundance (N_c) estimate divided by the historical abundance (N_h) estimate). Starting the population at 391,200 versus 754,200 (lowest and highest N_c used in simulations: Wade and Gerrodette, 1992) resulted in a 12–27% increase in relative abundance. Of even more significance is the range over which relative population size changes. Whereas Smith (1983) estimated relative population size for the eastern spinner dolphin population to be from 0.17 to 0.25, Wade (1991) using an N_c of 391,200 estimated relative population sizes from 0.21 to 0.33, and

Table 19

Dolphin mortality in the Eastern Tropical Pacific (ETP) purse seine fishery from 1959 through 1989.
Data from Hall and Boyer, 1991, 1992; Smith, 1983, 1979; IATTC Annual Report, 1988.

	Spotted		Spinner			Common				
	Northern	Southern	Eastern	Northern	Southern	Northern	Central	Southern	Other	Total
1959	72,000		27,000						19,288	117,288
1960	375,000		133,000	0					74,481	582,481
1961	402,000		150,000	0					101,751	653,751
1962	167,000		62,000	0					40,259	269,259
1963	183,000		69,000	0					38,427	290,427
1964	306,000		115,000	0					51,691	472,691
1965	337,000		126,000	0					50,069	513,069
1966	326,000		115,000	0					19,655	460,685
1967	206,000		77,000	0					24,295	707,295
1968	178,000		67,000	0					21,620	266,620
1969	305,000		122,000	15,000					102,222	544,022
1970	355,000		118,000	14,000					40,659	527,659
1971	176,000		59,000	7,000					19,928	261,928
1972	288,000		96,000	12,000					29,678	423,678
1973	131,000		32,000	33,000					68,973	264,973
1974	95,000		26,000	47,000					6,682	174,682
1975	105,000		45,000	34,000					10,457	194,457
1976	47,000		9,000	20,000					52,222	128,222
1977	22,000		5,000	5,000					19,353	51,353
1978	19,000		2,000	4,000					5,513	30,513
1979	8,870	2,348	1,460	674	638	4,161	2,342	94	880	21,426
1980	13,058	6,828	1,108	1,425	6,707	1,060	963	188	633	31,970
1981	16,324	6,376	2,261	1,815	4,597	2,629	372	348	367	35,089
1982	15,427	4,504	2,606	1,770	1,946	989	487	28	1,347	29,104
1983	3,414	3,608	745	1,640	2,697	845	191	0	353	13,493
1984	15,940	4,042	6,033	1,496	5,636	0	7,403	6	156	40,712
1985	31,309	2,786	8,853	2,648	4,331	0	6,839	304	1,777	58,847
1986	67,989	5,125	19,526	6,804	4,238	13,289	10,884	134	5,185	133,174
1987	51,685	3,285	10,358	3,594	2,432	8,216	9,659	6,759	3,200	99,187
1988	36,137	2,192	18,793	1,844	1,701	4,829	7,128	4,219	2,074	78,927
1989	52,093	3,863	15,245	6,444	1,858	1,066	12,711	576	3,123	96,979
Total	4,439,000	46,541	1,547,000	227,000	37,743	37,788	63,032	12,928		7,177,000

using an N_c of 754,200 estimated relative population sizes from 0.33 to 0.60.

For ETP dolphins the results of such 'back-calculation' models are confounded by lack of information on movement patterns and exchange rates between neighbouring population centres. In addition, the sample sizes on which mortality estimates are based are very small for the period 1959–1972. Repeating the above calculations using mortality estimates 20% lower and 20% higher resulted in estimated relative population sizes from 0.18 to 0.41 using an N_c of 391,200, and estimated relative population sizes from 0.29 to 0.73 using an N_c of 754,200 (Wade, 1991).

5.3.3 Delphinus delphis

COMMON NAMES

Common dolphin; white belly porpoise; *delfín común* (Spanish).

DISTRIBUTION

There are three recognised stocks of common dolphins taken by the tuna fleet in the ETP (northern tropical, central tropical, and southern tropical). Reilly (1990) recently reported that common dolphins do not seem to have seasonal shifts in distribution centres, as do spotted and spinner dolphins. Rather, year round density centres in up-welling modified waters were identified near the Revillagigedos Islands, along the coast of Baja California and Ecuador and near the Costa Rican Dome. The extent to which this pattern of distribution confounds traditional stock identification methods is currently being examined.

PROBLEMS AND CATCH STATISTICS

Mortality levels for the three stocks are highly variable from year to year, but considerably less in absolute number than for northern offshore spotted dolphins or eastern spinner dolphins. Quotas for US fishermen exist for all three stocks (1,890, 8,112, and 4,045). In recent years, the central stock has suffered the greatest mortality. Estimates of % mortality are given in Table 18 but are thought to be unreliable because of the uncertainty in estimating population size.

POPULATION ESTIMATES

Estimates of population size for common dolphins in the ETP are relatively imprecise. CVs from research vessel data are between 44% and 84%, while those from tuna vessel data are 40% for the northern stock, 30% for the central stock, and 30% for the southern stock. Abundance estimates of common dolphin stocks made by Wade and Gerrodette (1992) based on research vessel data are between 23,500 and 1,272,400 (average 467,400) for the northern stock, 261,000 and 1,487,600 (average 594,300) for the central stock, and 152,000 and 3,664,000 (average 2,117,500) for the southern stock for the years 1986 through 1990.

ASSESSMENT AND STATUS

Edwards and Glick (1991) reported significant declines in the northern stock between 1975 and 1984 and for the central stocks between years 1975 and 1984, 1976 and 1985, and 1978 and 1987. Anganuzzi *et al.*, (1992) reported a significant decline in the northern stock during the 1980s. Their estimate of relative abundance for 1989 was significantly lower than those for 1979–1981. The central stock showed evidence of a decline between 1978 and 1983, with stability since. Data were sparse for the southern stock, but abundance in 1989 was significantly lower than in 1976/78.

5.3.4 Stenella coeruleoalba

COMMON NAMES

Striped dolphin; streaker porpoise; *delfín listado* (Spanish)

DISTRIBUTION

There are three recognised stocks of striped dolphins (northern, central and southern) in the ETP. The range in the ETP has been divided into management units based on apparent latitudinal gaps in distribution (Smith, 1983). Further investigation into the distribution and osteological material has led Perrin *et al.* (1985) to recommend that the stock definitions be changed. They 'recommended combining the central and southern stocks into a single southern stock. The striped dolphin would then consist of two stocks (northern and southern).

PROBLEMS AND CATCH STATISTICS

Quotas for US fishermen for the northern, central and southern tropical stocks are 429, 1,822 and 4,095 respectively. Estimates of incidental mortality are not as accurate as for the other three species, because the incidental mortality is relatively rare. Mortality estimates by Hall and Boyer (1991) combine striped and other dolphins; observed mortality of striped in 1990 comprised approximately 6% of the observed mortality for all species.

POPULATION ESTIMATES

Wade and Gerrodette (1992) used research vessel data to estimate the abundance for northern and southern (including central) stocks of striped dolphins. The northern stock ranged between 40,700 and 323,400 (average 172,400; CVs between 37 and 62%), while the southern stock was between 612,000 and 1,927,900 (average 1,313,500; CVs between 27 and 30%).

ASSESSMENT AND STATUS

Striped dolphin stocks are only slightly involved with the purse-seine fishery (Smith, 1979). Assessments have been made primarily for those animals found in the areas previously designated to the central tropical stock which have been taken by the fishery since 1973.

5.3.5 Recommendations Concerning Kills of Dolphins in ETP Purse-Seine Fisheries

Since 1979, the Scientific Committee has made a series of recommendations concerning kills of dolphins in ETP purse-seine fisheries. Many of these recommendations have been, or are being, acted upon by member states with coordination of international efforts through the IATTC.

Recommendations have consisted of the following types of requests: that (1) governments of nations with purse seine fisheries involving dolphin mortality systematically collect and routinely report on data on effort and takes in these fisheries, preferably through participation in appropriate international schemes; (2) observer programmes be initiated or expanded to provide a basis for estimating kills; (3) a research programme be conducted to improve estimates of abundance and trends; (4) biological sampling continue or be increased and analysis of sampled materials be continued or accelerated as part of the assessment process and (5) research be conducted to improve gear and evaluate alternative fishing techniques.

In 1988, the Scientific Committee recommended that a review be carried out to identify and account for possible sources of bias in abundance estimates. The sub-committee agreed to five additional **recommendations.**

(1) Observer coverage of the international fleet should continue at high levels to provide reliable estimates of mortality.
(2) Research vessel surveys should be conducted at regular intervals to provide better estimates of absolute abundance. Tuna vessel data should be used to assess estimates of trends in abundance of all main stocks. Further extension and refinement of the research vessel estimates for estimating absolute abundance should be carried out.
(3) The degree of exchange between different stocks of the same species should continue to be investigated.
(4) For striped dolphins, mortality levels should be managed so that they do not exceed some fraction of the expected net production, since estimated trends in abundance are not available from tuna vessel data. For stocks of spotted, spinner and common dolphin, trends in relative abundance should be included in the management strategy.
(5) Continued and increased cooperation with other international organisations (e.g. IATTC) involved in programmes of research, monitoring and reduction of incidental kill of cetaceans in the ETP is recommended.

5.4 Live-capture fisheries[18]

5.4.1 Orcinus orca *in Puget Sound and off Iceland*

COMMON NAMES

Killer whale (English), *háhyrningur* (Icelandic), *spekkhogger* (Norwegian), *spekkhuggare* (Sweden).

DISTRIBUTION

The killer whale is a cosmopolitan species. Its distribution in polar seas is limited by ice cover. The density of whales appears to be higher in colder waters (Martin, 1990). Although densities vary, killer whales are clearly abundant and widespread, and there are no current fears for the species' survival (Martin, 1990).

In the northeast Pacific, two sympatric forms of killer whale, resident and transient, have been distinguished on the basis of appearance, behaviour, social structure, foraging habits and acoustics (Bigg, 1982; Ford and Fisher, 1982; Bigg *et al.*, 1990; Morton, 1990). Analysis of mtDNA suggested as great a genetic distance between the residents and transients in Puget Sound as between allopatric populations in the Atlantic (Hoelzel, 1991).

The social organisation is best known for the residents and is complex (Bigg, 1982; Bigg *et al.*, 1990). Long term studies of known individuals indicate that these pods of matrilines have long term stable membership. No dispersal event from one pod to another has been recorded during almost two decades of study, although slow, gradual splitting of pods along maternal lineages seems to occur.

PROBLEMS AND CATCH STATISTICS – PUGET SOUND

A total of 68 killer whales was removed by a live-capture fishery in British Columbia and Washington State waters between 1962 and 1977. Olesiuk *et al.* (1990) estimated that 63 were of the resident form and that 76% of those were from the southern community (see below).

[18] Initial draft by A. Bjørge and G. Donovan.

POPULATION ESTIMATES – PUGET SOUND

Bigg *et al.*, (1990) reported that in 1987 there were over 261 residents killer whales in the region. The total population consists of two resident communities, northern and southern, comprising 16 and 3 pods, respectively, and a few tens of transient pods.

ASSESSMENT AND STATUS – PUGET SOUND

Olesiuk *et al.*, (1990) examined trends in population size in the resident communities. Both showed significant increases over the period 1973–87; around 2.6% per annum in the southern community and around 1.3% per annum in the northern community. Simulation studies indicated that both communities represented populations below their 'carrying capacity' and that they could sustain harvesting at rates of between 1.9 and 3.2%, depending on the age and sex of the animals removed.

PROBLEMS AND CATCH STATISTICS – ICELAND AND NORTHEAST ATLANTIC

In 1975, the Icelandic government instituted a system of regulation providing permits to be issued for the live-capture of killer whales. Between 1975 and 1988, permits for taking 84 animals were issued. In this period, 59 whales were actually captured; 8 were released, 3 died in holding facilities prior to export and 48 were exported to dolphinaria (Sigurjónsson and Leatherwood, 1988).

Of the exported whales, 13 were less than 3m long, and the largest animals captured and exported were a 4.9m male and a 4.5m female. Based on information on length at sexual maturity of killer whales in Norwegian waters (Christensen, 1984) and in North American dolphinaria (Duffield and Miller, 1988), Sigurjónsson and Leatherwood (1988) concluded that all exported animals were sexually immature.

Killer whales in the northeast Atlantic have been subjected to direct exploitation for many years. A total of 2,435 were killed by Norwegian whalers in the period 1938–1981. This commercial hunt was halted when the IWC recommended a zero quota for the 1982 season (IWC, 1982a; b; c). The largest catches were made off Møre (634 whales) and Lofoten (662 whales). A total of 153 animals were killed in Icelandic waters and 442 in the Norwegian Sea, mainly between Iceland and Norway (Øien, 1988). The mean length of whales taken was 17.9ft for females and 20.2ft for males (Øien, 1988), indicating that sexually mature animals were removed from the matrilineal groups.

Substantial additional mortality has occurred as a result of cull operations off Iceland (Mitchell, 1975a) and hunting off Greenland (Heide-Jørgensen, 1988).

POPULATION ESTIMATES – ICELAND AND NORTHEAST ATLANTIC

Killer whales are common in Icelandic and Norwegian coastal waters, but little information is available on offshore abundance or migrations between the two areas. Christensen and Øritsland (1982) estimated about 1,400 killer whales for the entire Norwegian coastal waters. This estimate was based on a questionnaire survey of fishermen in 1982. Similar surveys were repeated in the period 1982–1986, and when summarising the surveys, Christensen (1988) concluded that at least 1,500 killer whales might be present in the coastal waters off Norway during January and February.

The international sighting surveys in the northeast Atlantic provided new information on the summer distribution and crude abundance of killer whales. About 3,100 (CV 0.63) whales were estimated for the Norwegian

Sea, Barents Sea and Norwegian coastal waters based on seven sightings (Øien, 1990), and about 6,600 (CV 0.32) whales for Icelandic and Faroese waters combined (Gunnlaugsson and Sigurjónsson, 1990).

ASSESSMENT AND STATUS – ICELAND AND NE ATLANTIC

A total of 143 killer whales had been photo-identified in Icelandic coastal waters up to 1986 (Sigurjónsson *et al.*, 1988). The authors noted that killer whales are widely distributed both around Iceland and far offshore, but the relationship of the study populations with these areas is unknown. To date, no matches exist with killer whales photo-identified off Norway. A total of 51 whales was removed by live-capture fisheries from 1976–1988 (Sigurjónsson and Leatherwood, 1988); another four were taken in 1989 and none in 1990.

The average annual removal rate (exported and dead whales per year) of about 3.6 in the period (1975–90), is within the range considered by Sigurjónsson and Leatherwood (1988) to be within the reproductive capacity of the overall Icelandic stock(s). The impact of removals on long-term matrilineal groups is unknown. The population structure and movements of killer whales in the northeast Atlantic are not well documented, but the live-capture fishery off Iceland may have cropped the same population units as were previously hunted by Norwegian whalers.

The regulatory system with possibilities to issue permits is still operative, but animals can no longer be captured for speculation; collectors must have a valid contract in hand. The Puget Sound killer whale fishery is closed and there is no known intention for it to be re-opened.

RECOMMENDATIONS

At the Workshop on Identity, Structure and Vital Rates of Killer Whale Population in 1981 (IWC, 1982c), it was recommended that precise data on the locality and date of capture for the live-capture fisheries in Iceland and elsewhere be provided. These data were provided for Iceland by Sigurjónsson and Leatherwood (1988).

In 1983, the Scientific Committee noted that killer whale population in a given geographical area consist of localised stocks and recommended that any planned live-captures by the USA, Iceland and Japan or elsewhere be preceded by an assessment of size and composition of the population to be affected (IWC, 1984a).

5.4.2 Tursiops truncatus *in the Gulf of Mexico and off the Atlantic coast of Florida*[19]

Bottlenose dolphins, *Tursiops truncatus*, particularly those taken from shallow, coastal environments, appear adaptable to captivity and have been the most common cetacean species maintained for public display and scientific research. The most common areas from which bottlenose dolphins have been collected have been the near-shore waters of the Gulf of Mexico and Atlantic coast of Florida in the USA. This section discusses issues related to the live-capture of bottlenose dolphins in the coastal waters of the Gulf of Mexico in the United States (Florida, Alabama, Mississippi, Louisiana, and Texas) and, to a lesser extent, off the Atlantic coast of Florida.

[19] Initial draft by A. Hohn.

DISTRIBUTION

Bottlenose dolphins are distributed throughout the coastal waters of the Gulf of Mexico in embayments, inshore waters and offshore waters. For a series of aerial surveys for bottlenose dolphins in the Gulf, inshore waters were defined as extending from the coast to the 18.3m isobath; offshore waters were considered to extend seaward from that depth contour, although the survey ended 9.3km seaward of the 182.9m isobath (Scott, 1989). On the basis of the above definitions, Scott *et al.* (1989) reported that the dominant proportion of bottlenose dolphins were seen in the offshore waters, an area that comprised 68.5% of the area surveyed. Bottlenose dolphins inhabit deeper offshore waters of the Gulf of Mexico as well, although density and abundance there are as yet unknown. Bottlenose dolphins also occur along the Atlantic coast of Florida, although in lower numbers than in the Gulf (Leatherwood, 1979; Hansen and Scott, 1989).

Most live-captures take place in the embayments and inshore waters of the Gulf of Mexico (Scott, 1990) and to lesser extent along the Atlantic coast in a lagoon system called the Indian River-Banana River complex where a community of dolphins is resident (Odell and Asper, 1990).

The stock structure of bottlenose dolphins in the Gulf of Mexico and Florida waters is unknown. In the Atlantic, at least two forms, generally referred to as coastal and offshore, exist (see Hersh *et al.*, 1990, for review). In the Gulf of Mexico, less information is available about the existence of these two forms. However, it is possible that relative discrete communities occupy some embayments (Wells *et al.*, 1987) and that the level of immigration and emigration by individual dolphins is very low. It is also possible that superimposed on the embayment system of discrete communities, coastally migratory groups of dolphins occupy specific sites in a seasonally predictable manner (e.g. Shane, 1980; Gruber, 1981), without significant exchange of individuals with dolphin groups in the embayments. In addition, in the Gulf of Mexico, bottlenose dolphins are seen quite far offshore where the water depth is still shallow. There may or may not be movement of bottlenose dolphins on– and offshore.

PROBLEMS AND CATCH STATISTICS

The live-capture fishery for bottlenose dolphins along the Atlantic coast of the USA began at least as long ago as 1914 and is thought to be the longest running sustained fishery of its type in the world (Leatherwood and Reeves, 1982). Leatherwood and Reeves (1982) estimated that between 1938 and 1980, over 1,500 bottlenose dolphins were removed by live-capture, mainly from the US Gulf of Mexico. Accurate records have been kept since 1973, after passage of the Marine Mammal Protection Act. From 1973–1989, 16–56 bottlenose dolphins were removed annually through live-capture or accidental mortality during attempts at live-capture. In total, 477 dolphins were removed from 1973–1987 (Scott, 1990, for data from 1973–1987). In addition, 34 dolphins were taken in 1988 (an updated figure from that given in table 1 in Scott, 1990), 16 in 1989, and none in 1990. Of these, 195 were removed from Mississippi Sound and environs. Nine removals were made from the east coast of Florida since 1982 and none occurred from 1984–1987. In May 1990 a temporary, voluntary moratorium on removal by live-capture was implemented in the Gulf until further information on the cause and effects of the mortality has been determined.

Since 1977, the number of animals removed by live-capture has been regulated by a quota system (Scott, 1990). The quota was revised in 1982, and remained constant until 1990. Quotas are under review in the light of recent survey results (Anonymous, 1990a).

Live-capture has been a controversial issue in the USA. Much of the controversy is due to the lack of information available, or in some cases to the lack of adequate analysis of available information. The controversy has arisen partly because the effects of removals may be greater than they would appear on the basis of numbers alone. The cumulative effects of human-induced (e.g. fishing incidental mortality, habitat changes, competition with fishermen for prey species) and natural factors (periodic high mortality events) on the dolphin populations are difficult to assess. For example, some embayments that previously contained bottlenose dolphins no longer do, possibly the result of human-induced changes in the environment. In those coastal areas where the residency of bottlenose dolphins has been investigated, at least some of the dolphins have been found to be resident (Caldwell, 1955; Caldwell and Golley, 1965; Shane, 1980; 1990; Gruber, 1981; Wells *et al.*, 1987; Odell and Asper, 1990; Scott *et al.*, 1990). If resident groups are repeatedly targeted and exchange rates of individuals by means of immigration are low, then the effects of removals on such resident groups could be severe.

ASSESSMENT AND STATUS

The total abundance of bottlenose dolphins in inshore and offshore waters in the US portion of the Gulf has been estimated as 35,000–45,000 (Scott, 1989). More localised surveys also have been conducted (summarised by Scott, 1990), but the data on stock structure are presently too limited to allow the stratification of abundance estimates so that they correspond precisely to stocks or relatively discrete communities. When stratified, estimates of abundance and density, as well as quotas for removal by live-capture, have been applied to management areas defined on the basis of where bottlenose dolphins have been live-captured historically (Scott, 1990).

Although the number of bottlenose dolphins removed by live-capture has been small relative to estimated total abundance (Scott, 1989), most live-captures have been from a small number of locations. Given our lack of knowledge about stock structure, the extent of other kinds of removal, such as fishery incidental mortality, and the effect of repeated removals from relatively discrete communities of dolphins, it is difficult to assess the effects of the removals on bottlenose dolphins in the areas where live-captures have been concentrated.

RECOMMENDATIONS

The Scientific Committee stated in 1983 that it considered the guideline for takes pending stock assessment of 2% per year to be prudent and that this guideline could be safely followed pending results of other assessments (IWC, 1984a). It recommended that the USA be encouraged to continue research on stock identity and that population census and interim management procedures be initiated for ongoing or planned live-captures of bottlenose dolphins elsewhere.

The sub-committee noted that the work called for was continuing in the USA.

5.4.3 Delphinapterus leucas in Hudson Bay and in the USSR[20]

COMMON NAMES

White whale, beluga, *belukha* (Alaska and USSR)

DISTRIBUTION

The species has a circumpolar distribution in the Northern Hemisphere, mainly north of 55°N (see section 5.1.2.1).

PROBLEMS AND CATCH STATISTICS

White whales have been captured alive and transported to marine parks and exhibitions since the 1860s (Reeves and Leatherwood, 1984). The first such collections were made in the St. Lawrence River, eastern Canada. In the late 1950s and 1960s, a few whales (10 or less documented by Reeves and Leatherwood, 1984) were captured in Bristol Bay, Alaska, for facilities on the east and west coasts of North America. From 1967 to the mid 1980s, all known collections were made in western Hudson Bay at the mouths of the Seal and Churchill rivers, Manitoba, Canada. The total known captured in this area from 1967 through 1988 is 73 (Reeves and Leatherwood, 1984; R.W. Moshenko, *in litt.* to Reeves, 13 February 1989). Approximately 70% of the whales taken in this fishery have been females.

Ognetov and Minibayeva (1986, as summarised by Ivashin, 1987) described the first attempt to capture and transport live white whales from the Kara Sea. At least one large and several younger white whales were taken. Subsequent papers summarised by Ivashin (1988) refer to work with captive white whales in the USSR. Tobayama (1991) referred to the capture of 12 white whales in Sakhalinskiy Bay, Sea of Okhotsk, for the TINRO Aquarium, Vladivostok, USSR, between 1988 and 1990. Three of these were delivered to Kamogawa Sea World, Japan, in October 1990.

POPULATION ESTIMATES

The population of white whales summering along the west coast of Hudson Bay, including the Seal and Churchill river estuaries, was estimated in 1987 as more than 23,000 whales (Richard *et al.*, 1990).

Available recent information on the white whale population in the Kara Sea does not include a population estimate. A commercial fishery for white whales was conducted in the Kara Sea as recently as the mid 1980s. The population of white whales in the Sakhalin-Amur area was estimated at 7,000–10,000 from aerial surveys in 1987 (Popov, 1990).

ASSESSMENT AND STATUS

The white whale live-capture fishery in western Hudson Bay represents no threat to the wild population, considering its presently small scale relative to the size of the population. Too little is known about the Kara Sea population's current status and the scale of the live-capture operation there to assess the impact of the fishery. Removals made to date from the large stock of white whales in the Sakhalin Amur area of the Sea of Okhotsk would have had little impact on the stock. In all cases where white whale live-capture fisheries have developed, there has been no information on their impact on white whale social groups and behaviour.

[20] Initial draft by R.R. Reeves.

RECOMMENDATIONS

Routine reporting of captures and the regulation by permit in Canada should continue. Basic information on the number of whales taken and the size of the stock in the Kara Sea should be made available, for example, in the USSR's annual progress report to the IWC.

5.4.4 General recommendations on live-capture fisheries

Live-capture fisheries are also known from a number of other areas. Those most active at present include Japan (multispecies), Cuba (*Tursiops*, mainly for export) and the Black Sea (*Tursiops*, *Delphinus* and *Phocoena* for display mainly in Bulgaria, Romania and USSR, and for research in USSR). Little or nothing is known of the status of the stocks from which these and other, live-captures are made. All governments with live-capture fisheries in their waters are urged to initiate the necessary studies to implement effective management regimes.

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Appendix 2

LIST OF SMALL CETACEAN SPECIES

There follows a list, in taxonomic order, of the living small cetacean species recognised by the IWC Scientific Committee (scientific names and English common names).

Suborder Odontoceti (toothed whales)
Superfamily Platanistoidea
Family Platanistidae
Platanista gangetica — Ganges river dolphin
Platanista minor — Indus river dolphin
Family Pontoporiidae
Subfamily Lipotinae
Lipotes vexillifer — baiji
Subfamily Pontoporiinae
Pontoporia blainvillei — franciscana
Family Iniidae
Inia geoffrensis — boto
Superfamily Delphinoidea
Family Monodontidae
Subfamily Delphinapterinae
Delphinapterus leucas — white whale
Subfamily Monodontinae
Monodon monoceros — narwhal
Family Phocoenidae
Subfamily Phocoeninae
Phocoena phocoena — harbour porpoise
Phocoena spinipinnis — Burmeister's porpoise
Phocoena sinus — vaquita
Neophocaena phocaenoides — finless porpoise
Subfamily Phocoenidinae
Australophocaena dioptrica — spectacled porpoise
Phocoenoides dalli — dall's porpoise
Family Delphinidae
Subfamily Stenoninae
Steno bredanensis — rough-toothed dolphin
Sousa chinensis — Indo-Pacific hump-backed dolphin
Sousa teuszii — Atlantic hump-backed dolphin
Sotalia fluviatilis — tucuxi
Subfamily Delphininae
Lagenorhynchus albirostris — white-beaked dolphin
Lagenorhynchus acutus — Atlantic white-sided dolphin
Lagenorhynchus obscurus — dusky dolphin
Lagenorhynchus obliquidens — Pacific white-sided dolphin
Lagenorhynchus cruciger — hourglass dolphin
Lagenorhynchus australis — Peale's dolphin
Grampus griseus — Risso's dolphin
Tursiops truncatus — bottlenose dolphin
Stenella frontalis — Atlantic spotted dolphin
Stenella attenuata — pantropical spotted dolphin
Stenella longirostris — spinner dolphin
Stenella clymene — clymene dolphin
Stenella coeruleoalba — striped dolphin
Delphinus delphis — short-beaked common dolphin
Delphinus capensis — long-beaked common dolphin
Lagenodelphis hosei — Fraser's dolphin
Subfamily Lissodelphinae
Lissodelphis borealis — northern right whale dolphin
Lissodelphis peronii — southern right whale dolphin
Subfamily Cephalorhynchinae
Cephalorhynchus commersonii — Commerson's dolphin
Cephalorhynchus eutropia — black dolphin
Cephalorhynchus heavisidii — Heaviside's dolphin
Cephalorhynchus hectori — Hector's dolphin
Subfamily Globicephalinae
Peponocephala electra — melon-headed whale
Feresa attenuata — pygmy killer whale
Pseudorca crassidens — false killer whale
Orcinus orca — killer whale
Globicephala melas — long-finned pilot whale
Globicephala macrorhynchus — short-finned pilot whale
Subfamily Orcaellinae
Orcaella brevirostris — Irrawaddy dolphin
Superfamily Ziphioidea
Family Ziphiidae
Tasmacetus shepherdi — Shepherd's beaked whale
Berardius bairdii — Baird's beaked whale
Berardius arnuxii — Arnoux's beaked whale
Mesoplodon pacificus — Longman's beaked whale
Mesoplodon bidens — Sowerby's beaked whale
Mesoplodon densirostris — Blainville's beaked whale
Mesoplodon europaeus — Gervais' beaked whale
Mesoplodon layardii — strap-toothed whale
Mesoplodon hectori — Hector's beaked whale
Mesoplodon grayi — Gray's beaked whale
Mesoplodon stejnegeri — Stejneger's beaked whale
Mesoplodon bowdoini — Andrews' beaked whale
Mesoplodon mirus — True's beaked whale
Mesoplodon ginkgodens — ginkgo-toothed beaked whale
Mesoplodon carlhubbsi — Hubbs' beaked whale
Mesoplodon peruvianus — pygmy beaked whale
Ziphius cavirostris — Cuvier's beaked whale
Hyperoodon ampullatus — northern bottlenose whale
Hyperoodon planifrons — southern bottlenose whale
Superfamily Physeteroidea
Family Kogiidae
Kogia breviceps — pygmy sperm whale
Kogia simus — dwarf sperm whale

Appendix 3

COMMERCE IN NARWHAL MUKTUK, IVORY AND OTHER PRODUCTS

R.R. Reeves

Narwhal muktuk (called mattak or maktak in some areas), meat and sinew have long been sold by hunters for resale within Greenland (Bruemmer, 1971; Born, 1987). Some prices are given in Table 1. Bruemmer (1971) stated that about 80% of the muktuk obtained by hunters in Thule district was sold to the Greenland Trading Company (KGH, now KNI). Some of the muktuk obtained by hunters in Pond Inlet and Arctic Bay on northern Baffin Island is sold and exported to population centres elsewhere in the Northwest Territories (unpubl. data).

Born (1987) noted an apparent increase in the amount of muktuk bought in Thule district during the 1980s and suggested that this development represented a shift away from trade in relatively unprofitable sealskins. The price of muktuk is kept strong by the high demand for it in towns south of Thule district. Local residents in Upernavik district have expressed concern about the activities of trawl fishermen from the Disko Bay region who hunt narwhals along the ice edge in spring. This hunt is primarily for muktuk that is sold in urban areas (O. Hertz, pers. comm., 11 August 1990).

Human populations are growing rapidly in Greenland and the eastern Canadian Arctic. Although the number of people involved directly in hunting or in the local consumption of hunting products may not be increasing as rapidly, the internal trade of hunting products makes it possible for urban dwellers to continue their consumption of hunting products such as muktuk. Dog traction remains an important aspect of hunting in northwest Greenland, and there has been a resurgence of interest in maintaining dog teams in parts of the eastern Canadian Arctic. It should be expected, therefore, that the demand for narwhal skin and meat as human food and dog food will increase.

Since 1979, the narwhal has been on Appendix II of CITES, and this has obliged signatory states to document exports of tusks and other narwhal products. At least some of the apparent increase in the numbers of items, mainly tusks, exported under CITES permits from both Greenland and Canada (Tables 2 and 3) is due to improved documentation procedures rather than increased volume of trade. In 1984 the European Economic Community (EEC) banned the commercial importation of narwhal products by member countries, effectively eliminating an important market for tusks from Canada. Before 1984, most tusks from Canada were exported to the UK. Since 1984, more than 75% of the tusks legally exported from Canada have gone directly to Japan (Table 3). E. Bradley-Martin (*in litt.*, 23 February 1991) considers his photograph of a narwhal tusk on display next to a rhinoceros horn in the window of a traditional medicine shop in Kyoto, Japan (Bradley-Martin, 1983), to be unusual. In the course of his investigations into the use of rhinoceros horns, he has found no evidence to suggest the continuing widespread use of narwhal ivory in Japanese folk medicine (c.f. Hawley, 1960). Nor has he found any evidence of narwhal ivory being carved in Japan in modern times, 'as the tusks are more valuable plain for decoration in their original state.' Since the EEC ban does not apply to Greenland, most of the narwhal ivory exported from Greenland goes to Denmark, information on re-export destinations of narwhal ivory from Denmark has been requested but not yet received. Unlike Canada, Greenland exports a considerable amount of carved narwhal ivory (Table 2).

The increasing trend in the price of narwhal ivory in Canada was reversed in 1984; however, the price has recovered substantially since then (Table 4). When the EEC ban took effect in 1984, the narwhal ivory market in northern Baffin Island was controlled by a single private dealer and the Hudson's Bay Company. As the value of the ivory declined abruptly, both parties agreed to begin buying from hunters by the foot of length, rather than on the traditional per-pound of weight basis. This change rationalised the system, since the previous policy of buying by the pound and selling by the foot was illogical (K. Harper, pers. comm., 20 March 1991).

The statement by Newman and Cavanagh (1986) that the price paid to Canadian hunters for narwhal ivory increased from $2 to $120 per pound during the 1960s is incorrect (Table 4). At the end of the 1960s, the price was $10 per pound (Bisset, 1968; Mary-Rousseliere, 1971). Newman and Cavanagh also greatly exaggerated the prices for 1982, stating that they peaked at $300 to $400 per pound. The price paid to hunters on Baffin Island never rose consistently above $100 per pound before 1984 (K. Harper, pers. comm., 20 March 1991). Information on prices paid (unadjusted for inflation) for narwhal ivory in Greenland are given in Table 5.

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Table 1

Prices paid to Greenlandic hunters by the Greenland Trading Company (KGH, KNI) for narwhal products other than ivory. All prices in Danish crowns, uncorrected for inflation.

Year	Product: Muktuk (per kg)	Meat (per kg)	Sinew (per kg)	Reference/Source
early 1960s	1.00			Bruemmer, 1971
1967		2.50		Hansen, 1970
1968	7.50			Hansen, 1970; Bruemmer, 1971
1969	5.50*			Bruemmer, 1971
1970	6.00*			Bruemmer, 1971
1971	7.50		100.00	Bruemmer, 1971
1975	13.00	13.00		Durham, 1978
1976	13.00	13.00		Durham, 1978
1985	35.00	25.00		Born and Olesen, 1986; Born, 1987
1990	49.50			Heide-Joergensen, in litt. to Reeves, 1990

*Derived from total amount purchased divided by total Dkr paid.

Table 3

Greenland CITES permits issued for narwhal products, 1984-1990. Source: Gronlands Hjemmestyre, Sekretariatet, Nuuk.

Year	No. permits	No. raw tusks	Min. weight [1]	No. carvings [2]	Min. weight [3]	Whales[4]
1984	1	0	0	3	?	1
1985	47	58	242	17	?	59
1986	98	111	277	79	?	111
1987	119 [5]	100	210	174	8	101
1988	134	170	616	170	31	177
1989	152 [6]	169	679	153	16	172
1990 [8]	108 [7]	220	809	78	2	221

[1] Weights (in kg) available for only about 70-80% of the tusks. Figure listed is total weight of all tusks for which the weight is indicated.

[2] Includes carvings described as 'tupilaks' as well as jewellry (bracelets, necklaces, rings), crochet hooks/needles, lampstands, flagstands, and unspecified carvings and souvenirs.

[3] Weights (in kg) are available only sporadically for these items, and it is often unclear whether the weight includes other ingredients such as metal or wood. Figure listed is total weight of all carvings for which the weight is indicated.

[4] Assumes each raw tusk represents one whale. Minimum weight of carvings is divided by the average weight of raw tusks that year, to give an estimate of the minimum number of tusks needed to produce the carvings.

[5] One permit was for 2kg of muktuk exported to Denmark.

[6] One permit for shipment of 516kg of 'meat' (muktuk?) from Greenland to Greenlandic Society in Aalborg, Denmark. Under a special provision of CITES, up to 10kg per person can be imported to Denmark per year.

[7] Two permits for a total of 98kg of muktuk exported to Denmark.

[8] Preliminary figures.

Table 4

Prices paid to hunters for unbroken narwhal tusks in the E. Canadian Arctic (Reeves, in prep.). In Canadian dollars, per pound of weight.

Year	Actual	Inflation-adjusted[1]	Sources
1905-6	2.50-3.00	-	Low (1906)
1961	0.75	2.37	J.McDonald (pers. comm. to Reeves)
1965	1.25	3.68	Bruemmer (1966)
1966	2.00	5.68	Bissett (1968)
1967	10.00	27.40	Bissett (1968)
1970	10.00	24.39	Mary-Rousseliere (1971)
1971	11.00	26.07	A.W. Mansfield (pers. comm.)
1972	20.00	45.25	Riewe (1977)
1974	15.00	28.41	Treude (1977)
1975	25.00	42.74	Reeves, Unpubl. data
1976	30.00	47.69	Hay and Sergeant (1976)
1978	37.00-50.00	50.07-67.66	Kemper (1980)
1979	45.00	55.76	Finley and Miller (1982)
1981	60.00-70.00	60.00-70.00	Anonymous (1985)
1982	70.00-90.00	63.18-81.23	Anonymous (1985)
1983	55.00-75.00	46.93-63.99	Anonymous (1985)
1984	23.60[2]	19.30	Reeves, Unpubl. data
1990	135.00[3]	85.31	Reeves, Unpubl. data

[1] Using 1981 dollar as standard; inflation-adjusted values are expressed in 1981 dollars. Based on Consumer Price Index for Canada, all items.

[2] Prices were per tusk: $150 for 4-5ft, $200 for 5-6ft, $250 for 6-7ft, $300 for over 7ft. Price per pound calculated by assuming an average tusk weight of 5.3kg (11.66lb) and that such a tusk would be 7ft long (i.e., worth approx. $275).

[3] Prices were per foot of length (those used were for Arctic Bay, Northern Stores [formerly Hudson's Bay Company]): $100 for 5-6ft, $150 for 6-7ft, $200 for 7-8ft, $250 for over 8ft. Price per pound calculated as in footnote 2.

Table 5

Prices paid for narwhal ivory by Greenland Trading Company (formerly KGH, now KNI) (Reeves, in prep.). In Danish crowns, per kg of weight except as indicated.

Year	Actual	Sources
1968	45	Hansen (1970)
1971	45 (broken)	Bruemmer (1971)
1975-6	300	Durham (1978)
1984	715	Born (1987)
1985	500	Born (1987)
1990	660 (unbroken) 215 (broken)	M.P. Heide-Joergensen (*in litt.*, 1990)

Table 2

Export destinations of raw narwhal tusks from Greenland and Canada according to CITES permit data, 1975-1990. Canadian data are from CITES Reports issued by Canadian Wildlife Service; Greenland data are from files of Gronlands Hjemmestyre, Sekretariatet, Nuuk, Greenland withdrew from the EEC effective 1 Feb. 1985. This implied withdrawal from the EEC/Denmark custom area and meant that CITES export permits would thenceforth be issued by Greenland Home Rule authorities, incl. for exports to Denmark and other EEC countries.

Year	From:/To:	AU	GB	CH	BE	FR	JP	DK	DE	IT	US	SA	IE	MC	NO	FO	CA	SE	NC	GL	NL	AT	SG	CU	NZ	FI	MX	Tusk totals
1975	Canada	-	38	-	7[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	38
1976	Canada	1[1]	26	-	42[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26
1977	Canada	-	25	-	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28
1978	Canada	-	48	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52
1979	Canada	-	96	-	-	2	2	-	-	6	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	107
1980	Canada	-	60	-	-	3	3	-	-	3	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70
1981	Canada	-	36	1	-	-	1	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	41
1982	Canada	3	33	-[2]	-	4	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	42
1983	Canada	-	63	2	-	3	4	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-[3]	1	-	-	90
1984	Canada	-	33[4]	1	-	3	16	-	2	1	-	-	-	-	-	-	-	-	1	-[5]	-	-	-	-	-	-	-	57
1985	Canada	-	-	-	-	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-[6]	-	-	-	-	-	-	-	15
	Greenland	-	-	-	-	1	-	42	-	-	-	-	-	-	-	1	3	2	-	-	-	-	-	-	-	-	-	49
1986	Canada	-	-	-	-	1	20	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	23
	Greenland	-	-	2	-	1	11	93	-[7]	-	-	-	-	-	1	2	1	-	-	-	-	-	-	-	-	-	-	111
1987	Canada	-	-	10	-	-	9[8]	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	21
	Greenland	-	4	-	-	-	1	90	2	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	99
1988	Canada	-	-	2	-	-	27	-	4	3	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	38
	Greenland	-	-	-	-	2	2	158	-	-	-	-	-	-	4	-	3	1	-	-	-	-	-	-	-	-	-	170
1989	Canada	-	1	17	-	-	104	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	123
	Greenland	-	-	3	1	-	3	153	4	-	-	-	-	-	1	2	-	2	-	-	-	-	-	-	-	-	-	169
1990	Canada	-	-	23	-	-	76	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	107
	Greenland[9]	-	-	-	-	-	2	190	1	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	1	-	196
																											Total:	1,6712

[1] Carved, carvings; [2] One preserved brain from a narwhal; [3] Bag of small tusk pieces; [4] Also one 'carved tusk'; [5] 13.3kg of 'meat' (muktuk?); [6] 20kg of 'meat' (muktuk?); [7] One skull; [8] Also one skull; [9] Preliminary.

Note: AU - Australia, GB - United Kingdom, CH - Switzerland, BE - Belgium, FR - France, JP - Japan, DK - Denmark, DE - West Germany, IT - Italy, US - United States, SA - Saudi Arabia, IE - Ireland, MC - Monaco, NO - Norway, FO - Faroe Islands, CA - Canada, SE - Sweden, NC - New Caledonia, GL - Greenland, NL - Netherlands, AT - Austria, SG - Singapore, CU - Cuba, NZ - New Zealand, FI - Finland, MX - Mexico.

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North Atlantic
(including the Baltic and Mediterranean)

SC/O90/G6

Interactions Between Cetaceans and Gillnet and Trap Fisheries in the Northwest Atlantic

Andrew J. Read

Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA

ABSTRACT

Gillnet and trap fisheries of the Northwest Atlantic and their potential for cetacean entanglement are reviewed. Ten major categories of passive fisheries are identified, five of which are known to take substantial numbers of cetaceans during the course of their operations: Atlantic Canada and Gulf of Maine groundfish gillnets; Atlantic Canada cod traps; Bay of Fundy and Gulf of Maine herring weirs; Atlantic Canada and Greenland salmon gillnets; and US east coast swordfish driftnets. The cetacean species most threatened by incidental mortality in commercial fisheries in this region are the harbour porpoise, *Phocoena phocoena*, which is taken in large numbers and the endangered northern right whale, *Eubalaena glacialis*.

KEYWORDS: INCIDENTAL CAPTURE; NORTH ATLANTIC; FISHERIES; PINNIPEDS; HARBOUR PORPOISES; WHITE-SIDED DOLPHINS; WHITE-BEAKED DOLPHINS; LONG-FINNED PILOT WHALES; WHITE WHALES; HUMPBACK WHALES; MINKE WHALES; FIN WHALES; RIGHT WHALES

INTRODUCTION

Cetaceans frequently encounter fishing gear in the Northwest Atlantic, due to the intensive fishing activity and large numbers of whales, dolphins and porpoises in this area. The concentration of researchers in the region has assisted in the documentation of interactions between cetaceans and fisheries (e.g. O'Hara *et al.*, 1986; Kraus *et al.*, 1990). Despite past research into these interactions, however, our efforts to understand the impacts of fisheries on cetaceans are still in their infancy. In none of the fisheries described in this paper do we have an accurate estimate of the numbers of cetaceans killed or a clear understanding of the impact of this incidental mortality on affected populations. The numbers of cetaceans taken by some of these fisheries are startling; they should spur us to work harder in attempts to understand and mitigate these conflicts.

My objective in this paper is to review all major passive gillnet and trap fisheries in the northwestern Atlantic and document their known interactions with cetaceans. The review is incomplete; we know little of either cetaceans or fisheries in some areas. I have restricted my review to gillnets and traps that are truly passive in nature and have not included fisheries that employ gear in an active fashion, such as the 'run-around' gillnets used to take a variety of species in the southeastern United States. Neither have I included trap and pot fisheries for crustaceans, although whales and dolphins are known to become entangled in crab and lobster pot lines on occasion (e.g. Douglas, 1989). Cetaceans were probably taken by two gillnet fisheries that are currently inoperative: the sturgeon fishery of the mid-Atlantic states (Reynolds, 1985) and the king mackerel fishery off the southeast coast of Florida.

To restrict the review to a manageable size, I have pooled similar fisheries together in major categories. Thus, all groundfish gillnet fisheries in Atlantic Canada and the northeastern USA are considered together. Ten major categories of fisheries are identified. These categories are divided into two groups: those that are known to take substantial numbers of cetaceans in their operations and those in which incidental catches have been reported only infrequently. In some cases, inclusion in the second category may reflect poor documentation of cetacean fisheries interactions rather than their infrequent occurrence.

Fisheries in the first category are considered in more detail than those not known to take large numbers of cetaceans. For these fisheries, I have attempted to obtain the following information, although it was seldom possible to obtain complete data: (1) location of ports; (2) target species; (3) area of operation; (4) description of vessels and crew; (5) description of gear; (6) description of operation; (7) economics and history; (8) landings; (9) fishing effort; (10) interactions with cetaceans; (11) interactions with pinnipeds; (12) information requirements.

There are several biases inherent in the amount of coverage given to different fisheries. As noted above, certain fisheries have been better documented than others, particularly in regard to their interactions with cetaceans. In addition, I bring my own biases to the review, formed by having worked with groundfish gillnet and weir fisheries for several years.

FISHERIES KNOWN TO TAKE LARGE NUMBERS OF CETACEANS

Atlantic Canada and Gulf of Maine groundfish gillnet fishery

Various forms of this fishery exist throughout eastern Canada and the Gulf of Maine. Intensive fishing effort occurs in southern Labrador, eastern Newfoundland, the Gulf of St. Lawrence, the eastern shore of Nova Scotia, the Bay of Fundy, and the Gulf of Maine. Groundfish gillnets are also used in southern New England (Ruais and Goodreau, 1987). In eastern Canada, gillnet fishermen tend to operate out of small ports that are scattered along the coastline. The US groundfish gillnet fishery is similarly dispersed.

The main target species are Atlantic cod (*Gadhus morhua*) and, in the southern range of the fishery, pollock (*Pollachius virens*) and white hake (*Urophycis tenuis*). A variety of demersal species are also taken and in many areas spiny dogfish (*Squalus acanthias*) often comprise a large proportion of the catch. Haddock (*Melanogrammus*

* Unless otherwise stated $ refers to US dollars.

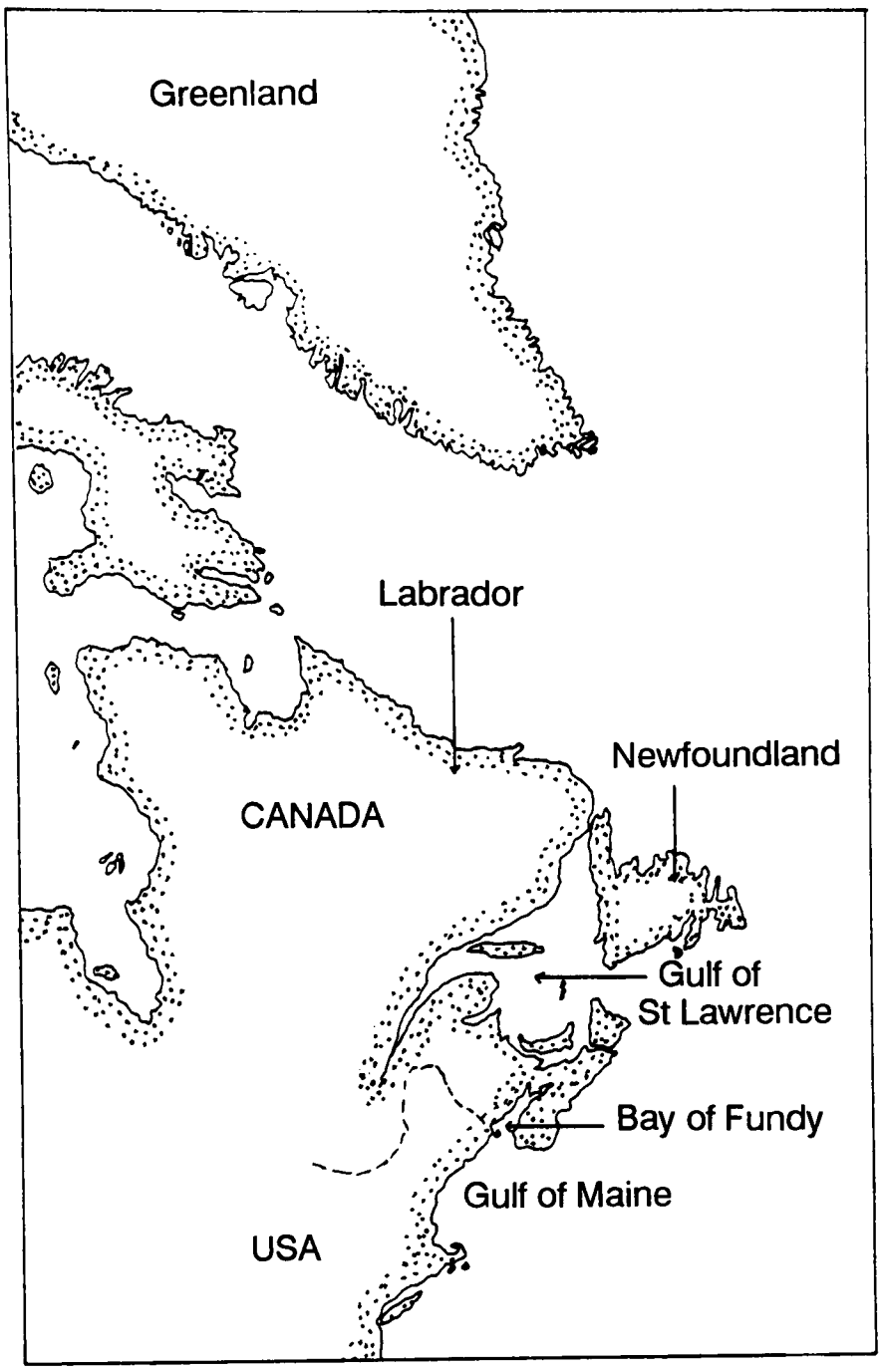

Fig. 1. Eastern Canada and Greenland, showing fishing regions described in the text.

aeglefinus) was once a major species taken by gillnets in the southern range of this fishery, but stocks of this species no longer support significant catches. In some areas fishermen configure their nets to take other species of groundfish, notably lumpfish (*Cyclopterus lumpus*) or flatfishes.

Groundfish gillnets are set throughout the inshore waters of eastern Canada and Gulf of Maine. Areas of operation are constrained by both water depth and local regulations. In the Bay of Fundy and Gulf of Maine, nets are usually set in water depths of less than 600ft (Read and Gaskin, 1988; NMFS, 1990b). Complex regulations restrict the use of gillnets in many nearshore areas to minimise conflicts with vessel traffic and other fisheries; these regulations are not reviewed here.

Groundfish gillnet fishermen typically employ small, versatile inshore vessels that are also used in a variety of other fisheries. In the Gulf of Maine between 1974 and 1981, the mean length of groundfish gillnet vessels varied between 31 and 44ft and mean vessel weight varied between 20 and 29 gross registered tons (GRT) (Ruais and Goodreau, 1987). Gillnet vessels are typically operated by their owners and an additional crew member or two. Fish are usually gutted at sea and brought back to port either fresh or on ice.

An excellent description of the gear used by groundfish gillnet fishermen in the Gulf of Maine is given by Drew (1990). Although there is some variation in gear configuration in this fishery, many fishermen use a standard monofilament gillnet. In the United States, minimum stretched mesh size is restricted to $5\frac{1}{2}$ inches; maximum mesh size is 9 inches (Drew, 1990). Canadian fishermen in the Bay of Fundy use nets with a similar mesh size (Read and Gaskin, 1988). Panel depth varies between 8 and 12ft (Drew, 1990), but panel length is much more variable. In the Bay of Fundy, most fishermen use five strings of net, each 1,800ft long (Read and Gaskin, 1988). Fishermen in the Gulf of Maine may only set four strings of net, but each string is usually between 1,500 and 3,600ft long (Drew, 1990). Total net length is the most variable component of gear type; fishermen in the Gulf of Maine set nets between 1,500 and 7,500ft in length.

The nets are strung between a lower lead line and an upper float line. Nets set for flounder and other flatfishes have tie-down lines that keep the float line only 2–3ft above the lead line, allowing the webbing to lie slack (Drew, 1990). Gillnet locations are marked by buoys and radar reflectors in some areas, such as the Bay of Fundy. In other areas, gillnets are not marked in a consistent manner (Ruais and Goodreau, 1987). Most vessels set nets over the stern as they travel; the nets are usually hauled to the surface with hydraulic gear.

Groundfish gillnets are anchored on the bottom in depths of 360–600ft. In the Bay of Fundy, the nets are set in the morning and retrieved, whenever possible, the following day (Read and Gaskin, 1988). Occasionally the nets are left in the water for longer periods, although fish quality deteriorates if the nets are not retrieved each day. In areas where fishermen set a large amount of gear or fish far from shore, fishermen are unable to retrieve all of their gear each day and haul nets on alternative days. Flounder nets are often left for longer periods because these species can survive long periods of entanglement (Drew, 1990). In general, fishermen operating close to shore make day trips and those setting nets further offshore stay at sea for two or more consecutive days.

Most of these fisheries are seasonal in nature, reflecting the migratory nature of target species and their seasonal availability in inshore waters. In Newfoundland, the fishing season is short and gillnets are used only between early June and mid-August (Piatt and Nettleship, 1987). In the Bay of Fundy, fishermen set groundfish gillnets between June and October (Read and Gaskin, 1988). Further to the south, in the Gulf of Maine, gillnets are used throughout the year, with peak operations between April and November (Payne *et al.*, 1990). Peak seasons may vary from location to location, reflecting local conditions and the existence of alternative fisheries. In the Bay of Fundy, for example, the gillnet season ends in September or October so that fishermen can prepare their gear for the lobster season, which begins in November.

There is little information available on the history or economics of this fishery. Ruais and Goodreau (1987) noted that gillnets have been used in the Gulf of Maine since the late 19th century. The introduction of monofilament provided a durable and inexpensive net material and undoubtedly had an immense impact on the groundfish industry. According to fishermen in the Bay of Fundy, monofilament nets were first used in the mid-1970s (B. Carey, pers. comm.) at about the same time that they were introduced in the Gulf of Maine (Ruais and Goodreau, 1987). In some areas, the level of gillnet activity appears to have increased over the last twenty years (NMFS, 1990b), although accurate effort data are difficult to obtain (see below). In other areas, it is impossible to ascertain trends in gillnet effort.

The price fishermen receive for groundfish fluctuates both annually and geographically, reflecting a bewildering variety of market forces. For example, the landed value of cod rose from $0.22 to $0.38 per lb between 1986 and 1987 in the Bay of Fundy, causing a temporary expansion of the gillnet fleet (L. Murison, pers. comm.). Most of the groundfish captured in US gillnets is either consumed fresh or frozen; all processing occurs in New England (NMFS, 1990b). In Canada, most groundfish is frozen and exported to the USA, although a portion is exported fresh or salted. About 80% of groundfish from the Scotia-Fundy region is exported to the USA (Hache, 1990).

Total landings are seldom compiled by gear type, so it is often difficult to determine how much of the total groundfish landings each year are made by gillnets. Ruais and Goodreau (1987) estimated that in 1984 gillnet fishermen landed approximately 14,000 tonnes of groundfish in New England. In 1983, Canadian fishermen landed over 13,400 tonnes of groundfish in the provinces of New Brunswick and Nova Scotia (DFO, 1985).

It is clear that the groundfish gillnet fishery is an important industry in both eastern Canada and New England. In the Canadian provinces of New Brunswick and Nova Scotia, the landed values of groundfish captured in gillnets during 1983 was $3 million and $6 million ($CAN), respectively (DFO, 1985). The landed value of cod in New England was $48 million in 1989 and gillnets accounted for approximately 40% of landings of this species (NMFS, 1990b).

Effort is perhaps the most difficult statistic to obtain for this and other fisheries, because fishermen are seldom required to report the relevant data. In many areas it is even difficult to determine how many licence holders are actively fishing in any particular year. There are a large number of fishermen licenced to use groundfish gillnets in eastern Canadian waters, although it is impossible to determine how many individuals actually participate in the fishery. In 1989, approximately 6,800 groundfish fixed gear licences were issued to fishermen along the southern coast of Labrador, and northeast and southern coasts of Newfoundland (G. Brocklehurst, DFO, pers. comm.). In the Gulf of St. Lawrence, there were approximately 3,900 groundfish fixed gear licences issued in 1989 (S. Guinchard, DFO, pers. comm.), and in the Bay of Fundy and southwestern Nova Scotia 659 fishermen held groundfish gillnet licences (J. Conway, DFO, pers. comm.). The only information on the proportion of licenced Canadian fishermen that actually fish was obtained in the western Bay of Fundy, where approximately 25% of licence holders used gillnets in 1984 (Read and Gaskin, 1988). During August 1986, 14 Bay of Fundy gillnet fishermen set their gear on 46% of monitored days (Read and Gaskin, 1988).

Slightly better information exists on the level of fishing effort in US waters. In the Gulf of Maine there were 317 vessels registered to use groundfish gillnets under the NMFS Marine Mammal Exemption Program in 1989 (see below) (Payne *et al.*, 1990), although the number of active vessels is unknown. Gillnet vessels made over 12,000 trips in 1988, which increased to over 14,000 in 1989 (NMFS, 1990b).

Groundfish gillnets frequently entangle cetaceans during the course of their operations, resulting in damage to fishing gear and injury or death to the entangled animals. I will discuss groundfish gillnet interactions with cetaceans in three separate regions in which these fisheries operate: Newfoundland-Labrador, Gulf of St. Lawrence and Bay of Fundy-Gulf of Maine.

(A) Newfoundland and Labrador

A variety of cetacean species are known to become entangled in groundfish gillnets in this region (Perkins and Beamish, 1979; Lien, 1987; 1994; Piatt and Nettleship, 1987; Lien *et al.*, 1990) including: harbour porpoises (*Phocoena phocoena*); white-sided dolphins (*Lagenorhynchus acutus*); white-beaked dolphins (*Lagenorhynchus albirostris*); long-finned pilot whales (*Globicephala melas*); white whales (*Delphinapterus leucas*); humpback whales (*Megaptera novaeangliae*); minke whales (*Balaenoptera acutorostrata*) and fin whales (*Balaenoptera physalus*).

Most small cetaceans are killed during entanglement, because they are unable to reach the surface to breathe. Large whales are often able to break through gillnets and escape, although they may carry fragments of net with them. Lien *et al.* (1990) received reports of 34 humpback entanglements in groundfish gillnets in Newfoundland and Labrador during 1989. The majority of these whales were either released alive with the aid of an entrapment assistance crew from Memorial University (20) or escaped towing gear (11). A single whale extricated itself from a net and two died as a result of entanglement. Six minke whales were reported entangled in gillnets during 1989; five of these smaller whales died and the other individual escaped towing gear. Many small cetaceans that are killed in groundfish gillnets in this region are retained for human consumption. This is particularly true for harbour porpoises, which are frequently consumed by fishermen and their families in Newfoundland and Labrador (Lien, 1987). Larger cetaceans that die in gillnets are usually discarded.

There are no reliable estimates of the total number of cetaceans entangled by groundfish gillnets in this region. Lien (1987) noted that the majority of humpback and minke whale entanglements were reported, perhaps 90% and 75%, respectively. If these figures are accurate, approximately 40 humpbacks and 8 minke whales became entangled in 1989. It is more difficult to estimate the number of smaller cetaceans taken in gillnets, because fishermen seldom report these events. It is clear, however, that the incidental take of at least one species, the harbour porpoise, is substantial. The only information on the level of harbour porpoise entanglements was obtained by Lien (1987). In 1980, 100 fishermen from eastern Newfoundland were interviewed and asked how many small cetaceans they had encountered in their gillnets. The fishermen reported taking approximately 214 harbour porpoises during the course of the fishing season. Four fishermen, working in the St. Mary's Bay area, reported catches of 25, 29, 41 and 112 porpoises. The concentration of high porpoise catches in this location makes it impossible to extrapolate to other areas, even if adequate effort data were available. Recent reductions in fishing effort have occurred in Newfoundland and Labrador as a result of fisheries conservation measures implemented to protect overexploited groundfish stocks. The number of cetaceans entangled in these nets has presumably been reduced proportionally to the reduction in fishing effort.

The mortality of large whales in groundfish gillnets and other fishing gear has been greatly reduced by the efforts of the entrapment assistance programme at Memorial University of Newfoundland (Lien *et al.*, 1990; Lien, 1994). Since 1978 this programme has trained fishermen to remove large whales from their fishing gear, reducing the risk of mortality to the animals and minimizing damage to the nets. Fishermen are able to call a 24 hour toll-free

phone to obtain advice and, if necessary, assistance. Prior to the initiation of this programme, mortality of humpbacks entrapped in fishing gear was about 50% whereas the mean level of humpback mortality from entrapment between 1987 and 1990 was only 11% (Lien, 1994). This programme should serve as a model for other attempts to reduce the mortality of large cetaceans in fishing gear.

Historically, groundfish gillnets posed potential threats to two cetacean populations in this area. Incidental entanglement posed a serious threat to northwestern Atlantic humpback whales with the high mortality rates observed prior to the initiation of the entrapment release programme. The catches of harbour porpoises, however, may have been large enough to have had a deleterious effect on the population of porpoises in this area. Harbour porpoises in Newfoundland and Labrador are believed to form a distinct stock (Gaskin, 1984), but at present there are no estimates of abundance for this population. Assessment of the impact of porpoise mortality in groundfish gillnets will require information on abundance and more data on the historical level of incidental catches. Harbour porpoises were listed as threatened in eastern Canada, due in large part to the perceived threat caused by incidental mortality in gillnet fisheries. Recent fisheries conservation measures make it unlikely that these fisheries will pose a threat to cetacean populations in the near future.

(B) Gulf of St. Lawrence

Until recently, the only research into incidental mortality of cetaceans in fisheries of this area was the work of Laurin (1976), who noted that an undetermined number of harbour porpoises were taken in groundfish gillnets each year. Fontaine *et al.* (1994) have recently initiated a programme to examine the extent of this problem. Their work indicates a substantial incidental catch of harbour porpoises and smaller takes of white whales, white-beaked dolphin, and unidentified rorquals (*Balaenoptera* spp.). Minke whales are abundant in the Gulf of St. Lawrence and probably become entangled in gillnets on occasions (R. Sears, pers. comm.). There is no information on the proportion of cetaceans that are killed during the entanglement process in this area. As noted above, however, it is unlikely that any of the smaller cetaceans survive encounters with groundfish gillnets. Harbour porpoises captured in gillnets are often retained for food by fishermen in the Gulf of St. Lawrence.

There are no direct estimates of the numbers of cetaceans taken by groundfish gillnets in the Gulf of St. Lawrence. Fontaine *et al.* (1994) sent questionnaires to 968 coastal fishermen and asked them about the numbers of harbour porpoises they encountered in their nets. One-third of the fishermen responded and indicated that between them they had caught approximately 445 porpoises in groundfish gillnets during 1988 (Fontaine *et al.*, 1994; P. Fontaine, pers. comm.). If the respondents were representative of the entire sample, and it is not possible to determine whether or not this is the case, over 1,900 porpoises were captured in groundfish gillnets during 1988. Although such extrapolations are risky, it is clear that the take of harbour porpoises in this area is substantial. Most porpoises were taken in July, but some were caught in all months from April to November.

Groundfish gillnets pose a potentially serious threat to the harbour porpoise population in this area. As is the case in Newfoundland, the animals in the Gulf of St. Lawrence are believed to form a single stock (Gaskin, 1984), but estimates of abundance are lacking. Further research is required to address the impact of incidental catches on harbour porpoises in this area. The only other potential threat to cetacean populations may be the occasional capture of white whales from the endangered St. Lawrence population (IWC, 1992, table 9). The available information is insufficient to address the impact of incidental catches on this population.

(C) Bay of Fundy and Gulf of Maine

A large body of information exists on the nature and magnitude of incidental catches in this area, due in large part to the concentration of marine mammal researchers in the region. The species known to be taken in groundfish gillnets in this area (Katona *et al.*, 1978; Reeves *et al.*, 1978; Gilbert and Wynne, 1983; Read and Gaskin, 1988; Douglas, 1989) include: harbour porpoises; white-sided dolphins; pilot whales; minke whales; humpback whales; and northern right whales (*Eubalaena glacialis*).

Most small cetaceans die after becoming entangled in groundfish gillnets in the Bay of Fundy and Gulf of Maine. Researchers have suggested that small cetaceans, such as harbour porpoises, become entangled either as the nets are being set or as the nets are fishing on the bottom (Gilbert and Wynne, 1983). Experimental sets conducted by Read and Gaskin (1988) were too limited to demonstrate which of these alternatives is correct. As noted above, many large whales survive their encounter with gillnet gear. There have been six records of right whales becoming entangled in groundfish gillnet gear in the Bay of Fundy and Gulf of Maine between 1975 and 1990 (Kraus, 1990; NMFS, 1990a; L. Murison, pers. comm). In all six instances, the right whales were either released or escaped on their own, although several whales have been observed carrying net fragments (S. Kraus, pers. comm.). Humpback whales also frequently survive encounters with groundfish gillnets. Eleven of fourteen humpback whales known to have become entangled in Gulf of Maine gillnets since 1975 either escaped or were released alive (C. Coogan, NMFS, pers. comm.). A few harbour porpoises are still consumed by fishing families in the Bay of Fundy, but this practice has been largely discontinued. A moderate number of small cetaceans and a few large whales that die in groundfish gillnets are made available to researchers.

There have been several attempts to estimate the magnitude of incidental mortality of harbour porpoises in the groundfish gillnet fishery in the Bay of Fundy and Gulf of Maine. Incidental catches of other species occur relatively infrequently and have received correspondingly less attention. Based on anecdotal evidence, Prescott and Fiorelli (1980) suggested that gillnet vessels might take two porpoises per vessel per year. In 1979, there were approximately 150 gillnet vessels active in the Gulf of Maine (Ruais and Goodreau, 1987), leading Prescott and Fiorelli to suggest that as many as 300 porpoises might be taken each year. The first study to systematically estimate harbour porpoise incidental mortality in this area was conducted by Gilbert and Wynne (1983). These researchers interviewed 17 gillnet fishermen from the state of Maine, who reported an incidental catch of 118 small cetaceans, predominantly harbour porpoises, during 1982. Gilbert and Wynne (1983) considered the results of interviews to provide only minimal estimates of the numbers actually taken by fishermen. Gilbert and Wynne (1987) later used logbook data to suggest a maximum figure of 600 porpoises taken annually in the entire Gulf of

Maine. This maximum figure was derived by applying the reported average annual catch per vessel (5.1 porpoises) to the total fleet (estimated as 90 – 120 active vessels). Gilbert and Wynne (1987) considered this maximum figure unrealistic, because they felt vessels with a high level of incidental catch were over-represented in the logbook sample. As noted by Polacheck (1989), sampling problems associated with the diffuse and varied nature of this fishery complicate attempts to estimate total incidental mortality in groundfish gillnets.

Read and Gaskin (1988; 1990b) investigated the incidental take of harbour porpoises in the western Bay of Fundy, an area not covered by the work of other researchers. Year-end interviews were made with the majority of vessel operators in this relatively small fishery (20 to 30 active vessels each year). The results of these interviews were used to generate estimates of annual mortality, which varied from 80 to 129 porpoises between 1986 and 1989 (Read and Gaskin, 1990b). Kraus *et al.* (1990) combined these data from the Bay of Fundy with estimates of incidental catches in the Gulf of Maine and suggested that the number of porpoises taken in the entire region may be as high as 1,000 per year.

Amendments to the US Marine Mammal Protection Act made in 1988 require the US National Marine Fisheries Service (NMFS) to classify fisheries based on their likelihood of killing marine mammals and to assess the impacts of such incidental takes. NMFS has classified the Gulf of Maine groundfish gillnet fishery as likely to take marine mammals frequently during the course of its operations (Category I) and has placed observers on gillnet vessels to collect information on the number of cetaceans taken. From August 1989 to July 1990, 158 fishing days were observed, during which 15 harbour porpoises were killed (Payne *et al.*, 1990). Most observed sets had no porpoises killed; the maximum number of porpoises killed in a single set was three (T. Smith, NMFS, pers. comm.). Porpoises were entangled between October and April; no porpoises were taken during other months. The observed seasonality of this catch agrees well with the hypothesized north-south migration of harbour porpoises in the region (Payne *et al.*, 1990). During the summer months, harbour porpoises leave the Gulf of Maine and are found further to the north in the Bay of Fundy. The number of trips observed comprised between 1 and 3% of total fishing effort but were not, however, proportional to the geographical distribution of fishing effort, making extrapolation to an estimate of total kill difficult (Payne *et al.*, 1990). Increased observer effort in 1990, 1991 and 1992 allowed better estimates to be generated of the magnitude of these incidental catches in the Gulf of Maine. During these years, bycatches of harbour porpoises varied between 900 (95% CI 700 to 1,200) and 2,400 (95% CI 1,600 to 3,500) (Smith, *et al.*, 1993). These bycatch estimates only include observations from the US waters of the Gulf of Maine north of Cape Cod.

The above data indicate that groundfish gillnets have the potential to exert significant effects on two cetacean populations in the Bay of Fundy and Gulf of Maine. Gillnets pose a threat to northern right whales in such areas where both whales and nets can be found in close proximity. Although there have been no deaths directly attributed to gillnets, the precarious status of the right whale population magnifies the threat associated with such fishing gear (NMFS, 1990a). Over half of the known individuals in this small population have scars resulting from entanglement in fishing gear (Kraus, 1990). Gillnets also pose a significant threat to the harbour porpoise population in this region. Although it is difficult to generate an actual estimate of the current harbour porpoise incidental mortality caused by groundfish gillnets, it seems clear the take is large relative to population size. Estimates of abundance for this stock range from 37,500 (95% CI 26,700 to 86,400) to 67,500 (95% CI 32,900 to 104,600) (Smith, *et al.*, 1993). Demographic models suggest that this population is unlikely to sustain mortality levels of 4% (Woodley and Read, 1991). Changes in summer distribution patterns and life history parameters (such as age at sexual maturity) have been documented that are consistent with a reduction in harbour porpoise density (Read and Gaskin, 1990a).

Groundfish gillnets also take unknown numbers of pinnipeds in several parts of eastern Canada and New England. In eastern Newfoundland, large numbers of harp seals (*Phoca groenlandica*), and lesser numbers of harbour (*Phoca vitulina*) and hooded seals (*Cystophora cristata*) are taken by demersal gillnets (Piatt and Nettleship, 1987). Similar nets also take harbour and grey seals (*Halichoerus grypus*) in New England waters (Gilbert and Wynne, 1985) and in the Gulf of St. Lawrence (P. Fontaine, pers. comm.). For unknown reasons, groundfish gillnets do not capture pinnipeds in the western Bay of Fundy (Read and Gaskin, 1988).

Large numbers of cetaceans, mostly harbour porpoises, are killed in this fishery each year. It is impossible to fully assess the threat to affected populations, even in the best studied areas, because of a lack of critical information. It should be evident, however, that the potential threats are serious enough to warrant comprehensive assessments of the impact of these incidental catches throughout the range of this fishery. These assessments will require accurate information on the numbers of cetaceans killed by gillnets in each area. Such data are best collected by on-board observations, such as in the NMFS programme, because data obtained from interviews with fishermen may not be reliable (e.g. Lien *et al.*, 1994). The assessments will also require much better information on fishing effort than is presently available. Particular attention should be paid to resolving problems of determining fishing effort in the Gulf of Maine, so that accurate estimates of total incidental mortality may be generated.

Atlantic Canada cod traps

The cod trap fishery is scattered along the coasts of Newfoundland and Labrador and, to a lesser extent, along the north shore of the Gulf of St. Lawrence. Most cod traps are found on the southern and eastern shores of Newfoundland and the Labrador coast. There are also an unknown number of cod traps set along the West Greenland coast (F. Larsen, pers. comm.). The diffuse nature of the fishery does not allow for concentration of fishermen in any particular port.

The primary target species is Atlantic cod, although a variety of demersal species may be taken in smaller numbers. The traps are fixed structures that are deployed in near-shore areas. Their areas of operation are dictated largely by water depth and local topography. The traps are tended by small inshore vessels of varying size and design. Each boat will tend from three to five traps each season (DFO, 1984).

Cod traps are essentially rectangular boxes of netting, open at the top and with an opening or 'door' on the inshore side (DFO, 1984). The trap is kept afloat with buoys and anchored on the corners to maintain position

and shape. Fish are guided into the structure by a long 'leader' that extends from shallow water to the mouth of the trap. Traps are of varying dimensions, depending on local topography, but a typical structure will measure 75ft in each direction. The length of the leader is also extremely variable. Once fish are inside the cod trap, fishermen can close the door, preventing their escape. The floor of the trap is hauled to the surface and across the boat, concentrating the fish in one corner of the trap. Fish are then removed with a dip net. Cod traps are often emptied twice daily during the fishing season. This is a highly seasonal fishery, dependent on the inshore cod run during the summer months. Cod traps are usually set out early in the summer and are often taken up by the end of August, when cod become scarce in nearshore areas (Perkins and Beamish, 1979).

As noted above, most Canadian groundfish are processed locally and then shipped to the USA. Cod is usually exported in frozen blocks. Inshore cod landings in Newfoundland have decreased dramatically over the past decade, although the causes of this decline are uncertain. In 1988, 46,778 tonnes of cod were taken by traps in eastern Newfoundland and Labrador (L.M. Collins, DFO, pers. comm.).

There were 3,121 cod traps operating in Newfoundland and Labrador during 1979, that fished over 320,000 trap days (Lien, 1980). Lien (1987) estimated that the number of cod traps had grown to approximately 7,500 by 1980. The cod trap fishery in Newfoundland was closed in 1993 due to the precarious state of the groundfish resources in northeastern Canada. At the time this paper was revised (May 1994) there were no plans to reopen this fishery.

Harbour porpoises, white whales, pilot whales, humpback whales, right whales and minke whales are known to become trapped or entangled in Newfoundland cod traps (Perkins and Beamish, 1979; Lien, 1980; 1994; Piatt and Nettleship, 1987). Entanglement is typically with the leader, rather than with the trap itself (Lien and Merdsoy, 1979), apparently as the whales and porpoises move parallel to shore pursuing prey. As with gillnets, there is considerable opportunity for live release, particularly with larger cetaceans. In 1989, only two of 22 humpbacks died after entrapment in Newfoundland cod traps (Lien *et al.*, 1990). Smaller whales, such as minkes, do not fare as well. All five minke whale entrapments in Newfoundland cod traps during 1989 resulted in the death of the animal (Lien *et al.*, 1990). Smaller cetaceans killed in cod traps may be used for local consumption; larger whales are cut free and discarded when possible.

The only information on entanglement rates in cod traps comes from the entrapment assistance programme at Memorial University of Newfoundland (Lien *et al.*, 1990; Lien, 1994). A summary of past entrapments reported to Memorial researchers is included in O'Hara *et al.* (1986). Between 1979 and 1990, Lien (1994) reported that about 47% of all humpback and minke whale entrapments in Newfoundland and Labrador occurred in cod traps. In 1989, the assistance programme was notified of 22 humpback and six minke whale entrapments. Using the estimates of under-reporting presented for groundfish gillnets, Lien *et al.* (1990) estimated that about 25 humpbacks and 8 minke whales became entangled in Newfoundland cod traps during 1989. A much larger number of collisions is reported to Memorial University by fishermen; presumably these collisions do not result in the entanglement of the whale, although they may damage the gear. The entrapment assistance programme has greatly reduced the mortality of large whales in Newfoundland cod traps. With this programme in place, cod traps do not appear to pose a serious threat to the humpback whale population. The numbers of minke whales and other small cetaceans killed each year in cod traps are probably too small to exert significant effects on any population.

Pinnipeds are adept at navigating around fish traps in shallow water, so it is unlikely that cod traps kill many seals in Newfoundland. Piatt and Nettleship (1987) report a single harbour seal captured in a cod trap, but do not provide details of the entrapment. It is likely, however, that many seals are shot around cod traps by fishermen.

The Newfoundland cod trap fishery is unlikely to exert significant mortality on any cetacean population, due largely to the efforts of the entrapment assistance programme and the recent decline of the fishery. The humpback population has increased during the last decade (Lien *et al.*, 1990), despite occasional mortality in cod traps. Katona and Beard (1990) estimated the Newfoundland-Labrador feeding aggregation of humpback whales at 2,310 (±580) for the 1978–83 period. Cod traps may have contributed some additional mortality to endangered or threatened populations, such as harbour porpoises and right whales, but are not responsible for the precarious status of these populations.

Bay of Fundy and Gulf of Maine herring weirs

Herring weirs are scattered along the shores of eastern Canada and New England. There are no particular ports in which herring weir fishermen congregate. Most herring weirs are located along the southwestern shore of the Bay of Fundy, with weirs also scattered along the western Nova Scotia and northern Maine coasts.

The main target species for this fishery is Atlantic herring (*Clupea harengus*). Various other pelagic species, particularly mackerel (*Scomber scombrus*), are also taken in quantity. Herring weirs are restricted to shallow near-shore waters and there are many local restrictions on the placement of these fixed structures that relate to navigation and spacing between weirs. In most areas it is only possible to construct a weir on a licensed site.

Weirs are usually tended by several vessels. In the Bay of Fundy, fishermen check weirs each day using small dories. More vessels are required to remove fish from a weir, including a seine skiff, pumper (often a multi-purpose lobster boat) and a carrier that transports the catch to a processing plant. A good description of herring weirs is given in McKenzie and Tibbo (1960). Weirs are usually kidney-shaped structures consisting of fine nylon mesh strung from stakes that are driven into the bottom of the sea floor. The shape of the weir is variable, to some extent, but always designed to minimise escape once fish have entered the structure. The mouth of the weir faces shoreward and a leader of varying length extends from the mouth towards the shore. The stakes are placed 10–15ft apart and are from 15–40ft in length, depending on the water depth. Fish are removed from herring weirs with a fine mesh (0.25 to 0.5 inch) purse seine.

Fishermen usually check their weir each morning around dawn, estimating the quantity of fish inside the structure with either an echosounder or a fine copper line with which they can feel the vibration of passing fish. If there is a sufficient quantity of herring in the weir, the mouth will be closed to prevent the fish from escaping. Fish are usually removed from the weir at low tide to facilitate handling of the purse seine. The seine is stretched around the inside perimeter of the weir until the fish are encircled. The seine

is then pursed and the fish pumped from the weir into the carrier. In the Bay of Fundy, weirs are constructed on a seasonal basis to take advantage of the migration of juvenile herring into inshore waters. The netting or 'twine' is taken down in the autumn in response to dwindling catches and the prospect of winter storms. In the spring or early summer, damaged or lost stakes are replaced and the twine is again restrung. The vast majority of herring weir catches in the Bay of Fundy are recorded from May to November (McKenzie and Tibbo, 1960).

Amongst a number of market factors, the price received by fishermen for herring reflects the size of the fish, the quantity of other species mixed with herring and the amount of herring being captured by other weirs. Smaller herring are canned and marketed as 'sardines.' In recent years, larger Canadian herring have been sold to Eastern European and Soviet factory freezer vessels under joint-venture agreements (Wilbur, 1990). Processing facilities are usually located close to weirs, because the fish are only lightly salted while being transported and spoil quickly. The herring weir fishery has a long history, dating back to at least 1820 in New Brunswick (McKenzie and Tibbo, 1960). In some areas along the Maine coast and in the Bay of Fundy, weirs are now being replaced by salmon aquaculture operations (C. Pendleton, pers. comm.). The landed value of the herring weir fishery in southwestern New Brunswick was estimated as approximately $2.2 million ($CAN) annually between 1974 and 1979 (Smith, *et al.*, 1983).

Herring weirs are capricious devices and a weir that fishes well in one year may catch nothing the next year. Recent landings in the Bay of Fundy have ranged from 30,000 tonnes in 1987 to 45,000 tonnes in 1989 (Wilbur, 1990). These figures do not include the relatively small weir fishery in American waters. There are no quotas for weirs, but markets may become saturated in years of good catches.

Effort in the herring weir fishery is usually measured by the number of weirs active each year. This does not, of course, account for variation in the number of months that each weir is active. In 1990, there were 180 active weirs in the western Bay of Fundy (Wilbur, 1990). The Maine Department of Marine Resources licenced 56 active weirs during 1990 (J. Fatterman, pers. comm.). In addition to those in the western Bay of Fundy and Maine, there are a few active weirs in western Nova Scotia and in southern New England.

The species of cetaceans known to become trapped in herring weirs include: harbour porpoises, humpback whales, minke whales and right whales (Smith, *et al.*, 1983; Kraus, 1990; A. Read, unpubl. data). Whales and porpoises apparently enter weirs when chasing prey and are then unable to find their way out of the structures. In the Bay of Fundy, fishermen reported that most harbour porpoises enter herring weirs at night (Smith, *et al.*, 1983). The vast majority of large whales that become trapped in herring weirs are released alive by fishermen, occasionally assisted by researchers. At least one weir in the Bay of Fundy has a net panel ('whale door') that can be opened to facilitate the release of a whale. Between 1980 and 1990, six humpback whales were trapped in Bay of Fundy herring weirs and all were released alive (A. Read, unpubl. data). Fifteen of seventeen minke whales were released alive during the same period; two whales died during seining operations. A right whale mother and calf were also released alive from a Bay of Fundy weir in 1976 (Kraus, 1990). Harbour porpoises trapped in herring weirs have a more uncertain fate. In questionnaire returns, fishermen indicated that 39% of harbour porpoises died after becoming trapped in weirs (Smith, *et al.*, 1983). Porpoises are either shot by fishermen or become entangled in the purse seine during the removal of the fish. Many fishermen attempt to remove harbour porpoises from weirs, however, and the practice of shooting porpoises is not widespread. As noted earlier, a few porpoises may still be used for human consumption in the Bay of Fundy.

The entrapment of a large whale in a herring weir is typically an unusual event, occurring only once or twice a year. 1990 was a highly unusual year in which ten minke whales and five humpbacks entered weirs in the Bay of Fundy. Weir entrapment is also unusual in New England; only four humpback and one minke whale entrapments have been recorded since 1975 – all escaped or were released alive (C. Coogan, NMFS, pers. comm.).

Smith *et al.* (1983) used questionanire returns to estimate that approximately 70 porpoises become trapped in Bay of Fundy herring weirs each year and that, on average, 27 die as a result of entrapment. In 1990, at least 43 porpoises were known to have become trapped in Bay of Fundy weirs, with an unknown number being killed (A. Read, unpubl. data). Since 1990, increasing numbers of porpoise entrapments are reported each year as part of a co-operative programme between Bay of Fundy weir fishermen and Canadian biologists. In 1993, over 100 porpoises were released alive as part of this programme (A. Read, unpub. data).

Fishermen operating herring weirs are acting in their own interest by removing whales from these structures alive, because large whales can easily damage both the netting and stakes. As noted above, many fishermen co-operate with researchers to free harbour porpoises from weirs and many porpoises have been tagged in this manner (Smith, *et al.*, 1983).

Herring weirs in New England and Atlantic Canada have little potential impact on cetacean populations. The only potential adverse effects are additional mortality on a stressed harbour porpoise stock and a very minor potential for mortality of endangered right whales. Herring weirs are listed as a Category III fishery under the 1988 amendment to the MMPA, because they have only a remote likelihood of taking marine mammals (Douglas, 1989).

Both harbour seals and grey seals feed around and inside herring weirs, but are able to navigate in and out of the structures with ease. Although the pinnipeds do not become trapped or entangled, large numbers of harbour seals and a few grey seals are shot each summer by herring weir fishermen in the Bay of Fundy.

Although herring weirs do not pose a direct threat to cetaceans in the Bay of Fundy or Gulf of Maine, the impact of harbour porpoise mortality in weirs must be considered in conjunction with the relatively large incidental mortality in groundfish gillnets. Action should be taken, therefore, to encourage fishermen to release harbour porpoises alive and minimise the number that are either shot or die during seining.

Atlantic Canada and Greenland salmon gillnets

This fishery operates along the western coasts of Greenland, and the Canadian shores of Newfoundland, Labrador and the northern Gulf of St. Lawrence. There are no ports of concentrated salmon gillnet activity. The target species is Atlantic salmon (*Salmo salar*). A variety of both pelagic and demersal species are also taken (see Christensen and Lear, 1977).

The northern limit of salmon gillnet operations in western Greenland is Godhavn at approximately 70°N. Most salmon nets are set in inshore waters along the Greenland coast (F. Larsen, pers. comm.). Salmon gillnets are set throughout inshore waters in northeastern Atlantic Canada.

The domestic Greenland fishery is dominated by small boats (less than 30ft in length) that work fairly close to shore (S. Northridge, pers. comm.). There was formerly a large driftnet fishery operated by vessels from the Faroes, Denmark and Norway in Greenland, but this practice ceased in 1976 and the fishery is now open only to Greenlandic vessels. In 1987 there were approximately 350 boats active in this fishery (S. Northridge, pers. comm.).

The number of active vessels declined in 1992 to 213 (J. Jensen, pers. comm.) and these Greenlandic fisheries were suspended in 1993 as a result of an agreement between fishermen and the North Atlantic Salmon Fund.

These fishermen used both monofilament and multifilament nylon nets, with mesh sizes of 130–140mm (Lear and Christensen, 1975; Christensen and Lear, 1977). Most nets were between 25 and 35m in length and extended from the surface to a depth of about 5m. The nets were suspended between a bottom lead line and an upper line equipped with floats. In the mid-1970s, the foreign fishery used up to 100 nets attached in 'links' which measured up to 1.8 n.miles in length (Christensen and Lear, 1977). Each foreign vessel set an average of 440 nets, extending for 7.8 n.miles (Lear and Christensen, 1975). In recent years domestic vessels seldom used more than 40 nets (S. Northridge, pers. comm.). In Canada, most commercial salmon gillnets are constructed of 5 inch (127mm) stretched mesh monofilament (B. Short, DFO, pers. comm.).

In the domestic Greenland fishery, both fixed and drift gillnets were used to take salmon (C. Kinze, pers. comm.). The foreign fleet used to set their nets just before sunset and started to haul just before sunrise, usually finishing before noon (Christensen and Lear, 1977). Salmon driftnets have been banned in Canadian waters and all commercial salmon gillnets must be fixed. Most nets are set with one end attached to the shoreline, although a few are anchored offshore (B. Short, DFO, pers. comm.). The nets fish in the upper portion of the water column.

The fishery is seasonal in both Greenland and Canada. In Greenland, the salmon fishery peaked in August and September (C. Kinze, pers. comm.). In Newfoundland, the season runs from early June to August or September, ending when the quota is filled or the weather deteriorates (B. Short, DFO, pers. comm.).

I have obtained little information on landed prices received by fishermen or market destinations. Nominal catches in the domestic Greenland fishery were 274 tonnes in 1990, 472 tonnes in 1991 and 237 tonnes in 1993 (J. Jensen, pers. comm.). Presumably most salmon is sold either fresh, iced, or frozen. The recent fishery in Greenland was considerably smaller than the fishery in the early 1970s when both domestic and foreign vessels were active. The domestic Greenland gillnet fishery took 963 tonnes of salmon in 1987 (NAFO, 1990). The Canadian driftnet fishery took 481 tonnes in Labrador, 794 tonnes in eastern and southern Newfoundland, and 306 tonnes in the Gulf of St. Lawrence (NAFO, 1990). Quotas exist in both Canadian and Greenland waters.

There are no effort data available for the Greenland fishery (F. Larsen, pers. comm.). There were 2,196 'gear units' used in southern and eastern Newfoundland and Labrador during 1989, each gear unit consisting of a net 300ft long. This gear was used by 549 individuals (B. Short, DFO, pers. comm.).

In Greenland, salmon gillnets took large numbers of harbour porpoises and an occasional pilot whale (Christensen and Lear, 1977; C. Kinze, pers. comm.). Salmon gillnets in Canada take a greater variety of cetaceans, including harbour porpoises and pilot, humpback and minke whales (Perkins and Beamish, 1979; Lien, 1980; Piatt and Nettleship, 1987; Lien *et al.*, 1990). In addition, an experimental driftnet fishery for salmon conducted by Canadian government researchers has taken the following species: harbour porpoises, white-sided dolphins, common dolphins (*Delphinus delphis*) and pilot whales (Stenson and Reddin, 1990).

There is little known about the entanglement process in salmon drift or fixed nets. Harbour porpoises are seldom reported to be released alive, although such an occurrence would be unlikely in Greenland where they are commonly consumed by local residents and occasionally used for bait (C. Kinze, pers. comm.). Five humpback whales entangled in salmon nets in Newfoundland during 1989 were either released alive or escaped unharmed (Lien *et al.*, 1990). Single humpback and minke whales both died after becoming entangled in salmon nets in Newfoundland during 1979 (Lien, 1980). Between 1979 and 1990, about 10% of humpback and 15% of minke whale entrapments occurred in salmon gillnets (Lien, 1994). There are few data on the number of cetaceans currently taken by salmon nets in eastern Canada. Both the foreign and domestic fisheries were known to have taken large numbers of harbour porpoises in the early 1970s. The foreign fishery is estimated to have taken approximately 1,500 porpoises in 1972 (Lear and Christensen, 1975) and the catch of the domestic fleet may have been almost as large (Christensen and Lear, 1977; Kapel, 1977). The number of harbour porpoises taken in Canadian waters is unknown, although catch rates reported by Newfoundland fishermen were lower for salmon gillnets than either groundfish gillnets or cod traps (Lien, 1987; Piatt and Nettleship, 1987). Laurin (1976) also noted that harbour porpoise entanglement rates were lower for salmon gillnets than groundfish gillnets in the Gulf of St. Lawrence.

With the limited data at hand, it is difficult to assess the potential impact of salmon gillnets on cetacean populations. It does appear, however, that this fishery affects only one species, the harbour porpoise, in its range of operations. Historical catches of harbour porpoises have been large and there is no evidence to demonstrate that they do not remain so. There has been no assessment of harbour porpoises in this area. Catches of harbour porpoises in Newfoundland, Labrador and the Gulf of St. Lawrence are unlikely to be as high as the historical records from Greenland. As noted above, however, these populations of harbour porpoises suffer considerable mortality from other fisheries; salmon gillnets contribute an unknown but additional mortality.

Salmon nets take harp seals, hooded seals, ringed seals (*Phoca hispida*) and bearded seals (*Erignathus barbatus*) in Greenland (Christensen and Lear, 1977) and harbour seals in Canada (Piatt and Nettleship, 1987). The magnitude of incidental catches of harbour porpoises should be assessed, if the salmon gillnet fishery is ever revived or expanded. At its current level of effort, this fishery is unlikely to exert a significant impact on any cetacean population.

US East coast swordfish driftnet fishery

This fishery operates from several ports in southern New England, although fishing operations are pelagic. The primary target species in this fishery is the swordfish (*Xiphius gladius*), but albacore (*Thunnus alalunga*), yellowfin tuna (*Thunnus albacares*), a variety of sharks and other large pelagic fish are also taken (NMFS, 1990b).

The fishery operates along the continental shelf break, north of Cape Hatteras from Block Canyon east to the boundary line separating the US and Canada. A few vessels may also operate in the waters of the Gulf of Mexico (Fox, 1990; NMFS, 1990b; Tillman, 1991). There is no information available on vessel size. This is a domestic US fishery, operating within the US EEZ. There are approximately 75 vessels registered in the fishery (Fox, 1990; Tillman, 1991), although only about 20 have been active (T. Smith, NMFS, pers. comm.).

The driftnets are made of 18 to 24 inch multifilament mesh and are up to 1.5 miles in length and 60ft deep (Gilbert and Wynne, 1987; NMFS, 1990b; T. Smith, pers. comm.). Fishing trips may last as long as two weeks, depending upon fishing success and weather conditions. Sets are made at dusk and the nets hauled at dawn. The nets are attached to the vessel at one end while the other end floats freely, with the net typically 2–6m below the surface. The vessel and net drift with currents and wind (NMFS, 1990b).

The catch is landed fresh at ports in southern New England, but there is little information available on landings for this fishery. Driftnets have been used to capture swordfish in New England since 1980 (Gilbert and Wynne, 1987). Effort data are recorded in logbooks maintained by each vessel and submitted to the International Commission for the Conservation of Atlantic Tunas (ICCAT). At the time of writing, these data were not available.

At least seven cetacean species have been taken, with common dolphins occurring most frequently in the bycatch (T. Smith, pers. comm.). Other species present in the bycatch are, in order of decreasing frequency: bottlenose dolphins (*Tursiops truncatus*), Risso's dolphins (*Grampus griseus*), beaked whales (*Mesoplodon* sp.), pilot whales, spotted dolphins (*Stenella* sp.), striped dolphins (*Stenella coeruleoalba*) and spinner dolphins (*Stenella* sp.). There is little or no opportunity for live release after entanglement in these driftnets. Cetaceans found entangled in the nets are either discarded or retrieved by researchers. No pinnipeds are taken by this fishery.

Swordfish driftnets are classified as a Category I fishery under the 1988 amendment to the MMPA (Tillman, 1991). Observations have been made by NMFS observers aboard these vessels since August 1989. To date, however, these observations have been voluntary and sampling has not been proportional to fishing effort. Despite these drawbacks, the observations do provide some idea of the relative magnitude of incidental mortality in this fishery. Between August and December 1989, 44 cetaceans were killed during 54 sets (T. Smith, pers. comm.). The number of animals killed per set varied from 0 to 12; at least one cetacean was killed in almost half of observed sets, but few sets kill more than two (T. Smith, pers. comm.). Between January 1990 and December 1992, 208 sets were observed and a mean bycatch per set of 1.35 was recorded (T. Smith, pers. comm.).

The non-proportional sampling and lack of effort data make it impossible to generate an estimate of total kill at the present time. Approximately 5–10% of the fishing trips are thought to have been sampled, but the exact sampling intensity has not yet been determined (T. Smith, pers. comm.). It is clear, however, that the incidental catch level in this fishery is substantial and deserves further assessment. The observed levels of incidental take in this fishery are high enough to pose a potential threat to several cetacean populations. The impact of these bycatches needs to be evaluated, although the pelagic nature of these animals will complicate assessment of their status.

The relatively small size of this fishery, combined with the availability of reliable effort data and an existing observer scheme should allow the accurate estimation of total incidental mortality. Current research and management efforts should be directed towards this goal. Once an estimate has been generated, the status of affected stocks will have to be evaluated on a species by species basis. Proposed legislation that would ban the use of large-scale driftnets within the US EEZ would not apply to this fishery due to length of nets used (T. Smith, pers. comm.).

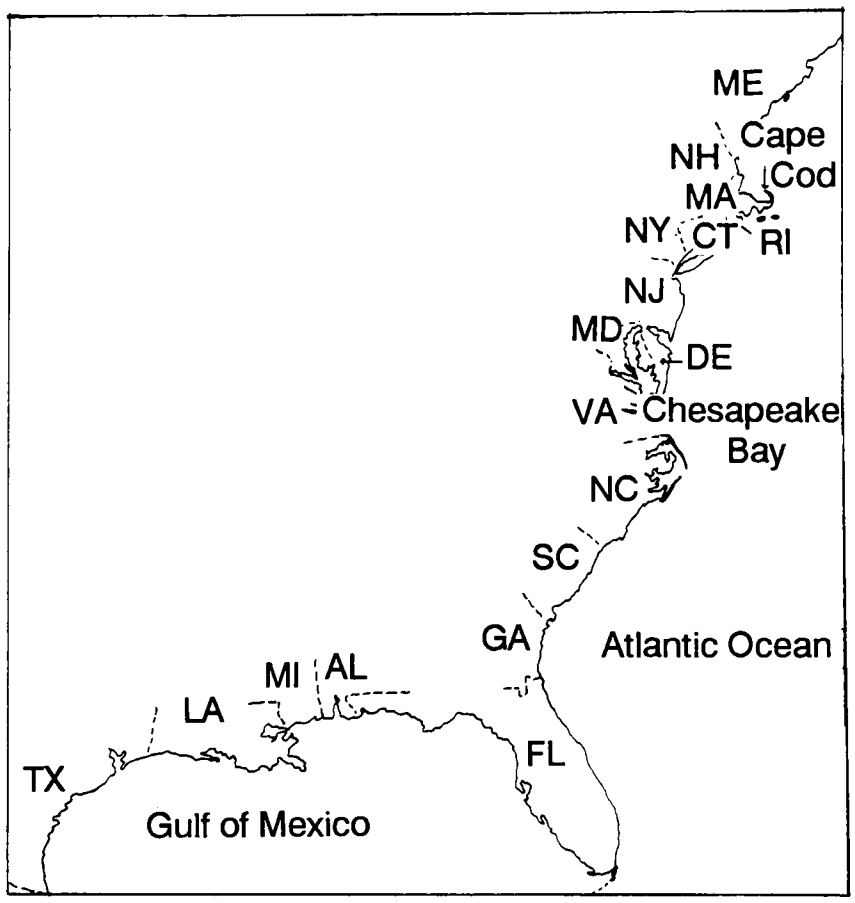

Fig. 2. Eastern United States, showing state boundaries and fishing regions described in the text.

FISHERIES NOT KNOWN TO TAKE LARGE NUMBERS OF CETACEANS

US East coast shad gillnets

A gillnet fishery exists for American shad (*Alosa sapidissima*) in near-shore waters from Connecticut to Georgia. The fishery is seasonal, taking advantage of the spawning migration of shad into river estuaries. Thus, in most areas, gillnets are set in ocean waters early in the season and are then moved into fresh water. In South Carolina, the shad fishery runs from February to May (C. Beardon, S.C. Marine Resources Inst., pers. comm.).

This fishery operates within the jurisdiction of coastal states, most of which require shad gillnets to have mesh sizes of 5 to 6 inches (NMFS, 1990b). Both drift and set nets are used, although most nets set in salt water are anchored or staked to the beach. The nets are constructed of monofilament nylon and are fished at or near the

surface. Net length is highly variable, with maximum allowable lengths ranging from 300ft in New Jersey (J. McLean, N.J. Division of Fish, Game, & Shellfisheries, pers. comm.) to 3,000ft in Delaware (R. Seagraves, Delaware Division of Fish & Wildlife, pers. comm.).

It is particularly difficult to obtain effort data for this and other small coastal fisheries, because fishermen are not required to report this information. In addition, it is often impossible to determine how many fishermen are active in each state, because individuals are required to obtain a general salt water commercial licence rather than a permit for each fishery. In its assessment of marine mammal interactions, NMFS estimated that approximately 4,500 individuals were active in this fishery (NMFS, 1990b). From conversations with state management personnel, however, this number appears to be high and may include recreational fishermen using shad gillnets in estuarine and freshwater areas; commercial fishermen setting nets in salt water probably number in the hundreds.

Although this fishery has declined during the last century, shad are still an important resource in many coastal states. The North Carolina shad fishery, for example, recorded landings of over 558 tonnes between 1985–1988, with a value of over $740,000 (Parker, 1990).

Several species of cetaceans are known to become entangled in shad nets, but there has been no systematic study of incidental catches in this fishery. Reynolds (1985) documented frequent reports of bottlenose dolphin entanglements in nets set for shad or Atlantic sturgeon (*Acipenser oxyrhynchus*) in South Carolina. The sturgeon fishery was probably responsible for most of this mortality, but has since been closed in both South and North Carolina for other reasons (C. Beardon, pers. comm.). It is likely, however, that a few bottlenose dolphins are still taken each year by shad nets.

Polacheck and Wenzel (1994) reported the incidental entanglement of a harbour porpoise in shad nets in the York River, which empties into Chesapeake Bay. J. Musick (Virginia Institute of Marine Science, pers. comm.) confirmed that harbour porpoises are occasionally taken in shad nets in the York River estuary and suggested that a few porpoises are taken each year in this manner. Recent observations of large numbers of stranded harbour porpoises bearing net marks and coinciding with the opening of the shad season (A. Read, unpublished data) have raised concerns over the numbers of this species taken in shad nets. Humpback whales have been entangled in shad nets set in Virginia on at least two and possibly three occasions since 1975, resulting in the death of two animals (C. Coogan, pers. comm.). Entanglement of large whales in this fishery is an unusual occurrence.

The shad gillnet fishery was classified in Category III by NMFS, as unlikely to take marine mammals during the course of its operations (Douglas, 1989). Although incidental captures probably occur each year in the fishery, the probability of capture of a cetacean in any particular net appears to be low. Nevertheless, a systematic evaluation of the fishery, including estimation of total effort and observations of net retrievals, would be useful.

Florida East coast shark driftnets

This is a small and poorly documented fishery operating on the east coast of Florida. In 1990, there were 11 vessels operating between Cape Canaveral and Jacksonville, Florida (E. Snell, NMFS, pers. comm.) using gillnets between 2,000–4,500ft in length and 60ft deep. The nets are made from 8–12 inch mesh and are usually allowed to drift within 10 miles of shore (NMFS, 1990b). The primary target species are blacktip sharks (*Carcharhinus limbatus*), but large numbers of brown sharks (*Carcharhinus plumbeus*) are also taken.

This fishery is currently unregulated, although a Fisheries Management Plan is being formulated. Permits, quotas, limits to net size, and reporting systems may be implemented in the future (NMFS, 1990b; C. Shelfer, Florida Marine Fisheries Commission, pers. comm.). In 1988, the fishery recorded landings of about 307 tonnes of sharks, valued at $352,523 (E. Snell, pers. comm.).

Almost nothing is known of the incidental catches made by this fishery. In its initial assessment, NMFS listed bottlenose dolphins as the only species taken and classified the fishery in Category III (Douglas, 1989). A subsequent review noted that the fishing methods were similar to those employed by US swordfish driftnetters and shark nets were, therefore, likely to take marine mammals. The fishery was thus reclassified as Category II (Fox, 1990). Turtles are also known to be taken at least occasionally by shark driftnets (C. Shelfer, pers. comm.).

As noted in the NMFS review, the large mesh size and drift operation utilized by this fishery makes it likely to take cetaceans during the course of its operations. A significant portion of the endangered northern right whale population winters in northeastern Florida and at least one right whale entanglement has been reported from this area although the type of gillnet was not identified (Kraus, 1990; NMFS, 1990a). A systematic evaluation of the incidental catches of cetaceans and other non-target species should be undertaken for this fishery; particular attention should be given to the potential for interactions between right whales and driftnets.

US East coast fish traps and pound nets

Pound nets, fyke nets and fish traps are used in the US mid-Atlantic states to take a variety of coastal fishes. These fishing devices are used from Massachusetts to North Carolina and are restricted to shallow near-shore areas. The nets are most useful where fish actively move through relatively narrow passages (Rounsefell, 1975). Pound nets, traps and fyke nets are constructed in varying fashion, depending on target species, regulation, topography and local tradition. Fyke nets are essentially long net cylinders, often supported by hoops, attached to net wings set obliquely on either side of the mouth of the cylinder (Rounsefell, 1975). As fish encounter the wings they are deflected towards the mouth of the net. Pound and trap nets are similar to the weirs and cod traps described above. These nets use a long leader that usually extends towards shore; as fish encounter the leader they are forced to turn and are lead into the mouth of the trap or pound. The mesh size used in these traps, pound nets and fyke nets varies with target species, but is typically fairly fine. In New York State, for example, fish traps are constructed from 2.25 inch mesh (A. Weber, N.Y. Department of Environmental Conservation, pers. comm.).

Many species of fish are taken with this gear. In Rhode Island, striped bass (*Morone saxatilis*), tautog (*Tautoga onitis*), mackerel, menhaden (*Brevoortia tyrannus*), scup (*Stenotomus chrysops*) and bluefish (*Pomatomus saltatrix*) are taken in fish traps (R. Sisson, Rhode Island Division of Fish & Wildlife, pers. comm.). In North Carolina, croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), weakfish (*Cynoscion regalis*), summer flounder (*Paralichthys dentatus*) and bluefish are taken in pound nets (Burns, 1990).

In many areas, pound nets, fyke nets and fish traps are in decline. In Rhode Island only six fish traps remain, operated by three companies. Earlier this century there were over 140 companies operating traps that took striped bass (R. Sisson, pers. comm.). Two or three pound nets still operate in Conneticut (E. Smith, Marine Fisheries Division, pers. comm.) and there are approximately 65 active fish traps in New York State (A. Weber, pers. comm.). Effort information was unavailable for other states. Pound nets are still used frequently in the waters of Chesapeake Bay, traditionally from spring to autumn (O'Hara *et al.*, 1986).

The only records of entanglement in these fisheries is of a minke whale killed in a Rhode Island fish trap in 1976 (C. Coogan, pers. comm.) and rare entrapments of bottlenose dolphins in pound nets (O'Hara *et al.*, 1986). These gears are classified as Category III fisheries (Douglas, 1989). The relatively small size of the structures, the fine mesh used in their construction and their location make it unlikely that they take many cetaceans.

US East coast and Gulf of Mexico mixed species coastal gillnets

This category contains a large number of diverse fisheries, most of which are limited in size and poorly documented. Because there is huge regional variation in the nature of these fisheries and because they fall within the jurisdiction of coastal states, I will describe the fisheries separately for each state. In most New England states (Maine, New Hampshire, Massachusetts, and Conneticut) coastal gillnets are set for groundfish; these fisheries are described above. Coastal gillnets have been banned in three states: South Carolina, Georgia and Texas, largely to conserve fish stocks. All of the remaining Atlantic and Gulf states have some form of coastal gillnet fishery.

In Rhode Island, a small gillnet fishery exists for flounder and tautog. Five or six fishermen set nets up to 300 or 600ft in length, depending on their location. The nets are constructed of 5.5 inch monofilament mesh and set on the bottom. Fishermen must tend their nets and haul them every 24hrs (R. Sisson, pers. comm.).

In New York, gillnets are set for striped bass and weakfish in the spring, summer and autumn. The mesh size of the nets varies from 3.5 to 7 inches depending on the target species. There are various restrictions on net length and operation that vary from location to location. In 1989, 181 commercial fishermen reported using some type of gillnet, although this number includes individuals that set fine mesh nets for lobster bait (A. Weber, pers. comm.).

Commercial fishermen in New Jersey set driftnets for bluefish and weakfish during the summer months. The minimum mesh size is 2.75 inches, but some individuals use mesh as large as 5 inches. The maximum net length is 1,200ft, although it is possible to put two nets together end to end. A total of 300 to 400 fishermen use gillnets, but this number includes bait fishermen (J. McLean, pers. comm.).

Weakfish are also taken in the spring, summer and autumn in Delaware, where 30 to 40 fishermen set both anchored and driftnets. Mesh size varies from 3.5 to 5.5 inches and nets are no more than 3,000ft in length (R. Seagraves, pers. comm.). Gillnets in Delaware also take croaker, striped bass and bluefish (O'Hara *et al.*, 1986).

Bluefish and weakfish are taken in anchored gillnets in Maryland during the summer by 20 to 30 fishermen. These nets are similar to those used in Delaware and New Jersey, with mesh sizes of up to 5 inches and maximum length of 3,000ft. There is also a fishery for white perch (*Morone americana*) in Chesapeake Bay that employs small mesh (minimum 2.5 inch) driftnets. Approximately 350 individuals participate in this fishery, setting nets that range from 250 to 2,400ft in length (H. Spear, Maryland Department of Natural Resources, pers. comm.). A small gillnet fishery also takes striped bass in Maryland, using 5–7 inch mesh nets that are limited to 1,200ft in length. This fishery is highly restricted, operating only during the month of January in 1991 (Valliant, 1991).

A variety of gillnets are used in the waters of Virginia, including a large number of weakfish nets set by recreational fishermen. Approximately 5,000 recreational gillnet licences were issued in 1988, but there is no information on actual effort. A total of 278 commercial licences were issued for staked gillnets during 1988. These commercial nets have mesh sizes ranging from 3–6 inches and may measure up to 1,200ft in length. There is also a very limited fishery for black drum (*Pogonia cromis*) that employs 11–13 inch mesh in shallow water (E. Smoller, Virginia Institute of Marine Science, pers. comm.). In general, gillnets are gradually replacing the pound net fishery in Virginia (J. Musick, pers. comm.).

Bottom set gillnets are referred to as 'sink nets' in North Carolina. These are heavily weighted monofilament nets with mesh sizes from 3–6 inches. The average vessel fishes approximately 3,000 to 4,500ft of net that is from 12 to 15ft deep. The fishery operates mainly from late autumn to early spring in water depths of up to 120ft. Most fishing activity occurs on the eastern shore of the Outer Banks. The nets are set on concentrations of fish and either hauled immediately or allowed to fish for several hours. The primary target species are weakfish, bluefish and Atlantic croaker (*Micropogonias undulatus*). The landed value of the fishery was $3.8 millions in 1987 (Ross, 1989). In 1989, over 100 vessels participated in this growing fishery (M. Street, N.C. Division of Marine Fisheries, pers. comm.). An excellent description of the North Carolina sink net fishery is given by Ross (1989).

Two major gillnet fisheries are used in the coastal waters of Florida: a near-shore fishery for pompano and a mixed species fishery in Florida Bay. Pompano nets are set perpendicular from shore for periods that vary from 30 minutes to several hours. The nets are usually made of 4.25–4.75 inch mesh and extend 600–1,200ft from the beach, where they are anchored onshore. The vessel is required to tend the net at all times (L. Fulford, pers. comm.). In Florida Bay, gillnets are used to catch fish either at the surface ('stab nets') or near the bottom ('sink nets'). These gillnets are up to 2,000ft in length and take a variety of species, depending on how they are employed. There are few data on effort in either of these fisheries (S. Kennedy, Florida Department of Natural Resources, pers. comm.; C. Shelfer, Florida Marine Fisheries Commission, pers. comm.).

Gillnets are also commonly employed in the northern Gulf of Mexico (Florida panhandle, Alabama, Missisippi and Louisiana). In Missisippi, for example, between 210 and 220 fishermen are licensed to use gillnets to take weakfish and a variety of other coastal species in the winter months. The minimum mesh size is 3 inches and nets can be up to 1,200ft in length (M. Buchanan, Missisippi Bureau of Marine Resources, pers. comm.).

So little is known about many of these fisheries that it is difficult to assess their potential for entanglement of cetaceans. A humpback whale was killed in a gillnet at Cape Henry, Virginia in February, 1975 (Perkins and Beamish, 1979). Harbour porpoises and bottlenose

dolphins are also known to become entangled in these coastal gillnets. A stranded harbour porpoise was recovered from the Outer Banks of North Carolina in 1979 with net marks on its body (Prescott and Fiorelli, 1980). A large number of harbour porpoises were stranded during the 1976–1977 winter on the Outer Banks; it is not known whether these animals died from natural causes or were entangled in fishing gear before washing ashore (Gaskin, 1984). Polacheck and Wenzel (1994) documented the strandings of several harbour porpoises that had been entangled in unknown fisheries along the mid-Atlantic coast: one from New Jersey; two from Virginia; and three from North Carolina. Bottlenose dolphins are known to be taken occasionally by gillnets in Chesapeake Bay (O'Hara *et al.*, 1986), in western Florida pompano nets (Reynolds, 1985; Morgan and Patton, 1990; R.S. Wells, pers. comm.) and gillnets in Missisippi Sound (Reynolds, 1985).

These gillnet fisheries are all classified as Category III fisheries by NMFS (Douglas, 1989). The opportunity for entanglement seems fairly low, although undoubtedly more animals are actually taken than reported. The entanglement of harbour porpoises along the mid-Atlantic coast should be examined to determine the actual extent of incidental catches in this area. The North Carolina sink net fishery has some striking similarities to the Gulf of Maine groundfish gillnet fishery and has the potential to take significant numbers of harbour porpoises if the winter range of the porpoise population overlaps with the area utilized by the fishery.

Atlantic Canada and US East coast small pelagic gillnets

These fisheries occur throughout Atlantic Canada and along the US east coast, taking small pelagic fish with fine mesh gillnets. The major target species are herring, mackerel and menhaden. Catches are used for human consumption and as bait for lobster and crab fisheries.

At one time, gillnets accounted for the majority of herring landings in Atlantic Canada. These catches have since dwindled and most herring is now landed by purse seiners (McKenzie and Tibbo, 1960). Both driftnets and anchored nets are still used; there were 4,273 herring and mackerel gillnet licences issued in the Bay of Fundy and western Nova Scotia region in 1989; most of these individuals take fish for use as lobster bait (J. Conway, DFO, pers. comm.). Mesh size varies from location to location; herring gillnets in the Bay of Fundy traditionally use mesh sizes of 2.25 to 2.75 inches (McKenzie and Tibbo, 1960). Gillnets in the Bay of Fundy took 2,289 tonnes of herring in 1987 (Stephenson and Power, 1988).

Mackerel gillnets are used throughout Atlantic Canada and along the coast of northern New England. As is the case with herring, gillnets used to account for the majority of mackerel catches, but have been largely replaced by purse seines in many areas. Mackerel may be captured in either drift or anchored gillnets fished near the surface. In Cape Cod Bay there is a small winter fishery for mackerel that uses nets constructed of 2 inch mesh, from 100 to 200ft long and 15ft deep (Gilbert and Wynne, 1983).

Fishermen from Maine to New Jersey set driftnets to catch menhaden and other small pelagic fish, largely for lobster and crab bait. These fisheries vary from area to area depending on local conditions and state regulations. The menhaden fishery in Rhode Island is probably typical of many bait fisheries in New England. The maximum mesh size allowed in Rhode Island bait nets is 3.75 inches and nets must not exceed 100ft in length. There are many restricted areas in which fishing is prohibited. All bait nets must be constantly tended by fishermen (R. Sisson, pers. comm.).

Small numbers of harbour porpoises are known to be taken in herring nets in the Gulf of St. Lawrence (P-M. Fontaine, pers. comm.), Nova Scotia (S. Smith, Dalhousie University, pers. comm.) and probably also in Newfoundland. Pilot, humpback and fin whales are all known to become entangled in Newfoundland herring gillnets on occasion (Lien, 1980; Loch, 1983). There is little information on cetacean incidental catches in Canadian mackerel nets, other than a record of a pilot whale entangled in Newfoundland during 1982 (Goodman, 1984). Incidental captures of both harbour porpoises and white-sided dolphins have been reported from the small mackerel fishery in Cape Cod Bay by Gilbert and Wynne (1983), a Category I fishery (Douglas, 1989). Fishermen reported entanglement of nine harbour porpoises and fourteen white-sided dolphins in 77 days of fishing in which a total of 1,500 nets were set. The majority of these animals were released alive (Gilbert and Wynne, 1983).

The fine mesh used in most of these gillnets, combined with their short fishing times, ensures that the potential for incidental capture of cetaceans is fairly low. The only exception to this may be the mackerel gillnet fishery in Cape Cod Bay, in which nets are fished for 24 hours (Gilbert and Wynne, 1983).

DISCUSSION

Substantial numbers of cetaceans have been and are taken in gillnet and trap fisheries in the Northwest Atlantic. The fisheries accounting for the majority of this mortality are the groundfish gillnet fishery, the Greenland salmon driftnet fishery and the US swordfish driftnet fishery. Entanglement usually results in the mortality of dolphins and porpoises; many large whales are able to survive their encounters with nets, sometimes with the aid of humans. In terms of numbers, harbour porpoises are the cetacean species most affected by incidental catches in gillnets and traps, followed by bottlenose dolphins, humpback whales and minke whales. Incidental mortality in commercial fisheries poses a serious threat to the several populations of harbour porpoises in this region. Occasional incidents of entanglement may also threaten the already endangered northern right whale population, due to its highly depleted status. The takes of pelagic dolphins and beaked whales by swordfish driftnets have an unknown effect on these populations.

There is an enormous amount of work still to do if we are to better understand the nature, magnitude and effects of this incidental mortality. In almost all major fisheries, we need to estimate the numbers of cetaceans killed each year. Assessments of the impact of these catches will of course require estimates of abundance and potential rates of increase. This is an enormous undertaking, even for only the most threatened populations.

Constructive management action should not be delayed while the effects of incidental catches are assessed. In the New England groundfish gillnet fishery, for example, managers, biologists and fishermen should explore potential means of reducing the impact of incidental mortality, without waiting for the results of the assessment. Short term management tools such as closed areas should be considered in addition to longer term options, such as gear modification. Groundfish gillnets are important components of the inshore fishing industry in eastern Canada and New England and provide a valuable income

to a large number of fishermen. Gillnets also cause the deaths of large numbers of marine mammals and seabirds (Piatt and Nettleship, 1987) each year. Management agencies will face a difficult task in assessing the detrimental effects of this fishery and finding means of mitigating the problem of incidental catch.

In my initial draft of this paper I made several recommendations for immediate action. These are listed in general order of priority below, with a brief statement on any subsequent action.

(1) Estimation of incidental catches of harbour porpoises made by groundfish gillnets in (i) Newfoundland and Labrador and (ii) the Gulf of St. Lawrence should be undertaken. Such estimates will require an on-board observation programme, if accurate data on catch rates are to be obtained. An observer programme should be formulated as soon as possible, even with very low sampling intensity, to provide rough estimates of the magnitude of mortality. This programme could be incorporated as part of DFO's existing on-board fishery monitoring programme. In addition, attempts should be made to improve the reporting of fishing effort. *No estimates of this mortality were made between 1990 and 1994. The situation in Newfoundland is now less critical because of regulated reductions or elimination of fishing effort. Large numbers of harbour porpoises continue to be taken in the Gulf of St. Lawrence, however.*

(2) Estimates should be made of the magnitude of past harbour porpoise incidental mortality in the Greenland salmon driftnet fishery. As noted for (1), this will require accurate information on both catch rates and total effort. *This fishery has now ceased, eliminating the requirement to estimate this mortality.*

(3) Efforts to estimate harbour porpoise incidental catch rates and fishing effort for the Gulf of Maine groundfish gillnet fishery should be continued and intensified. These efforts must ensure that sampling intensity is proportional to fishing effort and explore the effects of variation in gear type and mode of operation on mortality rates. In addition, the level of incidental mortality should be assessed in previously unstudied areas, such as southwestern Nova Scotia. *Considerable effort, on the part of fishermen, management agencies and conservation organisations, has been expended on this problem. At the time this paper was revised (May 1994), the New England Fishery Management Council has proposed the institution of time-area closures to reduce this mortality to sustainable levels.*

(4) On-board observations of the swordfish driftnet fishery should be continued in a fashion that is proportional to fishing effort. Consideration should be given to increasing sampling intensity given (i) the large number of cetaceans killed and (ii) the relatively small size of the fishery. It should be possible to sample a large proportion of all sets made by this fishery, increasing the reliability of statistical estimates of incidental mortality. Fishing effort data should be obtained from ICCAT, allowing the estimation of total kill. *These observations have been continued, but estimates of total mortality have not yet been made.*

(5) The magnitude of incidental mortality of cetaceans should be assessed for the Florida east coast shark driftnet fishery. A small observer programme would suffice to determine whether or not substantial incidental catches are recorded by this fishery. *I am unaware of any progress with this recommendation.*

(6) The magnitude of incidental mortality of cetaceans should be assessed for the North Carolina sink net fishery and some of the other small coastal gillnet fisheries in the mid-Atlantic states. As noted above, very small observer programmes would be sufficient to determine whether or not cetaceans are taken by these fisheries. *In 1993, observers were first used to monitor incidental mortality in fisheries south of Cape Cod. No data are yet available from this programme.*

(7) Projects such as Memorial University's entrapment assistance programme should be encouraged and supported. The threat of gear damage is an excellent incentive to persuade fishermen to co-operate in programmes that release entangled large whales. Unfortunately, there is no similar incentive for fishermen who encounter small cetaceans in their gear, because dolphins and porpoises cause little or no gear damage when entangled. *A programme has developed rapidly in the western Bay of Fundy, where fishermen and biologists co-operate to ensure the safe removal of harbour porpoises from herring weirs. Similar programmes run by the Center for Coastal Studies and other organisations on the US East coast have successfully disentangled many large whales from fishing gear in the coastal waters of New England.*

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Entrapments of Large Cetaceans in Passive Inshore Fishing Gear in Newfoundland and Labrador (1979–1990)

Jon Lien

Memorial University of Newfoundland, St. John's, Newfoundland A1C 5S7

ABSTRACT

In 1979 an assistance program was established for inshore fishermen in Newfoundland and Labrador who caught large whales and sharks in their fishing gear. The widely advertised program allowed fishermen to call toll-free for assistance and receive help from a trained crew in releasing the animal from the gear. From 1979–1990, 576 humpback whales, 124 minke whales, 13 fin whales, 68 long-finned pilot whales, 20 animals from other species of large whales and 51 large whales of unknown species have been reported entrapped in codtraps, groundfish gillnets, salmon gillnets and other passive inshore fishing gear. Mortality has varied according to the species entrapped and the duration of the entrapment. Distribution of the whales, variability of bait, fishing effort, numbers of animals in a population, and species characteristics each contribute to the relative frequency of incidental entrapments of large cetaceans.

KEYWORDS: INCIDENTAL CAPTURE; MORTALITY; FISHERIES; BEHAVIOUR; NORTH ATLANTIC; HUMPBACK WHALE; RIGHT WHALE; FIN WHALE; PILOT WHALE-LONG FINNED; BEAKED WHALE-SOWERBY'S; BOTTLENOSED WHALE; WHITE WHALE; NARWHAL.

INTRODUCTION

Incidental collisions and entrapments of cetaceans in inshore fishing gear in Newfoundland and Labrador have been occurring for decades or longer (Cuff, 1976; Scammell, 1980). However, written material is rare and anecdotal.

Typically, older fishermen stated that collisions by whales and sharks with fishing gear have always occurred. In the past, most whale collisions resulted in damage to the cotton and hemp fishing gear that was used but actual entrapments of animals in the gear were relatively infrequent. With the introduction of stronger synthetic ropes and webs, however, collisions have more frequently resulted in the whales becoming entangled and held by the fishing gear (Lien, 1980).

There is only one published summary of whale collisions with fishing gear in Newfoundland and Labrador prior to 1979. Perkins and Beamish (1979) reported a total of 19 humpback *Megaptera novaeangliae*, 13 minke *Balaenoptera acutorostrata* and one fin whale *Balaenoptera physalus* entrapments from 1969–1977. It is not possible to infer from their data, however, the actual numbers of entrapments or changes in the pattern or frequency of entrapments.

Some information on incidental collisions is available from a 1978 petition presented by a group of fishermen, that requested the resumption of whaling because of perceived increases in whale damage to fishing gear (Lien, 1980). The fishermen included figures on the amount of gear lost to whales but did not present information on down-time losses or on the numbers of whales caught. The petition contained 442 signatures, reporting 80 instances of whale damage at an average cost of $630, between 1976–1978 (Lien, 1980). It is not possible to extrapolate these data to the entire fishery. However, the fact that fishermen were sufficiently motivated by losses to organise a petition requesting reductions in the numbers of whales, and that 6% of the fishermen reported personal losses due to whales, indicates that whale collisions were a problem of some magnitude in the inshore fishery.

A third source of information is the weekly reports submitted by field officers in the Department of Fisheries and Oceans. Walsh and Lien (1978) reviewed these reports; they do not often contain references to whales. From 1975–1978 there were only 21 reports of whale collisions with fishing gear in the Newfoundland Region. Several comments in the field officers' reports, however, indicate that problems with whales in fishing gear may have been increasing (Lien, 1980).

A final source of information is the result of a questionnaire distributed to fishermen in 1979; it requested retrospective reports of incidental entrapments in fishing gear from 1974–1978 (Lien, 1980). A total of 2,200 questionnaire cards were distributed at fishermen's meetings; fishermen were asked to take them home, fill them out and return them through the mail. Response to the questionnaire was poor; only 136 replies were received (6% of total cards distributed). Most replies (72%) reported damages; 56% reported several instances of collisions. Fishermen who had experienced damage from whales were probably more likely to return the questionnaire card than were those who had not. If all fishermen in the sample who had received whale damage returned their report, and if these percentages were to be extrapolated to the entire inshore fishery of Newfoundland and Labrador, the annual average of whale collisions with fishing gear would be estimated as 320. Collisions which were reported involved all kinds of fishing gear: 27% groundfish gillnets; 35% surface gillnets and 39% codtraps (Lien, 1980).

Although it is clear from the evidence cited above that large cetaceans collided with and were entrapped by inshore fishing gear, it is not possible to infer the frequency of these events, their impact on the fishery, or the amount of whale mortality.

In 1979 a province-wide program was established to monitor the entrapment of large cetaceans in inshore fishing gear and provide assistance to fishermen in releasing animals from gear. Annual summaries of the program have been provided to the fishery management

agencies that sponsored it, but these have not been published. This paper summarises the results of the program for the period 1979–1990.

METHODS

Methods used in the Entrapment Assistance Program between 1979–1990 have varied slightly each year. Details are given in the annual program reports (Lien, 1980; Lien and Aldrich, 1982; Lien *et al.*, 1982; 1983; 1984; 1986; 1987; 1988; 1989a; 1990a) and summaries and analyses of the effectiveness of the methodology used are presented in Lien (1988) and Lien *et al.* (1989c). Details of the educational and publicity programs and an analysis of their role in the Entrapment Assistance Program are given in Lien *et al.* (1985a) and Lien (1989).

Each year, fishermen throughout Newfoundland and Labrador were encouraged to report whale and large shark problems to management officers of Fisheries and Oceans or the Newfoundland/Labrador Department of Fisheries. A toll-free number for reporting incidents was made available and was widely advertised. In some cases, entrapments were reported to the Royal Canadian Mounted Police, the Newfoundland/Labrador Department of Environment or the Canadian Coast Guard. All of these agencies relayed calls to the Entrapment Assistance Program at Memorial University of Newfoundland.

The University maintained a year-round capacity to respond to entrapment calls from any location in the province. As appropriate, fishermen were given advice or provided with access to tools. A trained crew was sent to help any who requested assistance in removing animals from gear. In all cases, assistance was given within 24 hours of the fishermen's request; usually the fishermen's problem was addressed within hours of receiving the report.

Because the program is an emergency assistance program for fishermen, it does not offer extensive opportunities for research on the whales themselves. However, for all entrapments the date, species, type of gear involved and outcome of the entrapment were recorded.

RESULTS

The number of large cetaceans reported entrapped in inshore fishing gear between 1979–1990, and the condition of the whales upon release from the gear are presented in Table 1. Mortality as a result of entrapment is presented in Table 2.

Humpback whales are most commonly caught; an annual average of 48 was reported (range 26–75), with an annual mean of 7.8 deaths; 83.6% of the entrapped humpbacks were released from the gear alive. Few large humpbacks (>12m) were entrapped. The pattern of entrapments has varied little from year to year; most humpback entrapments occur around the Avalon Peninsula, and along the northeast coast of the island of Newfoundland (Fig. 1).

The minke whale was the next most commonly reported species caught in fishing gear (n=124; mean=10.4/year); mortality was much higher (70%) than for humpback

Table 1

Large cetaceans reported entrapped in inshore fishing gear in Newfoundland and Labrador (1979-1990) and their condition on release. Misc. species includes Sowerby's beaked whale *Mesoplodon bidens*, northern bottlenose whale *Hyperoodon ampullatus*, white whales *Delphinapterus leucas*, narwhal *Monodon monceros*, right whales *Eubalaena glacialis*. * Increase due to special program in Labrador (Lien *et al.*, 1983).

Species	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Totals
Humpback													
Dead	13	17	8	5	5	6	8	3	3	12	4	10	94
Alive	34	44	23	30	30	20	44	31	41	54	66	65	482
Total	47	61	31	35	35	26	52	34	44	66	70	75	576
Minke													
Dead	9	9	8	4	4	6	7	4	8	7	10	11	87
Alive	1	3	3	5	7	2	2	3	4	2	2	3	37
Total	10	12	11	9	11	8	9	7	12	9	12	14	124
Fin													
Dead	4	1	1	0	0	0	0	0	1	0	0	0	7
Alive	3	2	0	0	0	0	0	0	0	0	0	1	6
Total	7	3	1	0	0	0	0	0	1	0	0	1	13
Pilot													
Dead	4	3	37	5	0	0	0	0	0	0	0	0	49
Alive	1	3	6	7	0	0	0	0	0	2	0	0	19
Total	5	6	43	12	0	0	0	0	0	2	0	0	68
Misc. spp.													
Dead	2	8	1	0	0	1	0	0	0	1	2	2	17
Alive	0	1	0	0	0	1	1	0	0	0	0	0	3
Total	2	9	1	0	0	2	1	0	0	1	2	2	20
Unknown spp.													
Dead	0	3	0	0	1	0	0	0	0	0	0	0	4
Alive	2	0	0	15	13	4	7	2	0	4	0	0	47
Total	2	3	0	15 *	14 *	4	7	2	0	4	0	0	51
Total (all species)													
Dead	32	41	55	14	10	13	15	7	12	20	16	23	258
Alive	41	53	32	57	50	27	54	36	45	62	68	69	594
Total	73	94	87	71	60	40	69	43	57	82	84	92	852

Table 2

Mortality of large cetaceans as a result of entrapment in inshore fishing gear in Newfoundland and Labrador (1979-1990) as a percentage of total number of entrapments.

Spp.	Mean %	Hump-back (n=576)	Minke (n=124)	Fin (n=13)	Pilot (n=68)	Misc. spp. (n=20)	Unknown (n=51)
1979	76	28	90	57	80	100	0
1980	44	28	75	33	50	89	100
1981	63	26	73	100	86	100	-
1982	20	14	44	-	42	-	0
1983	17	14	36	-	-	50	7
1984	18	23	75	-	-	0	0
1985	22	15	78	-	-	-	0
1986	16	9	57	-	-	-	0
1987	21	7	67	100	-	100	-
1988	24	18	78	-	0	100	0
1989	19	6	83	-	-	100	-
1990	25	13	79	0	-	100	-
Mean %	30	16	70	54	72	85	8

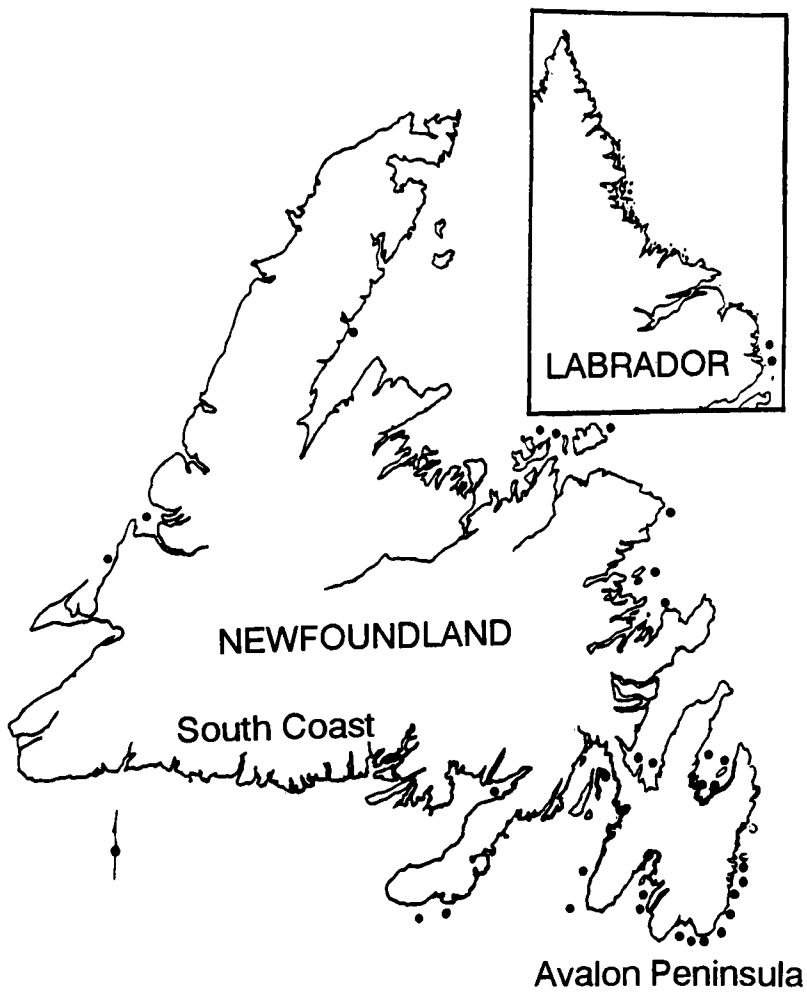

Fig. 1. (a) Humpback whale entrapments, 1979–80.

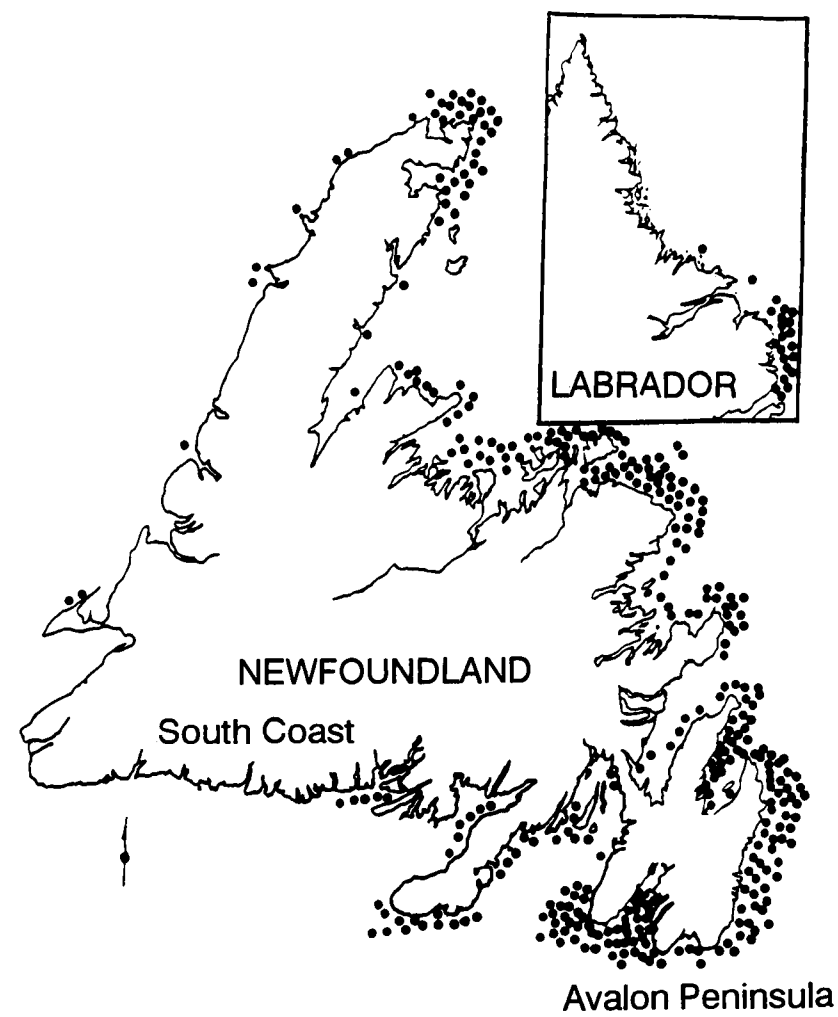

Fig. 1. (b) Humpback whale entrapments, 1981–87.

whales. The sizes of minke whales caught varied from small to full grown (3.7–9m). The primary areas of entrapments were similar to those for humpback whales (Fig. 2).

Although the number of humpback and minke whales entrapped in fishing gear in an area correlates with the number of fishermen there (Fig. 3), good estimates of effort by gear type in the inshore fishery are not available. Most fishing effort on the south coast of the island occurs in the winter; there is little summer effort. Fishing effort on the west coast of the island is generally lower and in summer, mostly directed to lobsters.

An annual average of just over one fin whale was reported entrapped in gear (n=13, mean=1.1), with 54% deaths. Most of the animals that died were small (<15m).

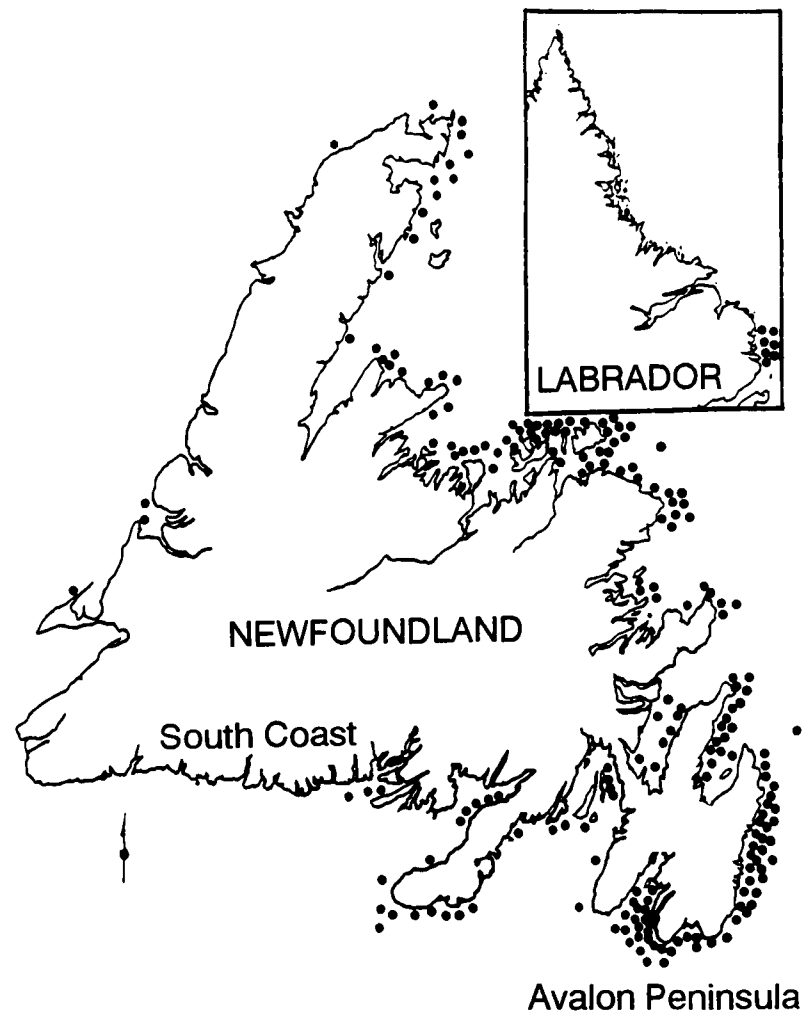

Fig. 1 (c) Humpback whale entrapments, 1988–90.

Fin whale entrapments were relatively frequent in 1979–1980, but have been reported only occasionally since then.

Most (97%) of the 68 long-finned pilot whale, *Globicephala melas*, entrapments occurred during the period 1979–1982. Mortality from entrapment was high (average=72%). There have been only two long-finned pilot whale entrapments since 1983.

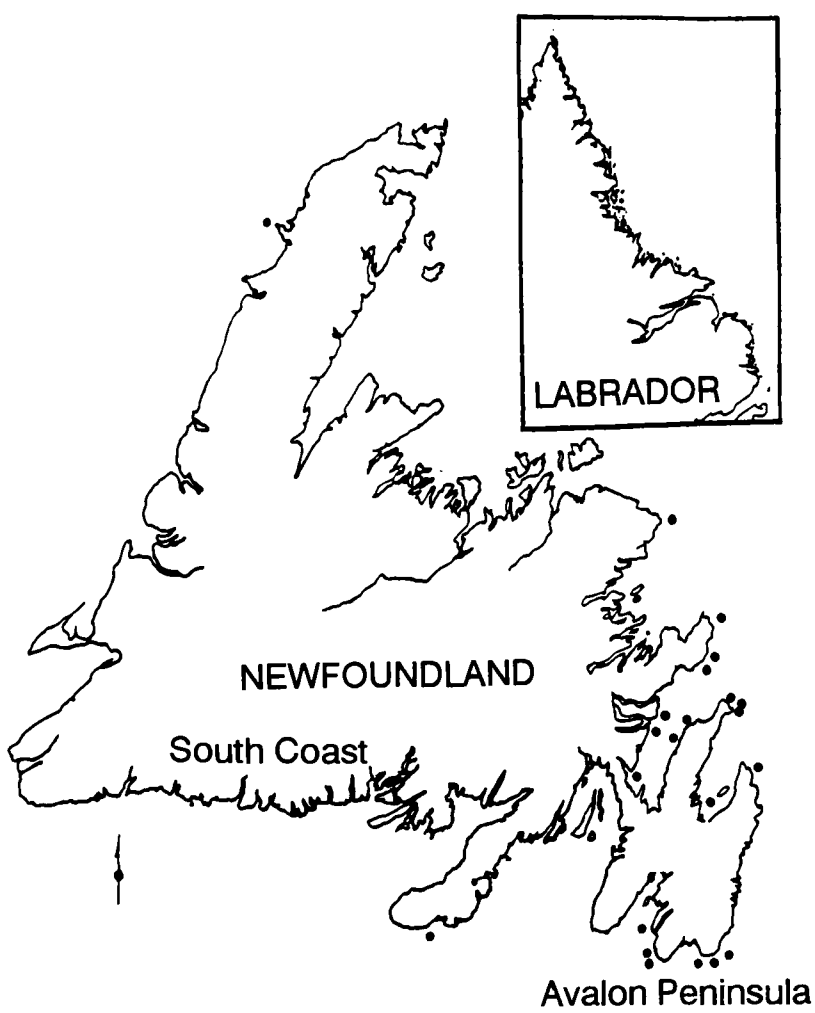

Fig. 2 (a) Minke whale entrapments, 1979–80.

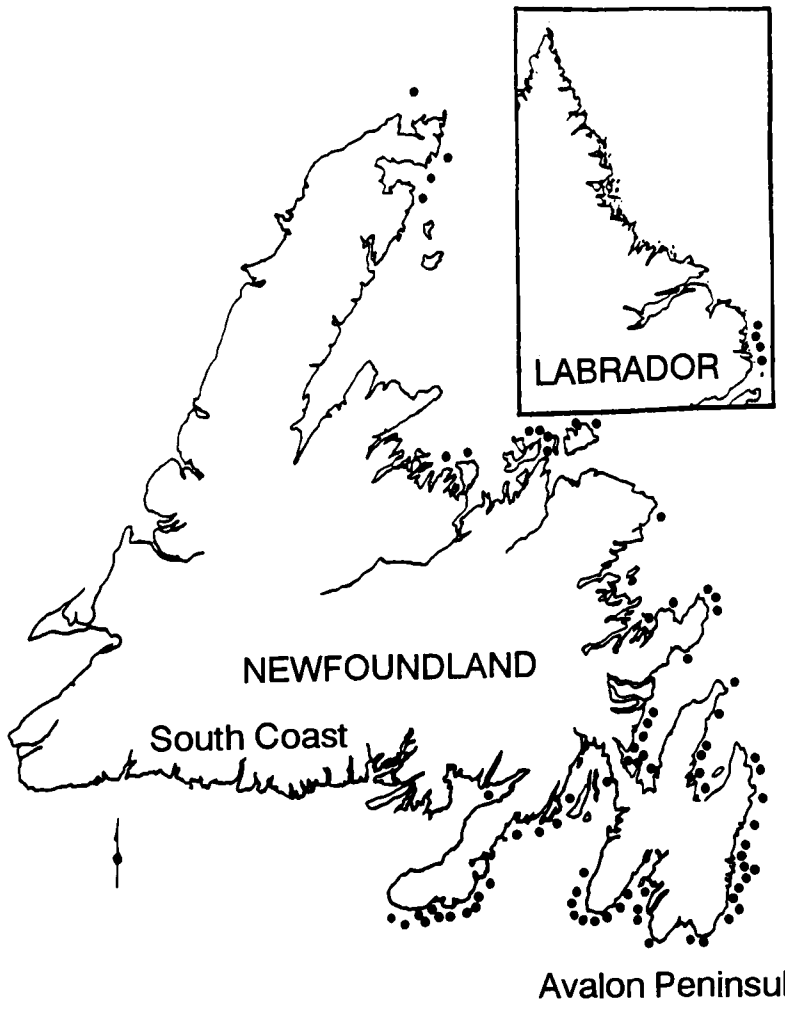

Fig. 2 (b) Minke whale entrapments, 1981–87.

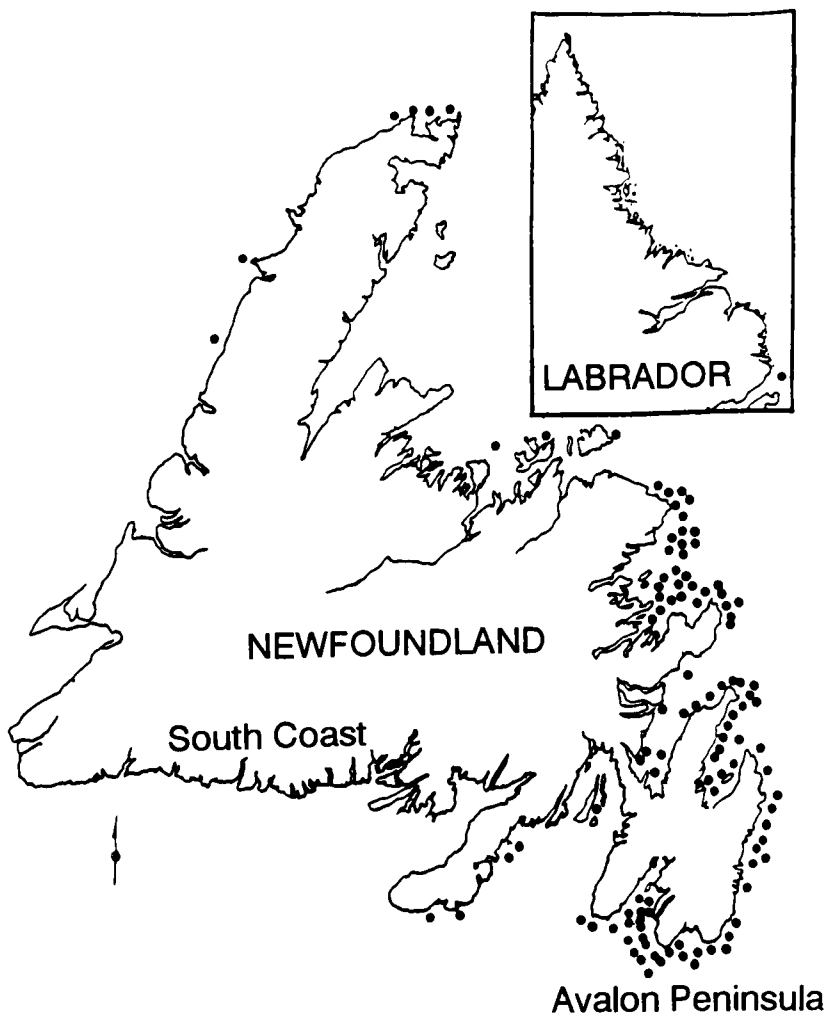

Fig. 2 (c) Minke whale entrapments, 1988–90.

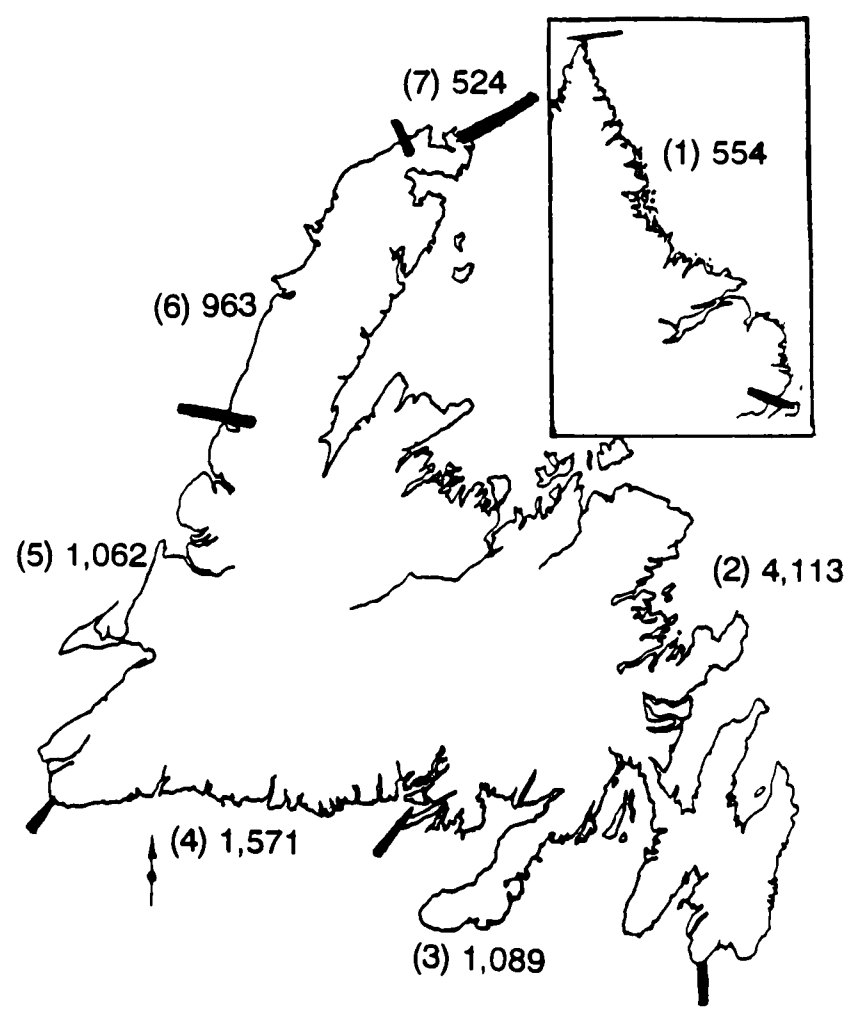

Fig. 3. Marine regions and number of fishing crews.

A variety of other species of cetaceans were also reported entrapped in inshore fishing gear (n=1.67/year). These included: 1 right whale, *Eubalaena glacialis*; 1 Sowerby's beaked whale, *Mesoplodon bidens*; 2 northern bottlenose whales, *Hyperoodon ampullatus*; 4 narwhals, *Monodon monoceros*; and 12 white whales, *Delphinapteras leucas*.

On occasion, large whales unidentified to species, were reported entrapped in fishing gear. These were typically groundfish gillnets, which were towed by the whale. In many of these cases, the whale's mobility made relocation impossible. Somewhat more than four reports each year (4.25/year) were in this category. Known mortality was low

for this group of animals (8.5%) because the final outcome of the entrapment could not be determined.

The overall average mortality for all large cetaceans reported entrapped in fishing gear between 1979–1990 was 30% (Table 2). Humpback whales had the lowest average mortality from entrapment (16%); minke (70%) and long-finned pilot whales (72%) fared less well. Mortality was highest in the 'misc. species' category (85%). Many of these less common species appeared to be young, injured, or diseased prior to entrapment in fishing gear.

The percentage mortality resulting from reported entrapments has been steady since 1982, ranging from 16–25%/year for all large cetaceans. This is much lower than during the first years of the Entrapment Assistance Program (and presumably before); from 1979–1981 mortality averaged 61%.

Table 3

Percentages of entrapments of humpback and minke whales in types of passive fishing gear used in Newfoundland and Labrador (1979-1990). Total number of humpbacks = 576; total number of minkes = 124.

	Type of fishing gear					
	Codtrap	Groundfish Gillnets	Salmon Gillnets	Other Gillnets	Other Traps	Other
Humpback						
Mean	46.8	37.7	9.7	0.8	1.7	3.3
SD	12.2	12.5	6.2	1.4	2.6	2.7
Range	32-69	11-51	0-20	0-4	0-7	0-8
Minke						
Mean	46.9	29.6	14.7	1.0	0	2.8
SD	18.7	18.7	15.2	3.5	0	6.9
Range	18-87	4-73	0-43	0-12	0	0-22

Codtraps and groundfish gillnets accounted for 80–90% of incidental entrapments of all large cetaceans (Table 3); there were species differences. Minke whales were more likely than other species to be caught in salmon (*Salmo salar*) nets and slightly less likely to be caught in groundfish gillnets. Long-finned pilot whales were almost always caught in squid (*Illex illecebrosus*) traps. The percentage of entrapments in different types of fishing gear varied widely among years; for example, the annual percentage of humpback whales entrapped in codtraps ranged from 32%-69% and for minke whales from 18%-87%.

The frequency of entrapments coincides with the peaks of effort in the inshore fishery (Table 4) which begins in May and, for the most part, ends in October. Most entrapments occurred in June, July or August; incidental entrapments before May and after October were unusual. On occasion, whales towing fishing gear from the previous fishing season were found and released during winter months (November-March).

DISCUSSION

Under-reporting

The number of large cetaceans reported caught in inshore fishing gear each year represents a minimum estimate of the number actually caught, for a number of reasons. First, it has been estimated that actual number of collisions with fishing gear by large whales are 4–5 times the numbers of entrapments (Lien, 1980; Lien *et al.*, 1987). In many of these collisions, the whale strikes the gear and becomes entangled, at least for a period. What percentage of these collisions involve brief entrapments, from which the animal struggles free before detection, is not known. It is also not known how often injury or mortality occurs in such brief entrapments with self-release.

A second reason is that fishermen under-report the events. Willingness of fishermen to report entrapments varies with the species of animal caught, location of the entrapment, anticipation of a market for the animal, compensation and the general state of the fishery (Lien *et al.*, 1989a; Lewis, 1992). Participation in the program by fishermen is voluntary; fishermen report large entrapped whales and sharks because the assistance which they receive results in lower gear loss and down-time (Lien, 1988). There is no legal requirement to report entrapped whales in Canada. The numbers of animals reported here are the number of entrapments that required the involvement of staff from the Entrapment Assistance Program.

Several methods have been used to estimate the degree of under-reporting of entrapped whales to the Entrapment Assistance Program. Observers have been placed in several locations and the reported catches of large whales compared with the numbers observed. In 1979 and 1980, when the Entrapment Assistance Program was first begun, estimates of under-reporting obtained by this method were about 30% for humpback whales (Lien, 1980; Lien and Aldrich, 1982); in later years, the estimates were about 10–20% (Lien *et al.*, 1982) and recent estimates have been 10% (Lien, 1988).

A second approach was to interview fishermen, by phone and in person, at the end of each fishing season. This similarly indicated under-reporting estimates of entrapped

Table 4

Entrapments of humpback and minke whales in passive inshore fishing gear in Newfoundland and Labrador by month. Values in percentages of total entrapments (1979-1990). Total number of humpbacks = 576; total number of minkes = 124.

	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Humpback										
Mean	0	0.2	5.7	28.0	52.8	11.5	1.2	0.9	0.1	0
SD	0	0.6	5.0	14.0	18.6	9.7	2.1	2.3	0	
Range	0	0-2	0-12	10-63	18-85	0-37	0-7	0-8	0-1	0
Minke										
Mean	0	0	3.1	30.8	52.8	9.2	1.3	1.0	1.3	0
SD	0	0	4.6	24.2	19.4	10.8	3.1	3.7	3.4	0
Range	0	0	0-10	0-71	18-86	0-33	0-9	0-13	0-10	0

humpback whales of 30% in 1979–1980 and about 10% in following years (Lien, 1988).

That almost all of the larger whales (humpback and finbacks) entrapped in fishing gear were reported during the last five years of the program seems evident as: (1) commonly, several calls from different individuals are received which report the same entrapment; (2) there were few instances of entrapments which were discovered through calls from secondary agencies, community visits, or end-of-season interviews that were not reported at the time by the fishermen themselves; and (3) rarely were fresh dead whales discovered with clear indications that fishing gear was implicated, that were not reported while entrapped.

Under-reporting of the smaller cetaceans (including minke, pilot whale and some misc. species) was higher as they tend to be less of a threat to fishing gear when entrapped, and fishermen often did not require assistance in removing them from gear (Lien, 1988). Under-reporting of entrapments of these species was estimated at about 25–30% (Lien *et al.*, 1988). Generally it is not possible to determine the numbers of small cetaceans, especially dolphins and porpoise, which are incidentally caught in fishing gear (SMRU, 1988).

Species numbers, distributions and entrapments

Numbers of entrapments which occur in inshore fishing gear are not closely correlated with the estimated sizes of whale populations in waters near Newfoundland and Labrador, although there are correlations between the frequency with which a species is sighted inshore and the number of entrapments.

There are no good estimates of numbers of fin whales in the area (Meredith and Campbell, 1988) but Lynch (1987) reports a decrease in the numbers seen in inshore waters since the early 1980s. This decrease in inshore sightings parallels the decrease in numbers of fin whales incidentally caught in fishing gear since 1981.

Inshore numbers of long-finned pilot whales fluctuate with abundance cycles of squid (Sergeant, 1962; Mercer, 1975). Squid were abundant inshore between 1979–1982 but have not been common since that time. Sightings of these whales inshore, mass strandings and entrapments in fishing gear follow this trend (Lien, 1988).

Although there are no useful estimates of abundance of the minke whale in Newfoundland and Labrador waters (Stewart and Leatherwood, 1985), it is an extremely common whale (Lien *et al.*, 1985b). The relatively low number of reported collisions, despite its apparent abundance in heavy inshore fishing areas, would seem to indicate that it is able to avoid collisions with fishing gear. However, inshore fishermen in Newfoundland believe that it does collide with gear quite frequently, but its pointed head and smooth body allow it to pass through the nets leaving just a hole, unlike humpback whales (see below).

Katona and Beard (1990) present an estimate of 2,310 (95% CI 1,730; 2,890) humpback whales for the feeding sub-population off Newfoundland and Labrador. In addition to their abundance, two factors contribute to the frequency with which humpbacks become entangled in fishing gear: one behavioural, the other morphological. Off Newfoundland and Labrador they are dependent on capelin (*Mallotus villosus*), the key bait species which attracts target commercial populations of fish and, therefore, fishing effort. Capelin abundance is correlated with the inshore abundance of humpbacks (Whitehead and Carscadden, 1985) which ensures that whales and fishing gear are found in the same locations. Given this, the morphology of the humpback whale (long pectoral fins and barnacles) is commonly the reason it is prone to being held by the nets (Lien, 1988)

Most of the species of large whales that have been only occasionally caught in fishing gear are rare in Newfoundland and Labrador waters. The right whale (Gaskin, 1987; Lien *et al.*, 1989b) and Sowerby's beaked whale (Dix *et al.*, 1986; Lien and Barry, 1989) only occasionally visit inshore waters. Other species uncommonly caught in fishing gear such as the narwhal (Merdsoy *et al.*, 1979; Strong, 1988), the white whale (Sergeant and Fisher, 1954; Sergeant *et al.*, 1970; Sergeant and Brodie, 1975) and the northern bottlenose whale (Mead, 1989) appear to be extralimital in Newfoundland's inshore waters.

How entrapments occur

The pattern of entrapments, or the relative frequency of entrapment of different species of cetaceans, provides little information on understanding factors which produce entrapments. It is not known how often whale activities in the vicinity of fishing gear result in incidental entrapment, or the type of activities which may enhance the probability of incidental entrapment. Feeding by the whales and human fishing activity both occur in the most productive inshore zones and therefore, coincidentally, result in contact (Lien, 1980).

Most entrapments of large cetaceans in inshore fishing gear in Newfoundland and Labrador appear to be the result of accidents where the whale does not detect the gear, at least in time to avoid it (Lien, 1980; Lien *et al.*, 1990b). Prime fishing areas, where nets are located, are often characterised by poor visibility (Lien, 1980). Sounds passively produced by nets and which might provide clues to the nets' presence are a function of drag characteristics; these can be modified as nets fill with fish, making the nets more difficult to detect acoustically (Lien *et al.*, 1990b). Generally, bait used by the whales is in the area of fishing gear, but is not the target species of the fishing gear. For example capelin will commonly school densely next to leaders of codtraps and avoid swimming through the meshes. Such schools may attract whales and stimulate feeding directly next to fishing gear. Further, the dense schools might obscure the fishing gear's presence behind the bait (Lien *et al.*, 1989a).

There are two exceptions where the presence of fishing gear appears involved directly in attracting whales and this attraction results in entrapments. Minke whales commonly establish ranges (Dorsey, 1983); these ranges may include codtrap berths. The whales appear to approach fishing boats engaged in hauling gear within their range. 'Pet' minke whales are a common phenomenon in Newfoundland, especially on the Southern Shore of the Avalon Peninsula and the Virgin Rocks. These whales will approach immediately when a trap is being hauled; fishermen feed the animals small, non-commercial codfish *Gadus morhua*. On occasion, it is these 'pet' whales that are later caught in the fishing gear.

Similarly, long-finned pilot whales are almost always caught in the net boxes of squid traps which hold the catch. The whales enter the box through doors and feed on the squid. As the box is small, and provides limited room to manoeuvre, the whale sometimes contacts the net sides of the trap and becomes caught.

Most humpback whales caught in fishing gear were small (<11m). It is possible that larger, more powerful individuals are better able to break free so fewer are found

entrapped, but it also may suggest it is the younger animals which are more commonly caught due in part at least, to a lack of experience.

Whales often receive wounds during entrapment (Lien, 1988) and these can leave scars which provide a record of prior entrapments (Kraus, 1990). While fresh wounds are observed on entrapped humpback whales, scars from previous entrapments are rarely seen (Lien *et al.*, 1983; Lewis, 1992). One encounter with fishing gear that results in an entrapment may increase wariness or avoidance of nets.

On release from an entrapment, humpback whales typically leave the area rapidly (Lien, 1988). On the three occasions when humpback whales were radio tagged during entrapment, each animal moved rapidly away from entrapment locations when released and travelled long distances, up to several hundred n.miles in the first few days after release (Mate, pers. comm.). There are only three known instances where a humpback released from fishing gear became entrapped a second time (Lien and Aldrich, 1982; Lien *et al.*, 1988; 1990b); these all occurred within a few minutes of initial release and are probably the result of the whale's efforts to quickly leave the area.

Mortality

Humpback whales have the lowest percentage mortality from entrapments while minke and pilot whales have high mortality (Table 2).

Mortality appears to be a function of: (1) the size and behaviour of the whale when entrapped; (2) the duration of the entrapment; and (3) the assistance given in releasing the animal.

Following a collision, humpback whales frequently become calm and lie restrained by the fishing gear without struggling. Following gear contact, minke whales commonly begin rolling; the net becomes wrapped around the body in such a manner that they can no longer surface to breathe. Long-finned pilot whales also tend to become quite frantic following a collision. Generally, the more vigorous or frantic the struggle once a collision occurs the higher the mortality (Lien, 1988).

There seems to be generally lower mortality for larger whales during entrapments. Smaller whales would certainly have more difficulty in repeatedly pulling long fleets of gillnets or gear the size of a standard codtrap to the surface in order to breathe.

The probability that an entrapped whale will die increases with the amount of time that passes before it is released. The highest numbers of dead whales caught in gear are reported on Mondays (the first day fishermen check their nets after the 1–2 day weekends) or following periods of bad weather in which the gear could not be worked (Lien, 1988). For example, 7 out of 10 humpback deaths which occurred during 1990 happened during the same week (Lien *et al.*, 1990a). For a time just prior to this week, a lucrative pulse market was available for capelin and fishermen were extremely busy with this fishery; additionally, weather was extremely bad and severely limited the amount of time that gear could be worked. Thus groundfish gillnets and codtraps were not checked; incidentally caught cetaceans were simply not detected within normal time limits. Another example occurred in 1988 when funding for the Entrapment Assistance Program did not become available until later in the fishing season. Mortality during the period before the program got underway was extremely high (Lien *et al.*, 1988).

Assistance given to free whales from fishing gear lowers resulting mortality. Prior to the Entrapment Assistance Program, mortality of humpbacks caught in fishing gear in Newfoundland and Labrador was estimated at 50% (Perkins and Beamish, 1979; Lien, 1980). During the first several years of the program mortality of humpbacks was from 26 - 28% (Lien, 1980; Lien and Aldrich, 1982). During this period, fishermen often saw the Entrapment Assistance Program only as a means of 'saving whales'; animals were commonly left in the gear, and without assistance, died. Later, when fishermen became more familiar with the program, and realised benefits through the assistance it provided in removing whales from gear, more of them co-operated with the program. Average humpback mortality from entrapment from 1987–1990 was 11%.

Impact on populations

The present levels of mortality resulting from incidental entrapment in inshore fishing gear in Newfoundland and Labrador probably only seriously affect one large cetacean species: the endangered right whale. Although only a single right whale has been reported entrapped in fishing gear, it died (Lien *et al.*, 1984); only five sightings of right whales have been made in Newfoundland and Labrador in the past decade (Lien *et al.*, 1989b). Fishing gear is believed to be a serious threat to the rare right whale in the western North Atlantic (Kraus, 1990; NOAA, 1990).

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Incidental Catches of Harbour Porpoises (*Phocoena phocoena*) in the Gulf of St. Lawrence and the St. Lawrence River Estuary, Québec, Canada

Pierre-Michel Fontaine and Cyrille Barrette

Département de Biologie, Université Laval, Québec, P.Q. Canada G1K 7P4

Mike O. Hammill and Michael C.S. Kingsley

Fisheries and Oceans Canada, C.P. 1000 Mont-Joli, P.Q. Canada G5H 3Z4

ABSTRACT

Incidental catches of harbour porpoise by commercial fisheries in the Estuary and Gulf of St. Lawrence, Canada were examined. Two questionnaires, one in 1989 and one in 1990, were sent to all active fishermen, asking for information on the number of porpoises caught during the previous season, gear type and mesh size, location and time of catch. Out of 968 questionnaires sent in 1989 and 731 in 1990, 33% and 18% respectively were returned completed. In both years, 29% of the fishermen said they had caught one or more porpoises during the previous year. The 316 responses to the first questionnaire indicated that 623 porpoises were caught during the 1988 fishing season for a mean of 1.97 (SD=6.3) porpoises per fisherman; the 135 responses to the second indicated that 326 animals were caught (mean 2.41; SD=10.9). Catches were mainly in gillnets set for cod (*Gadus morhua*), in July, near shore, but some porpoises were caught in all months from April through November. On average, for both surveys combined, 7% of fishermen said they had caught other cetaceans and 49% said they had caught seals. A total of 148 porpoise carcasses were retrieved from fishermen in 1989. The mean length of males was 135cm (SD=14.8) (n=64) including some large specimens (9>160cm).

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; NORTH ATLANTIC; HARBOUR PORPOISE; PINNIPEDS; WHITE-SIDED DOLPHIN; WHITE-BEAKED DOLPHIN; MINKE WHALE; WHITE WHALE.

INTRODUCTION

The development of commercial fisheries has led to increased competition between marine mammals and man for marine resources (Duguy and Hussenot, 1982). Monofilament drift or set nets and marine mammals are often present in the same areas resulting in large incidental catches, particularly among the phocoenidae, in many fisheries around the world (Ohsumi, 1975; Gaskin, 1984; Northridge, 1984).

The harbour porpoise (*Phocoena phocoena*) is one of the smallest cetaceans, with an adult length of about 1.55m and weight of around 52kg (Gaskin *et al.*, 1974). Found in northern temperate coastal regions, it appears to be particularly susceptible to capture in commercial fisheries (e.g. see IWC, 1992). In Canada, incidental catches of harbour porpoise by commercial fisheries have been examined off the east coast of Newfoundland and in the Bay of Fundy (Gaskin, 1984; Lien, 1987; Lien *et al.*, 1987). However, little is known about by-catches in what might be a separate population (Gaskin, 1984) occupying the Estuary and the Gulf of St. Lawrence. In a preliminary study on by-catch, Laurin (1976) visited 36 fishing communities in the Estuary over a three-year period and mentioned that some fishermen caught up to 15 animals during a fishing season. However he was unable to estimate the total by-catch in the St. Lawrence region. The objective of our study was to obtain more information on the incidental catch of harbour porpoises in the Estuary and northern Gulf of St. Lawrence.

MATERIAL AND METHODS

Questionnaires

The study area encompassed the Estuary and the northern Gulf of St. Lawrence, including the Magdalen Islands, a total area of some 71,370 n.miles^2 centered around 49°N, 63°W (Fig. 1). Questionnaires were sent to all active fixed-gear fishermen registered with the Department of Fisheries and Oceans Canada (DFO), Division of Statistics and Data Processing. A fisherman was considered active if he had landed fish at least once during the fishing season. Questionnaires were sent to fishermen during the winter of 1989 and during the summer of 1990 in order to obtain data for the 1988 and 1989 fishing seasons, respectively. Fishermen were asked how many porpoises they had caught during the previous season, the month of capture, the type of fishing gear used and were asked to indicate the location of capture on a map included in the questionnaire. They were also asked to report observations of harbour porpoises and of incidental catches of other cetaceans and seals. Information on fish tonnage landed in the area was obtained from the DFO.

Retrieval of carcasses

In 1989, we initiated a carcass retrieval program. Fishermen in the three main fishing harbours were contacted and offered a $40 retrieval fee paid per specimen in order to alleviate losses due to damaged nets and handling. The program started on 20 May, and was stopped, because of freezer space limitations, on 20 August after 148 specimens had been received. Each carcass was examined for evidence of net scars, and fresh cuts or wounds to ensure that no animal had been intentionally hunted for the purpose of collecting the fee. At the same time, information on the date, location and type of fishing gear used as well as the fisherman's name and address were obtained. Carcasses were frozen immediately and dissected later in the laboratory. Necropsies were done according to the standard method of the American Society of Mammalogists (1961). Ovaries were sectioned manually in 2mm slices and sexual maturity of the females was established by the presence of either a corpus albicans or

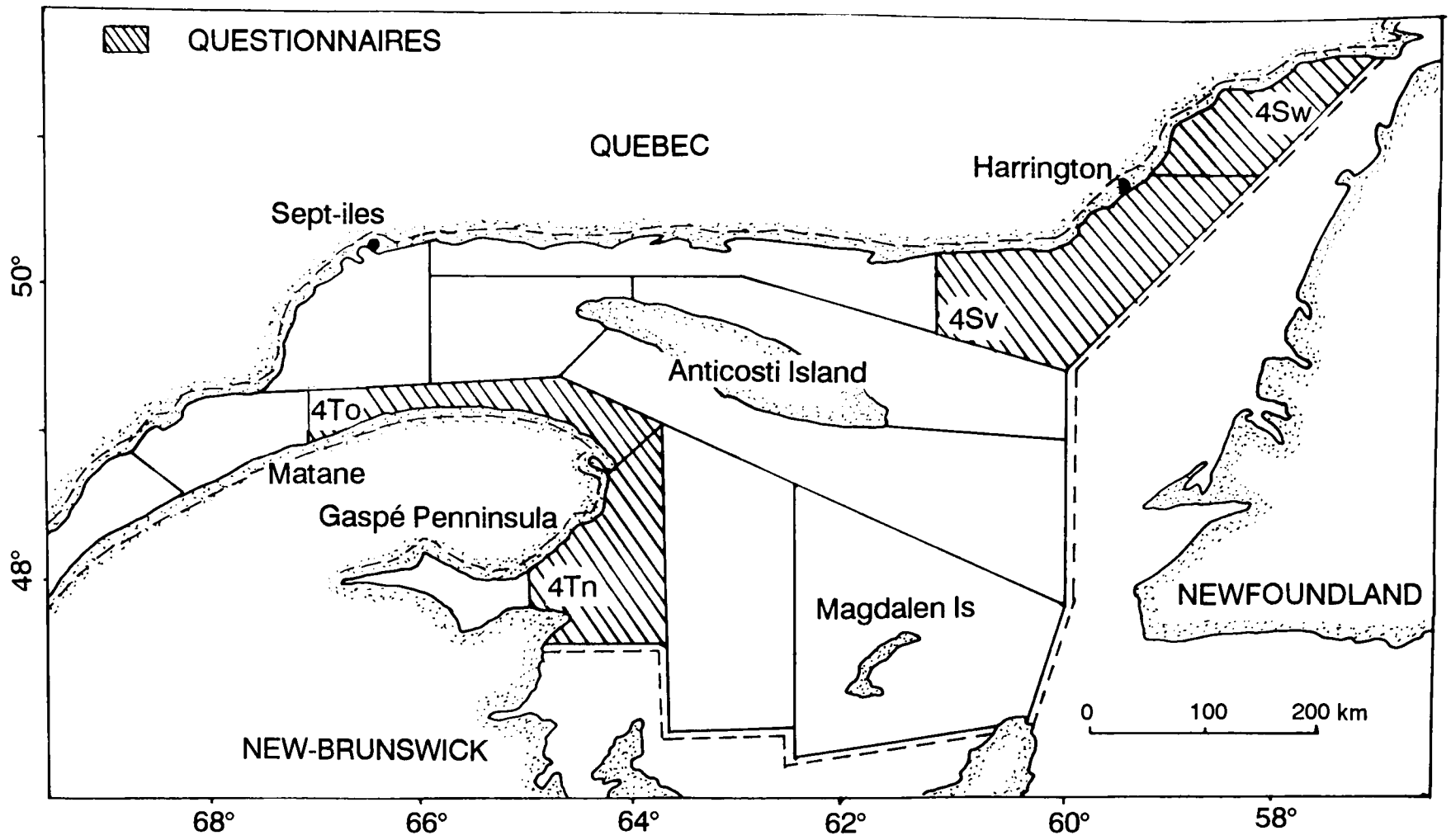

Fig. 1. The dotted line encloses the study area. Hatching shows the regions of high catches reported from the questionnaire. Abbreviations identify the North-west Atlantic Fisheries Organisation division of the area.

corpus luteum (Perrin and Donovan, 1984). Differences between means and frequency distributions of porpoise catches were examined using Student's *t*-test and the chi-square goodness of fit test.

RESULTS

Questionnaires

Out of the 968 questionnaires sent in 1989 and 731 in 1990, 33% and 18% respectively were returned completed (Table 1). The lower response rate in 1990 may be due to the questionnaires having been sent during the summer fishing season, whereas in 1989 they were sent in the winter, a time of reduced activity for fishermen. In both years, 29% of the respondents said they had caught one or more porpoises during the previous fishing season. In 1989, 42% reported that they had caught porpoises during their life. Results from the first questionnaire indicated that 623 porpoises were caught during the 1988 fishing season, with a mean of 1.97 (SD=6.3) porpoises per fisherman. The survey showed that 326 animals were caught in 1989, for a mean of 2.41 (SD=10.9) porpoises per fisherman (Table 1). There was no significant difference in mean catch per fisherman between years (t=-0.65, α>0.05).

Regional differences in bycatches were examined by dividing the study area into 14 regions following Northwest Atlantic Fisheries Organisation (NAFO) divisions. The distribution of porpoise captures did not follow the distribution that would be expected if proportional to the fish tonnage landed in the same regions (chi^2=897, df=13, p<0.0001, in 1988; chi^2=5,326, df=13, p<0.0001, in 1989). For instance, four regions consisting of the Gaspé Peninsula and the lower North shore (Fig. 1), were the source of 66% in 1989 and 72% in 1990 of the incidental catch reported, but accounted for only 39% and 41% of fish tonnage landed in 1988 and 1989 respectively.

Similarly, the monthly distribution of incidental catches did not follow the monthly distribution expected if proportional to the fish tonnage landed (chi^2=87, df=7, p<0.0001, in 1988; chi^2=32, df=7, p<0.0001, in 1989). For instance, for both years together, 80% of incidental catches were made in June-July-August, while only 51% of total fish tonnage landed occurred at that time (Fig. 2).

Table 1

Results from the questionnaires for the two fishing seasons and the program of carcass retrieval.

	Questionnaire		Carcass retrieval
	1989	1990	1989
Questionnaires sent (Active fishermen)	968	731	
Questionnaires received completed	316 (33%)	135 (18%)	
Fishermen who caught or delivered porpoises	93 (29%)	36 (29%)	36
Harbour porpoises reported or received	623	325	148
Harbour porpoises per fisherman (Mean±SD)	**1.97±6.3** [a]	**2.41±10.9** [a]	
Extrapolation of the number of by-catches	1907	1762	

[a] Inter year differences were non significant. (t=-0.65, α >0.05)

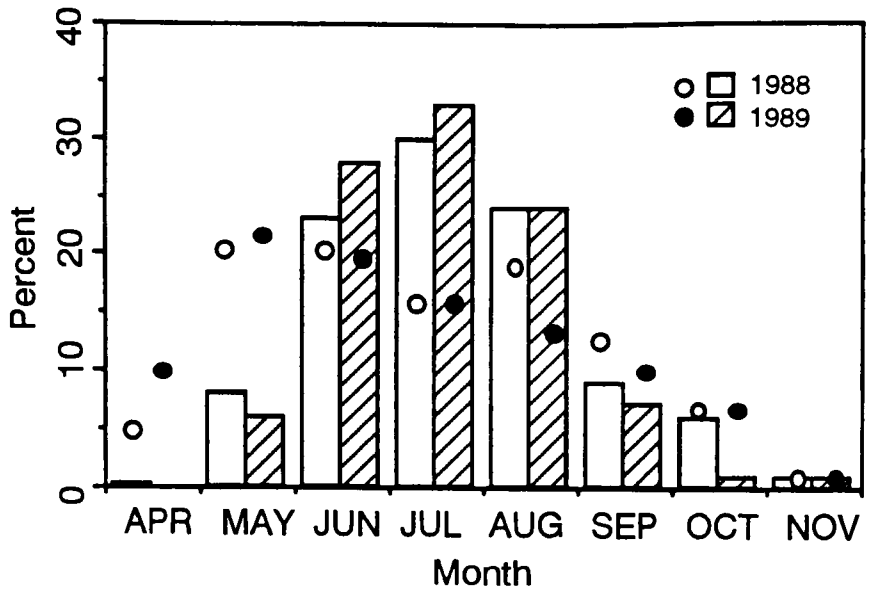

Fig. 2. Monthly distributions of incidental catches (bars) reported in the questionnaires and of fish tonnage landed (dots) for the two fishing seasons, both expressed as a monthly percentage of the annual total.

Almost all porpoises were caught in monofilament gillnets. Gillnets set on the bottom to catch cod (*Gadus morhua*) were responsible for 72% and 89% of the cases during the 1988 and 1989 fishing seasons, respectively. Next in importance were gillnets set for herring (*Clupea harengus*), salmon (*Salmo salar*), lumpfish (*Cyclopterus lumpus*) and mackerel (*Scomber scombrus*). Other types of fishing gear such as cod traps and herring traps, accounted for very few catches (Table 2).

Table 2

Type of gear responsible for the incidental catches of harbour porpoises as determined from the questionnaires for the two fishing seasons and from the program of carcass retrieval.

Type of gear and mesh size	Questionnaires 1989-1990	Retrieval Program 1989
*Cod 14-21cm	72%-89%	95%
*Herring 7cm	11%- 3%	5%
*Salmon 14cm	4%- 5%	0%
*Lumpfish 34cm	4%- 3%	0%
*Mackerel 5-10cm	3%- 0%	0%
Cod trap	3%- 0%	0%
Others	3%- 0%	0%

* Monofilament gillnets.

The number of porpoises captured, as well as the tonnage of fish landed by fishermen was related to the size of their boats. Boats greater than 14m in length made up 7% of the registered fleet during the two fishing seasons. However, they caught 38% of the fish in the two years (chi^2=376, df=1, p<0.0001) and 28% of the porpoises reported (chi^2=202, df=1, p<0.0001).

Fishermen were asked if they caught seals: 58% in 1988 and 40% in 1989 replied that they had at some time in the past. Fishermen that had caught porpoises were more likely to have caught seals: 83% of the fishermen who caught porpoises in 1988 (n=92) and 63% in 1989 (n=36) also caught seals. Whereas, of those who had not caught porpoises, only 42% (n=161) and 31% (n=94) said they caught seals in 1988 and 1989 respectively. The pinniped species caught were grey seal (*Halichoerus grypus*), harbour seal (*Phoca vitulina*) and harp seal (*Phoca groenlandica*).

Fishermen were also asked if they had caught other cetaceans in their nets: 10% in 1989 and 4% in 1990 responded positively but in many cases only indicated that they had caught unidentified whales. Several species were identified including the Atlantic white-sided dolphin (*Lagenorhyncus acutus*), white-beaked dolphin (*Lagenorhyncus albirostris*) and minke whale (*Balaenoptera acutorostrata*). White whales (*Delphinapterus leucas*) were also listed as having been caught in the past, but none were caught in 1988 or 1989.

Retrieval program of carcasses

Gillnets were implicated in all 148 carcasses obtained, 95% of which were set to catch cod and 5% were set to catch herring (Table 2).

Ten fishermen who returned the questionnaire for the 1989 season also supplied porpoises in the same season: 34.4% of the porpoises that they said they had caught were delivered to us.

More males (53%) than females (47%) were in the sample, but the sex ratio did not differ significantly from unity and is similar to that for other bycatch samples (Clausen and Andersen, 1988; Read, 1989). The mean length of males was 135 ±11.4cm (n=76), and the mean length of females was 142 ±14.8cm (n=68). Our sample included some very large specimens: nine females (14%) were more than 160cm long. Fifty three percent (n=66) of the females were sexually mature, and 58% of these were lactating.

DISCUSSION

The quality of information derived from questionnaire surveys depends on sample size, the bias of non-respondents and the accuracy of the data provided (e.g. Usher and Wenzel, 1987; Lien *et al.*, 1994). In this study, we contacted all registered fishermen in our study area, and the number of respondents was quite high. Estimating non-respondent bias is more difficult. Here, we have assumed that both respondent and non-respondent bias was similar. Previous studies of incidental catches in commercial fisheries have used telephone or mail surveys of fishermen (Smith *et al.*, 1983; Lien, 1987). We used mail surveys because they are more cost effective for contacting a large number of people. We also believe that these surveys may be more accurate, particularly the results from our 1989 winter sample when fishermen were less active and therefore felt less pressured to respond. We believe that those who took the time to answer, did so carefully. Lien *et al.* (1994) examined the accuracy of results based on 'memory recall' surveys and found that results were more accurate when the number of animals caught was low. In our study, most fishermen (93% in 1989 and 76% in 1990) said they caught less than 10 porpoises, making it likely that the answers to our questionnaires were accurate.

The fact that the ten fishermen who returned questionnaires and carcasses returned only 34.4% of the total number of animals that they said they had caught in that year could be due to: (1) in some cases too much effort would have been required to disentangle the carcasses; (2) the carcass retrieval program was cancelled before the end of the fishing season; and (3) in some areas, particularly along the North Shore and parts of the Gaspé peninsula, harbour porpoises are still used locally for food.

The absence of a significant difference in mean catch per fisherman between years indicates that either the questionnaire yielded a reliable estimate of the bycatch or,

if a bias was present, then the bias was consistent from year to year. Our overall average of 2.07±8.6 porpoises per fisherman per year is higher than the average Lien (1987) found along the eastern coast of Newfoundland ($\bar{x}$=1.4), but is much lower than reported for the Bay of Fundy ($\bar{x}$=5.5) by Read and Gaskin (1988). The Bay of Fundy is a smaller area with a high density of porpoises during the summer (Read and Gaskin, 1988) and may not be comparable to areas like Newfoundland or Québec.

Each active fisherman on our list (around 850) is the owner of a boat and can be considered to represent one crew. Lien (1987) estimated the number of crews in Newfoundland and Labrador to be 2,300 and the number of harbour porpoises taken incidentally per year to be 1,800–3,000 (0.81–1.4 porpoises per crew per season). Our study area is geographically and climatically similar to Lien's and it is interesting to note that our estimates (1.15 – 2.07 porpoises per crew per season) are similar to his.

Our questionnaire results showed that a minimum of 623 and 326 porpoises were caught accidentally in the northern Gulf and Estuary during commercial fishing in 1988 and 1989, respectively. Extrapolating the mean number of porpoises caught per fisherman returning questionnaires to the total number of active fishermen, results in an estimate of 1,907 and 1,767 porpoises caught in our study area in 1988 and 1989 respectively. This extrapolation assumes that all non-respondents expended similar fishing effort and caught similar numbers of porpoises to the respondents in our surveys. At this time, we are unable to verify these assumptions. However, owing to the similarity in the results between the two surveys and the high response rates, particularly to the first questionnaire (33%), we believe that the actual number of captures is closer to our higher estimate of 1,907 animals than our lower estimate of 1,767.

In evaluating the impact of incidental catches, the effect on the population of losing lactating females should not be neglected. Lactation in *P. phocoena* lasts for at least nine months (Read, 1990). During the fishing season, young of the year would be no more than five or six months old and, even if they are not captured with their mother, would be unlikely to survive. In our sample, only four calves were caught compared to 20 lactating females. We consider it necessary to increase our estimate of the total by-catch by 13% to account for mortality of orphaned calves.

Both the questionnaires and the carcass retrieval program agreed with Laurin's (1976) results, showing that a disproportionate number of animals are caught along the lower North Shore of the St. Lawrence and around the Gaspé Peninsula (Fig. 1). Differences between the spatial and temporal distribution of fish tonnage landed and porpoise catches, suggest that there is movement of harbour porpoise into the northern Gulf and Estuary during June, July and August.

Gillnets set for groundfish were responsible for most of the incidental catches in our area, as is true in the Bay of Fundy (Read and Gaskin, 1988) and Newfoundland (Lien, 1987). Such nets are usually set to capture cod. It is not surprising that porpoises become entangled given that they, as well as cod, feed on capelin (*Mallotus villosus*) and herring (Lilly, 1987; Fontaine, 1992). Many fishermen believe that porpoises are caught soon after the nets are set. However, Read and Gaskin (1988) failed to catch porpoises in an experiment in which the nets were retrieved immediately after being set. Four fishermen in the same area captured a total of 0–6 porpoises with similar nets set at the same time but left in place for the normal period of 24 hours. It would thus appear that most entanglements occur while nets are at the bottom.

The disproportionately high catches by large boats (>14m) may be due to greater fishing effort, but unfortunately, information on effort is not available. Alternatively, porpoises may be more susceptible to entrapment by large boats due to the use of different fishing techniques. For example, a single long net like those set by larger boats is more likely to catch porpoises than the same length of net broken up into short units (Ohsumi, 1975).

Changes in size distribution of porpoises have been used as an indicator of population status (Clausen and Andersen, 1988; Read and Gaskin, 1988). Our proportion of females greater than 160cm (14%) was much higher than that found by Read (1989) in the Bay of Fundy (5%) and by Clausen and Andersen (1988) in Danish waters (7%). Unfortunately, there are no historical data for the St. Lawrence area to compare with our sample on size distribution. However, the greater proportion of large specimens reported in other populations subjected to heavy catches, might suggest that the St. Lawrence population has been less affected than those in Danish waters and the Bay of Fundy (Clausen and Andersen, 1988; Read and Gaskin, 1988). It could also mean that the population in our study area is isolated from the one in the Bay of Fundy as suggested by Gaskin (1984). Despite the difficulty in ageing harbour porpoises (Watts and Gaskin, 1989), age distributions would be a better index of population status because they may be independent of ecological factors that may affect body size (Fontaine, 1992).

Fishermen reporting that they had caught porpoises were more likely to have caught seals as well. Both harbour porpoises and seals are associated with coastal regions and forage for similar food resources (Boulva and McLaren, 1979; Lilly, 1987; Benoit and Bowen, 1990; Murie and Lavigne, 1991; Sergeant, 1991; Fontaine, 1992). Fishermen tend to have a more negative feeling towards seals than towards porpoises (Read and Gaskin, 1988). Seals are caught much more often and cause more damage to the nets. Seals are also an intermediate host of the cod-worm (*Pseudoterranova decipiens*) which affects the commercial value of cod (Malouf, 1986).

Incidental catches of other cetaceans do not seem to occur frequently in comparison with those of harbour porpoises or seals. Fishermen were unable to identify reliably the various mysticetes encountered, so it is difficult to list the species taken or to estimate how frequently each species was caught. The questionnaires also indicated that white whales had been captured accidentally in the past, but not during the recent fishing seasons. We do not believe that commercial fishing affects white whales in the Gulf of St. Lawrence because fishing is concentrated downstream of the area currently occupied by this population (Michaud *et al.*, 1990).

CONCLUSION

This study indicates that there is a substantial incidental catch of harbour porpoises in Québec waters in the Gulf of St. Lawrence. Given our lack of knowledge on harbour porpoise abundance in this area, it is difficult to assess the impact of such catches. However, research is currently underway to obtain information on porpoise abundance, along with information on incidental catch of porpoises

from the west coast of Newfoundland and in the southern Gulf of St. Lawrence.

Our estimate of incidental catches in the northern Gulf (probably around 1,900) could be more accurate with better information on fishing effort and the variability of this parameter between fishermen. Obtaining this information and attempting to reduce the incidental take of harbour porpoise will be achieved most effectively by working with the fishing industry. It is, after all, with the cooperation of fishermen that we have been able to identify and to document the initial problem. As a first step, it would be important to provide fishermen with more information about the problem and its consequences.

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SC/O90/G47

Coastal Fisheries and Cetacean Mortality in Portugal

Marina Sequeira

Instituto da Conservação da Natureza, Divisão de Investigação e Estudos Ecológicos, R. Filipe Folque, 46–3°, 1000 Lisboa, Portugal

and

Carlos Ferreira

Instituto Português de Investigação Marítima, Departamento de Tecnologia da Pesca, Av. Brasília, 1400 Lisboa, Portugal

ABSTRACT

Considerable numbers of cetaceans are killed incidentally every year during fishing operations on the Portuguese coast. Although a small number of marine mammals are caught by trawlers and fishing traps, the highest mortality rates occur in the gillnet fishery. The common dolphin (*Delphinus delphis*) and the harbour porpoise (*Phocoena phocoena*) have been the major victims and the numbers of cetaceans caught are particularly high in the central areas of the Portuguese coast. However there is little reliable biological information available on the incidental taking of cetaceans on the Portuguese coast, and there is an urgent need for a monitoring programme there.

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; NORTH ATLANTIC; COMMON DOLPHIN; HARBOUR PORPOISE; STRIPED DOLPHIN; BOTTLENOSE DOLPHIN; MANAGEMENT

INTRODUCTION

Fishing zones

The Portuguese continental shelf covers a maritime area of *ca* 28,000km^2 (about 600km long between 37° and 42°N). As the Portuguese coast is almost devoid of island protection it is exposed to strong northwestern Atlantic influences, and is thus hardly propitious to fishing activities involving complex gear that has to remain at sea for long periods.

However, the Algarve coastline in Southern Portugal is sheltered from the dominant northwesterly winds and thus provides better conditions for bottom anchored fixed gear close to the coastline. Until quite recently this included fixed traps for tuna (*Thunnus thynnus*) and sardine (*Sardina pilchardus*).

The Portuguese coast can be divided into three fishing zones: northern, central and southern (Fig. 1).

Northern zone

The northern zone is about 200km long and stretches from the Minho river south to Mira. It includes 51 harbours with 37 fishing fleets that operate exclusively at sea (the remaining fleets operate essentially in freshwater and estuarine areas).

Central zone

The central zone spans almost 350km between Tocha and Azenha do Mar with 51 harbours and 34 fishing fleets operating at sea.

Southern zone

The southern zone extends about 160km between Odeceixe and Cape S. Vicente and includes 36 fishing harbours, most of them situated along the southern facing shoreline.

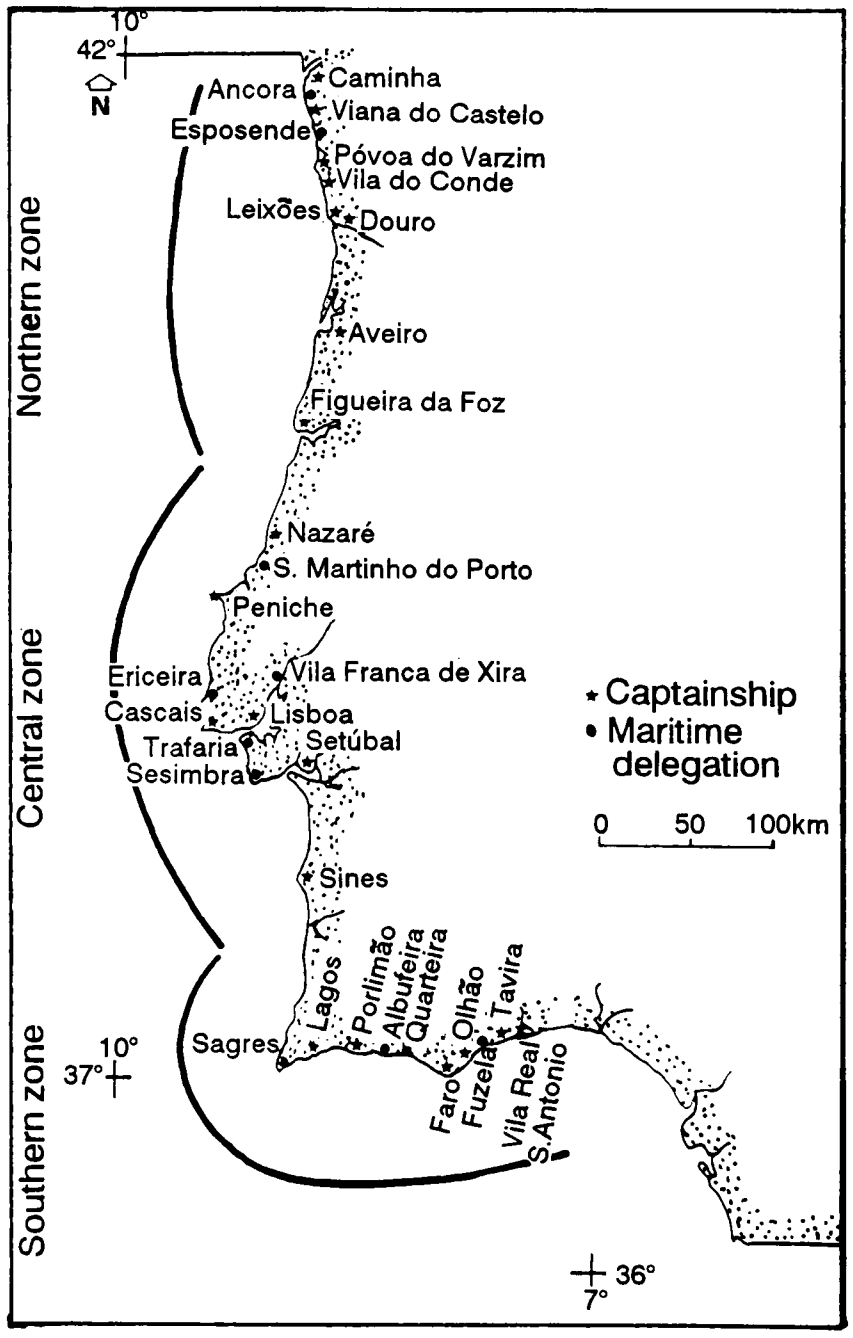

Fig. 1. Fishing areas, harbours and captainships.

Auctions

As many fishermen still do not report their total catches at the official auctions, the official data for the artisanal fisheries may represent a substantial underestimate. In addition, although this is no longer the case, in 1984 up to 50% of the artisanal fishing ports on the Portuguese coast did not have official auctions (Costa and Franca, 1982; 1985; Franca and Costa, 1984; Table 1).

Table 1

Fishing harbours (H) with official auctions (A) in 1984 (in Costa and Franca, 1982, 1985; Franca and Costa, 1984).

Zone	H	A	Zone	H	A	Zone	H	A
Northern	34	17	Central	34	17	Southern	36	18

Fleet

Depending on the fishing areas being exploited, the boats registered on the Portuguese coast are grouped into several categories (Table 2), based on overall length (m), gross registered tonnage (GRT), engine power (Kw) and length of fishing trip (days) as defined by national legislation.

Boats may obtain licenses to use up to a maximum of five of the different types of fishing gear allowed in Portuguese waters.

Local fishing boats with weather decks can operate up to six n.miles from the coast within the captain's jurisdiction area from the port of registration; awning deck boats are allowed to operate up to 30 miles from the coast and in areas of adjacent captainships (Duarte, 1990).

The areas allowed for the coastal fishing boats are established according to the registration port and type of fishery. Whenever technical and security requirements are fulfilled these boats can operate within EEC fishing areas. The Portuguese coastal fishing fleet includes boats using almost all types of gear, but the average size of the vessels decreases towards the South (Duarte, 1990).

As would be expected distant water vessels have comparatively higher GRT and longer trips; although they may operate in any fishing area, they are not allowed to fish within 12 n.miles of the coast (Duarte, 1990).

The geographical distribution of the fleet by number of boats, GRT, engine power and age is given in Appendix Table 1.

Table 2

Classification of the Portuguese fishing fleet.

	Local fisheries	Coastal fisheries	Distant-water fisheries
Length(m)	up to 9m	>9m	-
GRT	-	up to 100	>100
Engine power	up to 75Kw (awning deck) up to 45Kw (weather deck)	25Kw (minimum)	-
Length of trip	-	established according to the fishing area	15 days minimum

Fishermen

Data available for 1982–88 indicate that the number of fishermen registered has not changed substantially, with most of them operating in the coastal fleet (Appendix Table 2).

Only the most important coastal fisheries, that potentially may have incidental catches of marine mammals, are reviewed in this report. Technical data and information on by-catches associated with the activities of the Portuguese distant-water fisheries proved very difficult to obtain.

There are no accurate estimates of the number of cetaceans killed by any of these fisheries, nor any information on the impact of these mortalities upon the different populations. However, the information obtained so far suggests that trawling operations account for a considerable part of the overall cetacean mortality in active gear occurring in Portuguese waters.

Legislation

In 1981, national legislation was passed that protected all marine mammals in Portuguese continental waters. This made the killing of all cetaceans technically illegal and many fishermen no longer report their incidental by-catches as they are afraid of the legal consequences.

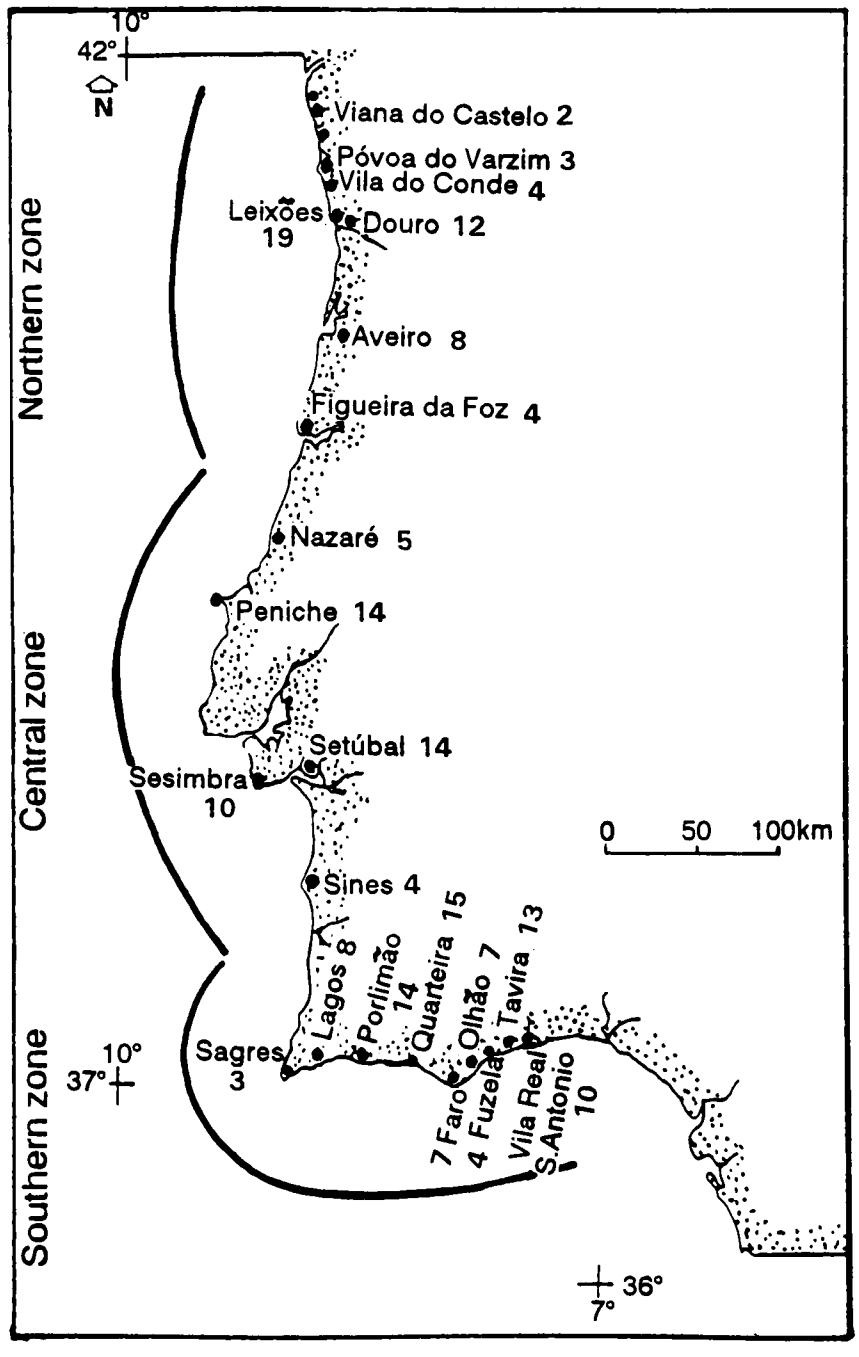

Fig. 2. Numbers of licenses issued in 1991 for purse seining fishing.

FISHING METHODS

Purse seine nets

Location of ports

Although this activity is scattered all along the coast, there are seven primary ports: Leixões, Portimão, Peniche, Setúbal, Quarteira, Douro and Tavira (Fig. 2).

Target species

The main target species are pelagic fishes such as the sardine (*Sardina pilchardus*), mackerel (*Scomber scombrus*), Spanish mackerel (*Scomber japonicus*), horse mackerel (*Trachurus trachurus*), blue whiting (*Micromesistius poutassou*), snipe fish (*Macrorhamphosus* spp.) and anchovy (*Engraulis encrasicholus*) (Costa and Franca, 1982; Pestana, 1989). Purse seines are also used in Azorean and Madeiran waters to catch small pelagic fish that are used as live bait for thunnids.

Area of operation

Purse seines are used in the coastal waters on the Portuguese continental shelf.

Vessels and crew

Wooden boats are used which are not able to keep fish on board for long periods of time. They therefore operate close to harbour and return immediately after fishing.

Purse seine nets may be operated by two main types of boat depending on their GRT and engine power: the larger and more powerful *traineiras* that operate seine nets all year round; and the *cercadoras* which may also use other types of fishing gear besides seine nets. The characteristics of the vessels operating in 1987 are given in Table 3.

Table 3

Characteristics of the purse seiners in mainland Portugal: age, GRT and engine power, as registered in 1987 (GEPP, 1987).

Age	GRT	Engine power
Max. 53.0yrs	Max. 42.2	Max. 189.87Kw
Min. 2.0yrs	Min. 1.4	Min. 7.44Kw
Mean 16.0yrs	Mean 18.3	Mean 83.61Kw

According to the Fisheries Planning Division national baseline (GEPP, unpubl.), there were 179 boats licensed to use seine nets from mainland Portugal in 1991. In addition, an undetermined number of boats operate small seine nets illegally along the Portuguese coast.

Crews comprise entirely Portuguese fishermen and their number is often higher than strictly necessary, with an adverse effect on economic profitability.

Gear

Seine nets capture shoaling fish by surrounding them laterally and ventrally, thereby preventing their escape by swimming under the net into deeper water. With only a few exceptions, these are surface nets equipped with buoys on the floatline. The minimum legal mesh size for seine nets is set at 18mm, with net length and height dimensions established according to the GRT of the boat as shown in Table 4. However, many boats still use illegal nets which are longer than allowed.

Table 4

Maximum length (L) and depth (D) of seine nets related to GRT of the fishing boats using them.

GRT	L	D	GRT	L	D	GRT	L	D
<20	300	60	20-49	700	120	≥50	800	150

Operations

The shoals are located visually or with the help of sounding lines and fishing is usually carried out at night with lights. The method used by most purse seiners has changed rapidly in recent years from most fishing ports (with the exception of Peniche and some areas in the Northern zone); the practice of fishing continuously in areas close to the shoreline, where the net reaches the bottom when closing is now widespread. Purse seiners often use buoys with several types of light sources scattered all over the fishing area to aid fishing (Costa and Franca, 1982; 1985; Franca and Costa, 1984). This often results in high mortalities of immature forms of demersal species, which has a deleterious effect on the main stocks.

Economics and history

Data relating to the economic aspects of the purse seine fishery in Table 5 refer to prices obtained at fish markets and include both fresh and frozen fish sales.

Landings

Data available on seine net landings at individual harbours suggests marked differences between the catch levels for the three zones (Table 6).

Effort

In 1991, the 179 licensed boats (Appendix Table 3), each operated only one net. The fishing effort for the purse seiners (CPUE) is expressed as tonnes per boat and the data for 1980–1988 (Pestana, 1989) are summarised in Table 7.

Table 5

Official auction sales (thousands of escudos) for the purse seine fishery (INE, 1988, 1989).

	1987				1988			
Area	Marine fish	Crustaceans	Molluscs	Other	Marine fish	Crustaceans	Molluscs	Other
Northern zone	1,948,858	4	935	21	2,096,556	37	2,964	16
Central zone	2,388,474	18	9,482	88	3,015,974	6	9,929	126
Southern zone	1,174,627	8	19,929	84	1,652,819	69	33,186	17
Total	5,511,959	30	30,346	193	6,765,366	112	46,079	159

Table 6

Seine net landings (tonnes) in mainland Portugal, 1987 and 1988 (INE, 1988, 1989).

Area	1987			1988		
	Fish	Molluscs	Other	Fish	Molluscs	Other
Northern zone	45,986	3	-	52,173	9	-
Central zone	38,741	23	4	38,321	19	2
Southern zone	21,849	41	2	24,218	61	-
Total	106,576	67	6	114,712	89	2

Table 7

Number of boats and CPUE for the purse seine fishery (Pestana, 1989).

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988
No. boats	211	193	184	196	192	192	198	208	208*
CPUE	427	557	521	399	441	582	496	411	450*

* Preliminary data only.

Interactions with cetaceans

There are no official records of cetacean mortality in seine nets on the Portuguese coast. However, as in other oceanic areas, it is likely that some marine mammals are caught by the purse seine fleet.

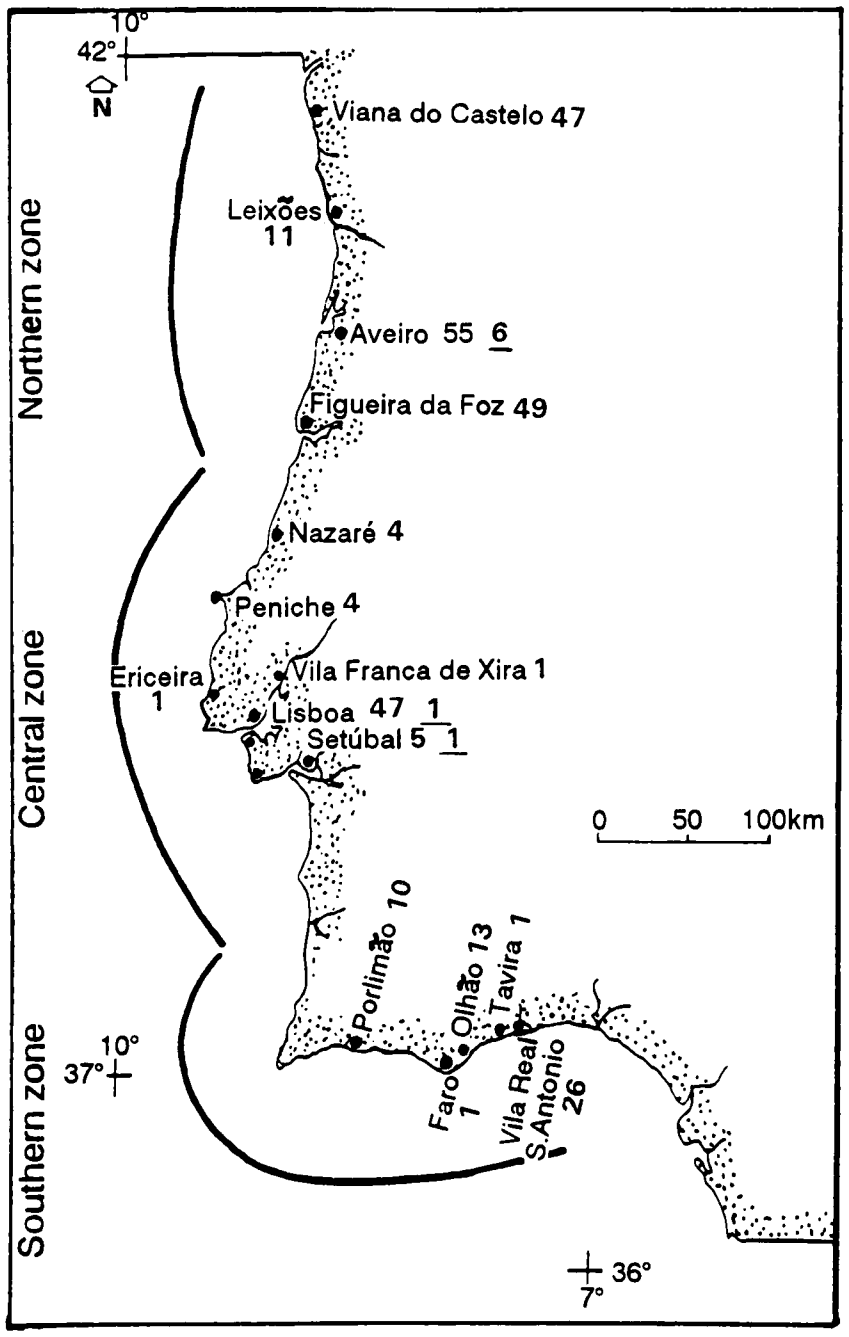

Fig. 3. Trawl licenses in 1991 (bottom and pelagic).

Trawls

Location of ports

The most important ports are Figueira da Foz, Aveiro, Viana do Castelo and Lisboa (Fig. 3).

Target species

The Portuguese trawl fishery is directed mainly to bottom-living or demersal species and catches include the horse mackerel, blue whiting, mackerel, Spanish mackerel, hake (*Merluccius merluccius*), megrim (*Lepidorhombus bosci* and *L. whiffiagonis*), monkfish (*Lophius piscatorius* and *L. budegassa*), cephalopods (octopus and squids) and the Norway lobster (*Nephrops norvegicus*).

Area of operation

Although national legislation prevents trawlers operating within 6 n.miles of the coast, trawlers occasionally fish illegally within that distance.

The areas in which boats are allowed to trawl are related to their individual GRT. Boats under 120GRT are allowed to operate within 12 n.miles of the shore, whereas those above 180GRT are only allowed to operate more than 18 n.miles offshore.

Vessels and crew

According to information provided by the General Directorate of Fisheries (Direcção-Geral das Pescas, 1986), the trawling fleet had almost 120 active trawlers in 1985, with 80 catching fish and 40 taking crustaceans. All of them used bottom trawls. The vessels were between 18–35m, 50–250GRT, with engine power ranging between 294–1,103Kw.

However, some of the trawlers fishing for crustaceans were smaller, with almost 29% of the boats aged 20 years and over and only 24% of them under 10 years old. A summary of information for the registered trawling fleet in 1990 is given in Table 8. More than half the vessels are now made of steel and almost 80% are stern trawlers. The crew is usually larger than necessary.

Gear

The bottom trawl is the most widespread type used on the Portuguese coast. Codend mesh size varies according to the target species. For each mesh size there is a minimum percentage of target species fixed by legislation and a maximum percentage of protected species that may be caught (Appendix Table 4).

Operations

Since the fishing areas are comparatively close to the shore, trips are typically one day long, although some boats may be capable of remaining at sea for up to three weeks. The catch may be landed at another port, for economic reasons.

Table 8

Age, GRT and engine power of trawlers (Cardador, *pers.comm.*).

Age	GRT	Engine power
Max. 64.0yrs	Max. 259.3	Max.1083.3Kw
Min. 1.0yrs	Min. 18.0	Min. 178.4Kw
Mean 20.0yrs	Mean142.7	Mean 481.16Kw

Trawlers operating along the Portuguese coast use only one net, although the Portuguese fleet operating in West Africa regularly uses outriggers. All vessels have radar, sounders and other navigation equipment, but many fishermen still ignore the echo-sounders when locating the shoals. The skippers go directly towards the traditional fishing grounds, where they throw the nets and tow for between 2 and 4 hours, depending on the target species. Fishing depth varies with local topography and target species, up to a maximum of 700m.

Economics and history

Total earnings from trawling operations in 1987 and 1988 are given in Table 9.

Landings

As in the purse seine fishery, the total landings from trawlers (Table 10) differ by zones.

Effort

The potential of the Portuguese trawling fleet is not fully realised, mainly because ships capable of trips of up to three weeks operate regularly for under 200 days per year, with individual trips averaging under two days. In addition, these ships do not fully utilise their bilge capacity and waste up to 30% of their gross income in fuel consumption (Direcção-Geral das Pescas, 1986).

In 1991, there were 283 boats licensed to use trawls, some of them operating in CECAF, NAFO and ICSEAF areas. Only eight boats were licensed to use pelagic trawls (at Aveiro, Lisboa and Setúbal).

Interactions with cetaceans

The official numbers of cetaceans reported caught during trawling operations are certainly underestimates, mainly because there are no observers on board to monitor the by-catches.

Official reports refer to only 18 dolphins found dead in trawl nets (17 common dolphins, *Delphinus delphis*, and 1 harbour porpoise, *Phocoena phocoena*). Twelve were recorded in 1980, when the killing of cetaceans along the Portuguese coast was still allowed and marine mammals could be sold at local fish markets. When these captures became illegal in 1981, the fishermen ceased reporting by-catches and the official records obtained since refer only to six common dolphins drowned in nets. Five of these were accidentally caught by the pelagic trawl of the Portuguese Fisheries Institute's own research vessel, in 1985 and 1987, suggesting that many more cetaceans may be caught every year by the whole trawling fleet. This mortality possibly involves a few tens of cetaceans killed every year.

Discussion

Trawling operations certainly contribute to the overall mortality of cetaceans recorded on the Portuguese coast. The mortality rates for the different species and the associated impacts on the cetacean populations need to be assessed as a matter of urgency. Furthermore, the fishing areas regularly exploited by trawlers should be carefully monitored. This might be accomplished by placing biologists on board selected trawlers.

Fishing traps

Location of ports

Of the two major types of fishing traps widely used on the Portuguese coast, basket traps and pots, the former predominate in the northern and central zones while the latter are particularly important in the southern zone (Fig. 4).

Target species

This fishery is especially aimed at octopus and crustaceans.

Table 9

Total earnings (thousands of escudos) from trawlers (Table 10) show differences for the three zones in Fig. 1.

	1987				1988			
Area	Marine fish	Crustaceans	Molluscs	Other	Marine fish	Crustaceans	Molluscs	Other
Northern zone	2,134,836	17,105	566,064	102	2,307,220	19,011	387,045	113
Central zone	1,685,551	35,596	128,084	161	1,759,546	19,253	85,959	665
Southern zone	948,268	1,946,905	144,941	32	1,194,714	2,835,319	195,895	64
Total	5,511,959	1,999,606	839,089	295	5,261,480	2,873,583	668,899	842

Table 10

Landings of the trawl fleet (tonnes) by zone and group of species in mainland Portugal, 1987 and 1988 (INE, 1988, 1989).

	1987				1988			
Area	Fish	Crustaceans	Molluscs	Other*	Fish	Crustaceans	Molluscs	Other*
Northern zone	21,217	19	2,074	2	18,899	20	1,291	2
Central zone	10,836	37	428	1	8,480	9	242	3
Southern zone	4,644	1,643	491	-	4,389	2,348	533	-
Total	36,697	1,699	2,993	3	31,768	2,377	2,066	5

* Diadromous fishes and lamprey.

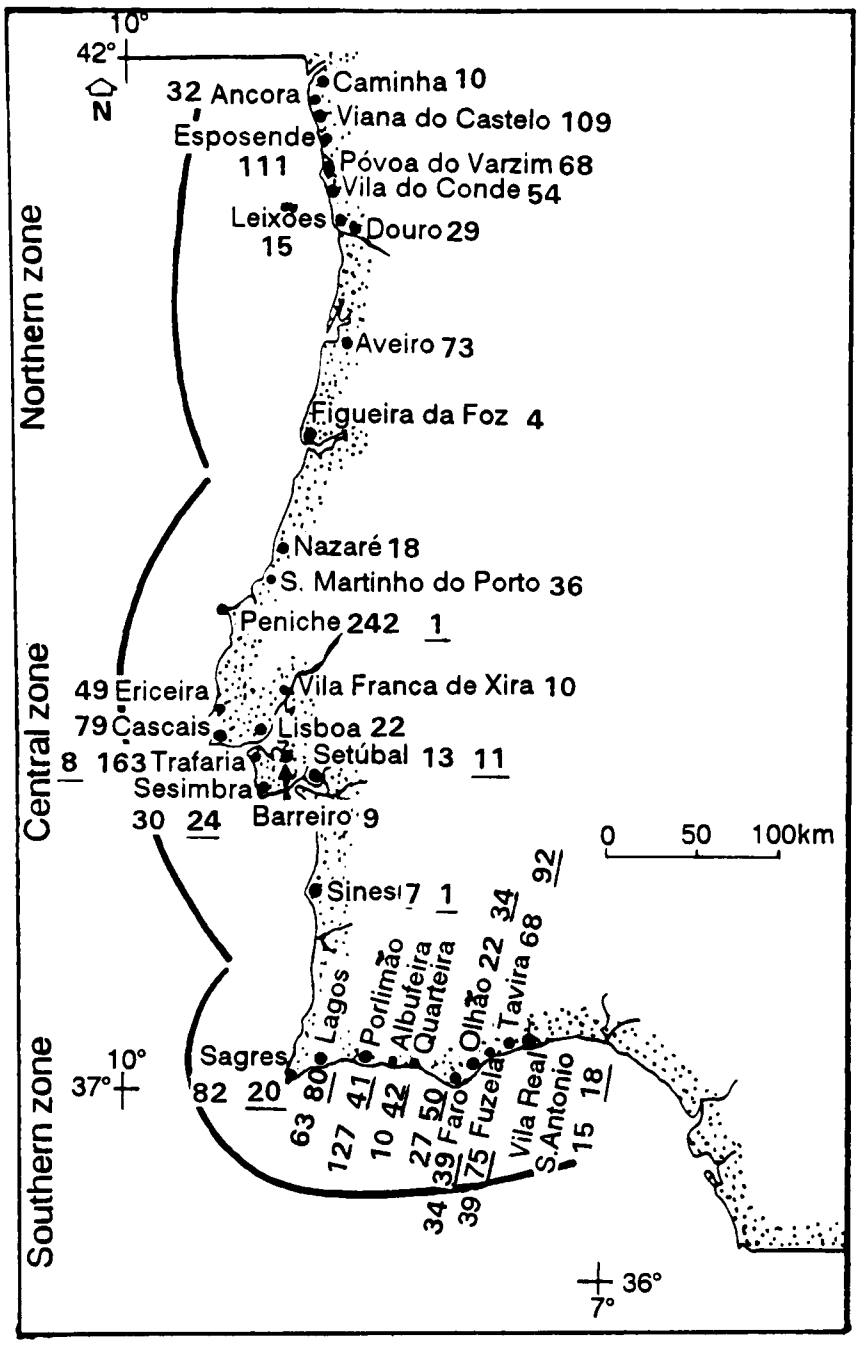

Fig. 4. Licenses for traps and pots in 1991.

Area of operation
Current legislation prohibits the use of traps within 0.5 n.miles of the coastline. For boats >5GRT this distance is increased to one mile.

Vessels and crew
These boats are typically built of wood and 6–20m long, with no refrigeration, and therefore unable to keep their catch on board for long periods. The crew consists of 2–8 Portuguese fishermen and in most cases is larger than strictly necessary.

Gear
Current legislation does not allow the use of traps made entirely of synthetic materials. The minimum mesh size allowed is 30mm and all parts in the trap must be sewn to each other and to the supporting structure by natural yarn without any anti-decay treatments. The traps are set out singly or in groups along a main line, according to specific legislation. Wire baskets are set out in groups of 13 to 100 units, with an average number of 30 to 40 traps per group (Costa and Franca, 1985). The traps are usually baited with sardines, although other species such as the common mackerel and horse mackerel may be used (Franca and Costa, 1984).

Pots are sheltered circular clay traps, widely used to catch octopus. These traps are always set in groups along a line anchored to the bottom. Pots used in shallow waters are typically 21cm high with openings 10cm wide, while pots used in deep waters are 32cm high with openings 13cm wide (Costa and Franca, 1982).

Operations
No boat is allowed to use more than 1,000 pots.

Economics and history
Reliable information on landing prices and earnings by the fishermen are difficult to obtain and are not readily available from the official fisheries statistics.

Total landings
There is no detailed information available on catches with fishing traps since these are included together with other gear in the official statistics for artisanal fisheries.

Effort
There were 1,670 boats licensed to use either basket traps or wire baskets in August 1991, and 546 boats had licenses to fish with pots (Appendix Table 3).

Interactions with cetaceans
The minke whale (*Balaenoptera acutorostrata*) is the only species known to become occasionally entangled in Portuguese fishing traps. In the three cases reported, the whales were caught in the wire leaders of the basket traps. All were dead when found by the fishermen.

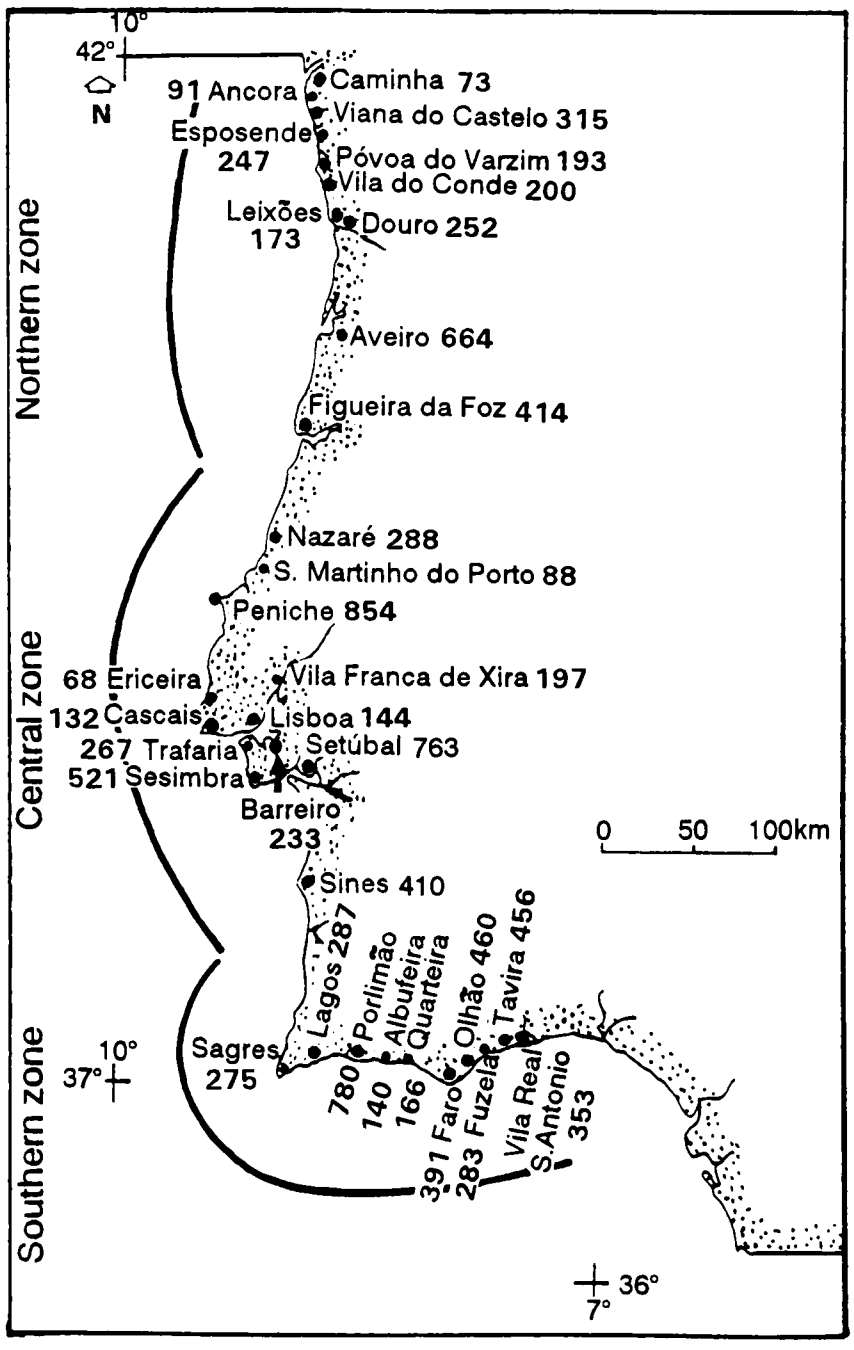

Fig. 5. Fishing licenses for longlines in 1991.

Discussion
Due to their intrinsic characteristics (bottom set fishing gear) most types of fishing traps currently used on the Portuguese coast are unlikely to cause high mortality of cetaceans. Nevertheless, special attention should be paid to the areas with higher rates of primary productivity and richer marine faunas. These include the oceanic areas adjacent to the Tejo and Sado estuaries and close to the Nazaré deep canyon in the central zone, where cetacean strandings and sightings have been frequently reported (Sequeira, 1988; Sequeira and Teixeira, 1990 and Sequeira *et al.*, 1992).

Longlines

Location of ports
This fishery operates all along the Portuguese coast but is concentrated especially in the northern and central zones (Fig. 5).

Target species
Longlines are regularly used to capture seabass (*Dicentrarchus labrax*), Atlantic pomfret (*Brama brama*), European conger (*Conger conger*), pout whiting (*Trisopterus luscus*), sargos and bream (*Diplodus* spp.), gilthead seabream (*Sparus aurata*), black seabream (*Spondyliosoma cantharus*), pandoras (*Pagellus* spp.), soles (*Solea* spp.), black scabbardfish (*Aphanopus carbo*), sharks and thunnid species.

Area of operation
The use of longlines is comparatively widespread within the Portuguese exclusive economic zone (EEZ), although target species may differ markedly between the areas fished.

Vessels and crew
Boats used for longlining are usually built of wood and most lack adequate means of maintaining the fish on board for extended periods. Trips are typically one day long and may end in a different port. Only a small minority of these boats fish exclusively with longlines.

There is a special longliner fleet for the black scabbardfish (*Aphanopus carbo*) at Sesimbra; its main characteristics in 1984–88 are shown in Table 11.

Gear
Longlines consist of groups of interconnected lines either set at the bottom or drifting, each line bearing a large number of baited hooks. For the capture of pelagic species such as tuna and swordfish, drifting longlines are used. In recent years, bottom longlines for black scabbardfish were developed at Sesimbra in the central zone. In this type of fishery the main line may have 3,600 to 4,000 hooks and the gear may spread for 6 to 8km (Martins *et al.*, 1989).

Operations
Longlines are usually set at dawn and stay in the water for periods ranging from a few hours up to a few days (Leite, 1990). However, longlines set to capture the black scabbardfish are set and hauled at dawn. The duration of individual hauls is usually between 40 and 65 hours (Martins *et al.*, 1989).

Economics and history
Among the Portuguese artisanal fisheries, longlines were of only limited importance in the northern zone in 1983–84, behind gillnets, purse seines and trawls. The types used in this area are either bottom set longlines or drifting bottom longlines. According to Franca and Costa (1984) longlines came in third place in the central zone, far behind gillnets and fishing traps. Longlines are most popular in the small harbours to the south of Sines and are used by almost all the artisanal fishing fleet operating there permanently. Two different types of lines are used, depending on the target species.

The longline fishery was of some economic importance in 1982 in the areas around Portimão in the southern zone. At nearby Quarteira, Ferragudo and Luz, longlines were used only when catches obtained with other gear went very low (Costa and Franca, 1982). Again, two types of lines are used in the southern zone, depending on the target species.

There are no readily available economic data for the longline fishery since it is included with other artisanal gear in the official statistics. Nevertheless, the high selectivity of this gear and the quality of the fish captured make it of some economic importance.

Total landings
There are no detailed statistics for longline fisheries since they are included with other gear in the artisanal fisheries statistics. Nevertheless, black scabbardfish landings at Sesimbra can be obtained for 1984–88 and are shown in Table 12.

Table 12

Black scabbardfish landings at Sesimbra (tonnes) in 1984-88 (Martins *et al.*, 1989).

Year	1984	1985	1986	1987	1988
Landings(t)	613	947	2,241	2,593	2,602

Table 11

Characteristics of the longliner fleet for black scabbardfish in 1984-88 (Martins *et al.*, 1989).

		Mean values		
Year	No. of boats	GRT	Engine power (Kw)	Length overall (m)
1984	15	16.6	95.53	11.2
1985	23	16.1	84.43	11.2
1986	28	16.1	87.04	11.3
1987	23	18.0	99.32	11.8
1988	27	20.1	107.89	12.4

Table 13

Total landings, fishing effort and CPUE for the black scabbardfish longline fleet at Sesimbra (Martins *et al.*, 1989).

	Fishing effort			CPUE	
Year	Landings(Kg)	Boats	Fishing days	Kg/boat	Kg/day
1984	403,986	15	2,170	26,932.4	186.2
1985	795,676	23	3,092	34,594.6	257.3
1986	1,722,736	28	5,662	61,526.3	304.3
1987	2,419,496	23	5,082	105,195.5	476.1
1988	2,594,716 *	27	4,691	96,108.6	553.1 *

* Estimated data only.

Effort
Fishing effort for the black scabbardfish at Sesimbra in 1984–88 was estimated in terms of number of boats and fishing day units (Table 13). There were 10,056 boats licensed to use longlines in 1991 (Appendix Table 3). According to Martins *et al.* (1989) individual trips average two days fishing.

Interactions with cetaceans
Although there are no published records of cetacean entanglement in longlines in Portugal, this does not necessarily mean that entanglement does not occur.

Discussion
The impact of longline fisheries on cetacean populations needs to be determined, especially in the areas most heavily fished.

Gillnets

Location of ports
Gillnets are widely used all along the Portuguese coast from Caminha to Vila Real de Santo António. The number of boats licensed to use this type of gear is higher in the northern and central zones (Fig. 6).

Target species
The main target species of the gillnet fishery are allis shad (*Alosa alosa*), flatfishes (Pleuronectidae), hake (*Merluccius merluccius*), pouting (*Trisopterus luscus*), monkfish (*Lophius* spp.), seabass (*Dicentrarchus labrax*), seabreams (Sparidae) and cuttlefish (*Sepia officinalis*).

Area of operation
Anchored gillnets can only be set out if at least 0.25 n.miles from the coast. Between 0.25 and 1.0 n.miles, only boats >5GRT or <10m may fish with anchored gillnets. Within 1–2 n.miles from the coast any boat may operate provided they use their nets in waters at least 20m deep.

Vessels and crew
Boats operating with gillnets are built mostly of wood and are unable to keep the catch for long periods on board. The composition of the Portuguese gillnet fleet in 1989 is shown in Table 14.

Table 14

The Portuguese gillnet fleet in 1989 (Cardador, pers. comm.)

Area	Boats	Power (Kw)	Length (m)	GRT
Northern zone	913	75.64	10.32	15.25
Central zone	1,422	63.89	9.17	14.26
Southern zone	994	44.75	8.97	10.55

Gear
Gillnets are among the most important fishing gear currently being used on the Portuguese coast and include both gillnets (*sensu strictu*) and trammel nets. Although gillnets maybe anchored or drifting, the use of drifting trammel nets is forbidden. Anchored gillnets are the most common at many fishing settlements in Portugal. Usually they are set out in fleets[1], while drifting gillnets are set out individually (Costa and Franca, 1985). The characteristics of gillnets vary with the harbours but they are generally made of synthetic monofilament, while trammel nets are made from synthetic multifilament. The minimum mesh sizes allowed for gillnets are shown in Table 15.

Table 15

Minimum gillnet mesh sizes allowed.

Type of net	Minimum mesh size (mm)
Gillnet bottom set	80
Trammel net bottom set	100 (at lint)
Drifting gillnet for small pelagic fish	36
Drifting gillnet for large pelagic fish	100

The use of bottom set gillnets with mesh sizes of 60–80mm is also allowed, but only in certain areas and periods. This applies also to trammel nets with lint mesh sizes of 80–100mm. Individual boats are not allowed to exceed a maximum length of gillnets depending on their GRT (Table 16). All nets or groups of nets must be set at least 0.25 n.miles apart and cannot exceed 4km, up to the maximum length allowed (Table 16). The maximum depth allowed is 10m for anchored and drifting gillnets and 2m for trammel nets.

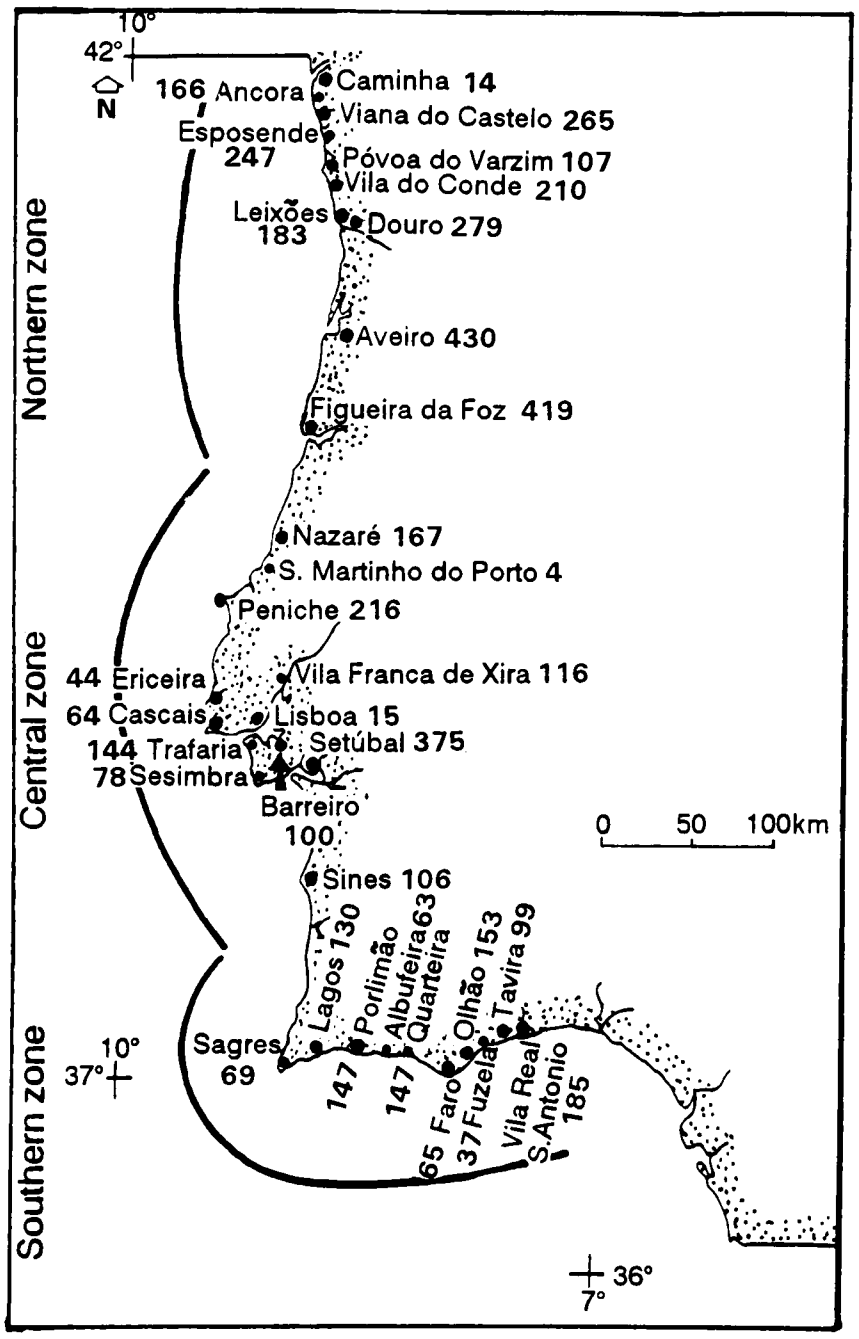

Fig. 6. Number of gillnet licenses in 1991.

[1] **Fleet** means any number of nets joined end to end and operated as a complete outfit.

Table 16

Maximum lengths of gillnets allowed per boat.

Type of net	GRT of vessel	Maximum length of net (m)
Gillnet bottom set	≤5: weather deck	1,500
	≤5: Awning deck	3,000
	5-9	4,000
	10-19	7,000
	20-39	10,000
	≥40	13,000
Trammel net bottom set	≤10GRT	1,500
	≥10GRT	3,000
Drifting gillnet for small pelagic fishes		300

Operations

Drifting gillnets are used by a comparatively large number of small fishing boats and are set seasonally, while anchored gillnets are mainly operated from larger ships and are set all year round. Nets are usually set for 6–24 hours. According to current legislation anchored gillnets may not be set for longer than 24 hours in consecutive 36 hour periods, except that (1) in the southern zone they may not be used for more than 12 hours in consecutive 24 hour periods and (2) if the mesh size is <100mm they may be set up to a maximum of 72 hours in consecutive 96 hour periods, provided they are in areas deeper than 300m (this latter provision also applies to trammel nets with lint mesh sizes >110mm).

Economics and history

There are no details readily available at this stage.

Total landings

There are no reliable data for gillnets since they are included with other artisanal gear in the official statistics. Nevertheless, data provided by Cardador (pers. comm.) indicate that total landings in 1989 were: northern zone – 15,714 tonnes; central zone – 12,915 tonnes; and southern zone – 5,776 tonnes. These figures may be overestimates, as many boats have licenses to operate more than one type of gear simultaneously.

Effort

In 1991, there were 4,844 boats licensed to use gillnets (Appendix Table 3).

Interactions with cetaceans

There are no accurate estimates of the total number of cetaceans killed in gillnets set along the Portuguese coast, mainly because fishermen do not report them as they fear legal sanctions from the authorities. Therefore, most marine mammals caught are simply thrown back into the sea. Trying to obtain detailed information on by-catches directly from the fishermen has proved to be difficult. Regular recording of cetacean by-catches has been attempted since 1977 and 132 cases of entanglement have been reported with 59 specimens killed in gillnets. The existing data indicate that incidental takes of common dolphins are substantial, particularly in the central zone. Other cetaceans regularly caught in these nets include the striped dolphin *S. coeruleoalba*, the harbour porpoise and the bottlenose dolphin *T. truncatus*.

The harbour porpoise is particularly vulnerable in the coastal areas around Aveiro where the continental shelf is wider, thus allowing a large number of gillnets to be set close to the shore. Data from early naturalists refer to the harbour porpoise as a very common species on the Portuguese coast (du Bocage, 1863; Nobre, 1895; Nobre, 1935), a situation that has changed drastically since then following a pattern similar to that of other Western European countries (Lindstedt and Lindstedt, 1989; IWC, 1991a; b). According to Teixeira (pers. comm.) most harbour porpoise sightings in recent years are of single animals or small groups. Furthermore, the stranding surveys initiated in 1977 suggest a substantial decrease in the abundance of *P. phocoena* relative to other species (Sequeira and Teixeira, 1988; 1990), and many of the stranded animals had net marks around the head and flippers.

Discussion

It seems possible that large numbers of cetaceans, particularly common dolphins and harbour porpoises, are dying in gillnets but lack of information does not allow an adequate assessment of the true mortality rates. As this mortality may be threatening some populations, both mortality and population size must be monitored as a matter of urgency.

In order to obtain accurate information on the numbers of cetaceans killed in gillnets, it may not be practical to use on-board observers, as the number of boats using gillnets is extremely high and gillnets may be often used to complement the main gear. Some useful information on by-catches may be obtained from questionnaire schemes run simultaneously with environmental awareness campaigns amongst fishermen. Such a campaign should lead to increased cooperation from fishermen and to all cetaceans being found dead in gillnets being reported to the scientific authorities.

In addition to assessing the impacts of gillnets, staff from the Fisheries and Environmental Departments must cooperate with fishermen to find out ways of reducing incidental captures. For example, the license assignment scheme could be used to control the number of boats allowed for each zone, especially in heavily fished areas where the impact of gillnets on cetaceans is most important. Further studies of gear technology and action on the modification and replacement of gillnets by other types of fishing gear should be developed, bearing in mind that longlines and traps may have comparatively low impacts on cetaceans and other marine fauna.

Gillnetting is currently one of the most important fishing activities on the Portuguese coast, and makes an important contribution to income. It is thus extremely important that fishermen are involved and consulted at all stages about any proposed modifications to reduce the negative impact of their activities on cetaceans. This should be seen as the best way to ensure better law enforcement and the avoidance of unnecessary social clashes.

CONCLUSIONS AND RECOMMENDATIONS

Although it is known that some cetaceans are caught during fishing operations, detailed information on the incidental mortality of marine mammals in Portuguese

waters is still lacking. More than half of these deaths are probably caused through entanglement in gillnets, with trawl incidents accounting for only a few tens of specimens killed per year. The impact of incidental mortalites upon the relevant cetacean populations is unknown. Urgent assessments are needed, including detailed studies on gear technology and estimates of abundance and population trends for all the species on the Portuguese coast.

In order to assess these mortalities and to reduce their impact on the population of cetaceans, it is recommended that:

(1) accurate information on current takes of cetaceans must be collected for all the fisheries operating in the Portuguese EEZ – fisheries causing high levels of mortality should be monitored continuously, through on-board observer programmes;
(2) the numbers and distribution of gillnets currently used on the Portuguese coast must be monitored and scientific staff from the Fisheries and Environmental Departments must cooperate with the fishermen involved to develop programmes of gear modification and the replacement of gillnets by other types of fishing gear in the most critical areas;
(3) studies must be developed for those species most affected by gillnets (including the harbour porpoise and the common dolphin) that include identification of stocks, assessment of abundance, seasonal distribution, population size and current trends.

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APPENDIX 1

Appendix Table 1(a)

Number of boats in the Portuguese fishing fleet by GRT classes (Duarte, 1990).

GRT	Local	Coastal	Distant water	GRT	Local	Coastal	Distant water
	No. GRT (sum) Kw (sum)	No. GRT (sum) Kw (sum)	No. GRT (sum) Kw (sum)		No. GRT (sum) Kw (sum)	No. GRT (sum) Kw (sum)	No. GRT (sum) Kw (sum)
0-1.9	5,051 3,492 8,996			50-99.9		189 12,644 50,911	
1-1.9	4,899 6,690 19,986	11 20 166		100-249.9		174 26,877 93,835	7 1,345 3,529
2-4.9	1,611 4,784 21,002	16 54 351		250-499.9		2 513 1,914	38 14,612 28,056
5-9.9	367 2,364 11,252	225 1,784 9,675		500-999.9		2 1,359 1,191	14 10,699 13,317
10-24.9	6 66 217	573 9,179 45,705		> 1000			44 63,889 74,703
25-49.9		386 13,105 63,409		TOTAL	11,934 17,396 59,156	1,578 66,535 217,158	103 90,515 119,60

Appendix Table 1(b)

Number of boats in the Portuguese fishing fleet by age classes (Duarte, 1990).

	Local	Coastal	Distant water		Local	Coastal	Distant water
0-5 years				**16-20 years**			
No.	297	104	10	No.	792	126	9
GRT	521	6,708	5,001	GRT	996	8,032	15,980
Kw	2,694	24,040	12,457	Kw	35,89	29,692	20,253
6-10 years				**>20 years**			
No.	1,242	194	14	No.	7,686	949	73
GRT	1,997	10,240	21	GRT	11,196	32,795	61,811
Kw	9,051	45,017	100	Kw	33,580	130,357	72,287
11-15 years							
No.	1,917	205	7	Total	11,934	1,578	103
GRT	2,686	8,760	6,023		17,396	66,535	90,515
Kw	10,243	38,072	9,851		59,156	267,157	119,606

Appendix Table 2

Number of fishermen registered in 1982-88 (GEPP, 1990).

	1982		1983		1984		1985		1986		1987		1988	
Fleet	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Local fisheries	11,664	37.04	12,349	37.03	12,352	36.36	11,961	36.36	12,761	36.72	11,777	33.06	13,526	36.84
Northern zone	5,448	46.71	6,231	50.46	6,058	49.04	5,884	49.19	5,996	46.99	3,712	31.52	5,985	44.25
Central zone	4,343	37.23	3,878	31.40	3,882	31.43	3,520	29.43	3,893	30.51	4,785	40.63	3,914	28.94
Southern zone	1,873	16.06	2,240	18.14	2,412	19.53	2,557	21.38	2,872	22.51	3,280	27.85	3,627	26.82
Coastal fisheries	17,044	53.13	18,047	54.11	19,021	56.00	18,432	56.02	19,736	56.80	21,244	59.63	20,631	56.20
Northern zone	6,002	35.21	8,818	48.86	6,834	35.93	6,638	36.01	7,003	35.64	6,353	29.90	7,246	35.12
Central zone	6,152	36.09	6,046	33.50	7,340	38.59	6,656	36.11	7,154	36.25	7,918	37.27	7,102	34.42
Southern zone	4,890	28.69	3,183	17.64	4,847	25.48	5,138	27.88	5,549	28.12	6,973	32.82	6,283	30.45
Distant water fisheries	2,781	8.83	2,957	8.87	2,596	7.64	2,507	7.62	2,251	6.48	2,605	7.31	2,555	6.96
Northern zone	2,016	72.49	2,566	86.78	2,345	90.33	2,278	90.87	1,968	87.43	279	10.71	2,288	42.27
Central zone	714	25.67	354	11.97	242	9.32	219	8.74	269	11.95	2,326	89.29	267	30.73
Southern zone	51	1.83	37	1.25	9	0.35	10	0.40	14	0.62	0	0.00	0	26.99
TOTAL	31,489		33,353		33,969		32,900		34,748		35,626		36,712	
Northern zone	13,466	42.76	17,615	52.81	15,237	44.86	14,800	44.98	14,997	43.16	10,344	29.03	15,519	42.27
Central zone	11,209	35.60	10,278	30.82	11,464	33.75	10,395	31.60	11,316	32.57	15,029	42.19	11,283	30.73
Southern zone	6,814	21.64	5,460	16.37	7,268	21.40	7,705	23.42	8,435	24.27	10,253	28.78	9,910	26.99

Appendix Table 3

Number of fishing liecnses for different types of gear in mainland Portugal in 1991.

Harbour	Seine nets	Trawls*		Traps		Longlines	Gillnets
		Bottom	Pelagic	Baskets	Pots		
Northern							
Caminha				10		73	14
Ancora				32		91	166
Viana do Castelo	1	47		109		315	265
Esposende				111		125	247
Póvoa do Varzim	3			68		193	107
Vila do Conde	4			54		200	210
Leixões	19	11		15		173	183
Douro	12			29		252	279
Aveiro	8	55	6	73		664	430
Central							
Figueira da Foz	4	49		4		414	419
Nazaré	5	4		18		288	167
São Martinho				36		88	4
Peniche	14	4		242	1	854	216
Ericeira		1		49		68	44
Cascais				79		132	64
Lisboa		47	1	22		144	15
Vila Franca Xira		1		10		197	116
Barreiro				9		233	100
Trafaria				163	8	267	144
Sesimbra	10			30	24	521	78
Setúbal	14	5	1	13	11	763	375
Sines	4			7	1	410	106
Southern							
Sagres	3			82	20	275	69
Lagos	8			63	80	287	130
Portimão	14	10		127	41	780	147
Albufeira				10	42	140	63
Quarteira	15			27	50	166	147
Faro	7	1		34	39	391	65
Olhão	7	13		22	34	460	153
Fuzeta	4			39	75	283	37
Tavira	13	1		68	92	456	99
V. Real S. António	10	26		15	28	352	185
Total	179	275	8	1,670	546	10,056	4,844
%	1.02	1.56	0.04	9.50	3.11	57.21	27.56

* Includes the fleet operating in CECAF, ICSEAF and NAFO areas.

Appendix Table 4(a)

Cod end minimum mesh size for trawls.

Minimum mesh size (mm)	Target species alllowed	Minimum percentage of target species	Maximum percentage of protected species allowed
65	All	-	100
Adjacent to mainland			
(a) 55	Norway lobster (*Nephrops norvegicus*)	30 (b)	60 (including 30 of hake) (c)
	Deepwater pink shrimp (*Parapenaeus longirostris*) Red shrimp (*Aristeus antennatus*) and Giant red shrimp (*Aristaeomorpha foliacea*)	30	50
40	Blue whiting (*Micromesistius poutassou*) Mackerel (*Scomber scombrus*) Spanish mackerel (*S. japonicus*) Herring (*Clupea harengus*)	50	10
20	Sardine (*Sardina pilchardus*) Eel (*Anguilla anguilla*)	50	10
16	Sprat (*Clupea spratus*) Anchovy (*Engraulis encrasicholus*) Sandeels (Ammodytidae)	50	10
25	Snipe fish (*Macroramphosus* spp.)	85	5
Adjacent mainland east of Cape Sta. Maria			
40	All but the protected species listed in Appendix Table 4(b)	90	10

(a) Norway lobster may be captured with selective trawl nets. This type of gear must have an upper cod end with 65mm and a lower cod end with 55mm minimum mesh sizes, separated by an horizontal panel. Under these circumstances, the maximum percentage of protected species allowed is 100%.
(b) 25% between 1 January and 31 March.
(c) This percentage is estimated only after the third haul of the trawl net.

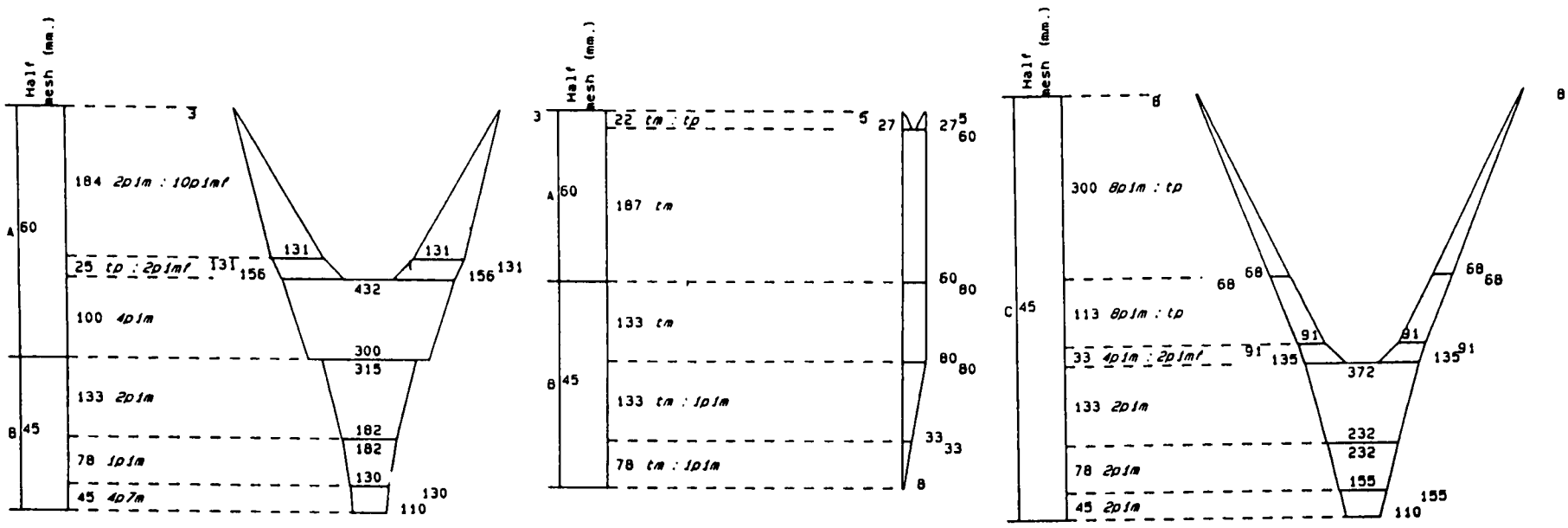
Appendix Table 4(b)

Minimum landing sizes for protected species in Portuguese waters. (a) To be established as defined under EC legislation.

Species	Minimum length (mm)	Species	Minimum length (mm)
Hake (*Merluccius merluccius*)	27	European ling (*Molva molva*)	63
Plaice (*Pleuronectes platessa*)	25	Allis shad and twaite shad (*Alosa* spp.)	30
Witch flounder (*Glyptocephalus cynoglossus*)	28	Mullet (*Mugil* spp.)	20
Lemon sole (*Microstumus kitt*)	25	Sea trout (*Salmo trutta*)	25
Common sole (*Solea vulgaris*)	24	European flounder (*Platichthys flesus*)	25
Turbot (*Psetta maxima*)	30	Anglerfish (*Lophius piscatorius*)	(a)
Brill (*Scophthalmus rhombus*)	30	European anglerfish (*Lophius budegassa*)	(a)
Megrins (*Lepidorhombus* spp.)	20	Cuttlefish (*Sepia* spp.)	(a)
Common dab (*Limanda limanda*)	23	European eel (*Anguilla anguilla*)	(a)
Saithe (*Pollachius virens*)	35	Little sole (*Dicologlossa cunesta*)	15
Spanish bream (*Pegellus bogaraveo*)	25	Blue ling (*Molva dyterygia*)	70
Red mullet (*Mullus surmuletus*)	15	Gilthead seabream (*Sparus aurata*)	19
Bass (*Dicentrarchus labrax*)	36	Black seabream (*Spondyliosoma cantharus*)	23
Conger eel (*Conger conger*)	58		

APPENDIX 2

SOME KINDS OF FISHING GEAR USED OFF MAINLAND PORTUGAL



I.N.I.P.	Ref: FGAV011	TRAWL 61.50m/83.50m	1 Boat
Instituto Nacional de Investigacao das Pescas	Date: JAN88	Type: Bottom 4 panels	550HP to 650HP
Copyright du logiciel: CENTRE NATIONAL		Species: Octopus	Twine area: 153.51 m2
DE LA MER/INFREMER		From: Euroredes	

Fig. 1. Trawl (61.55m/83.50m) for octopus. Type: bottom, four panels. Twine area: 153.51m^2.Boats: 550–650HP.

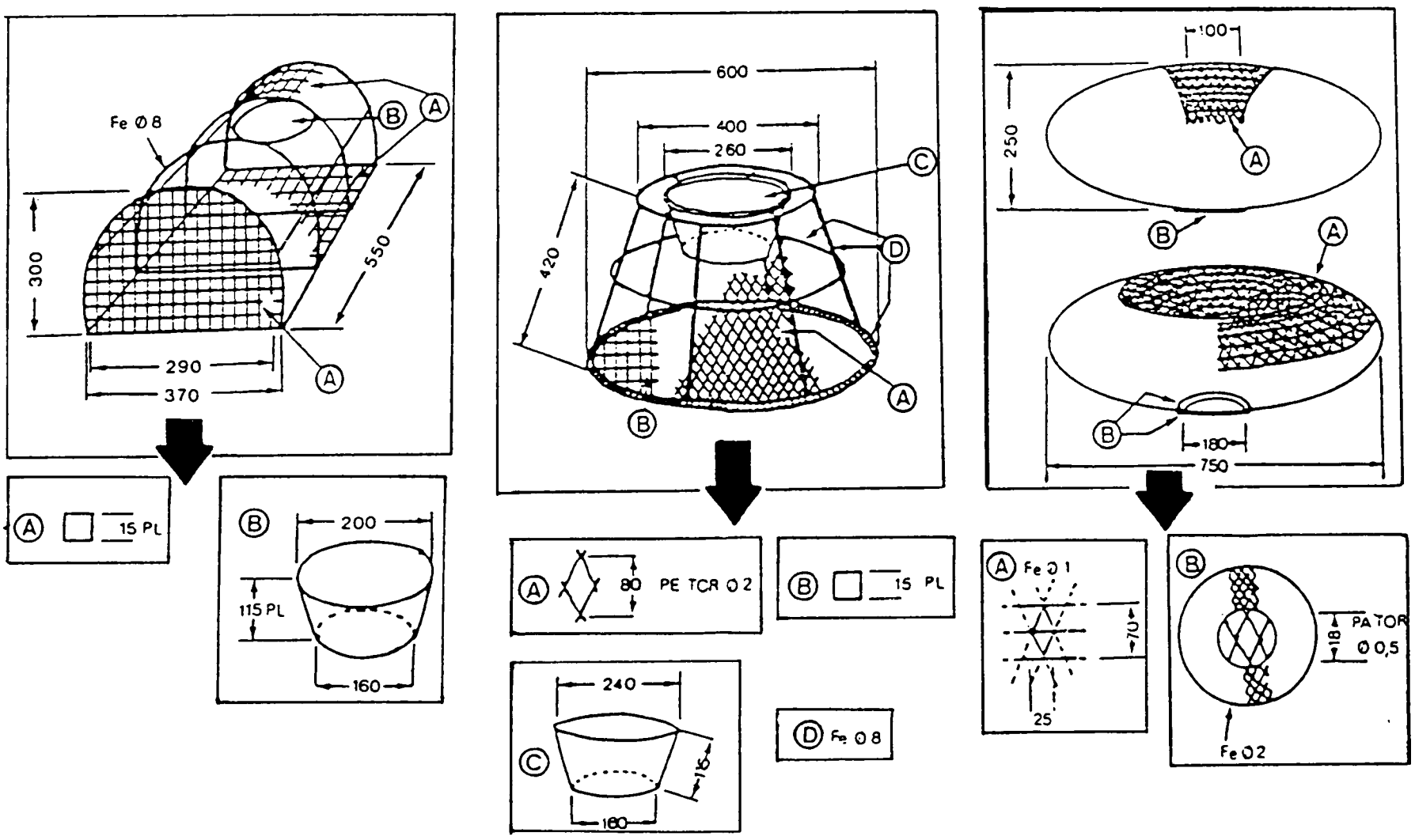
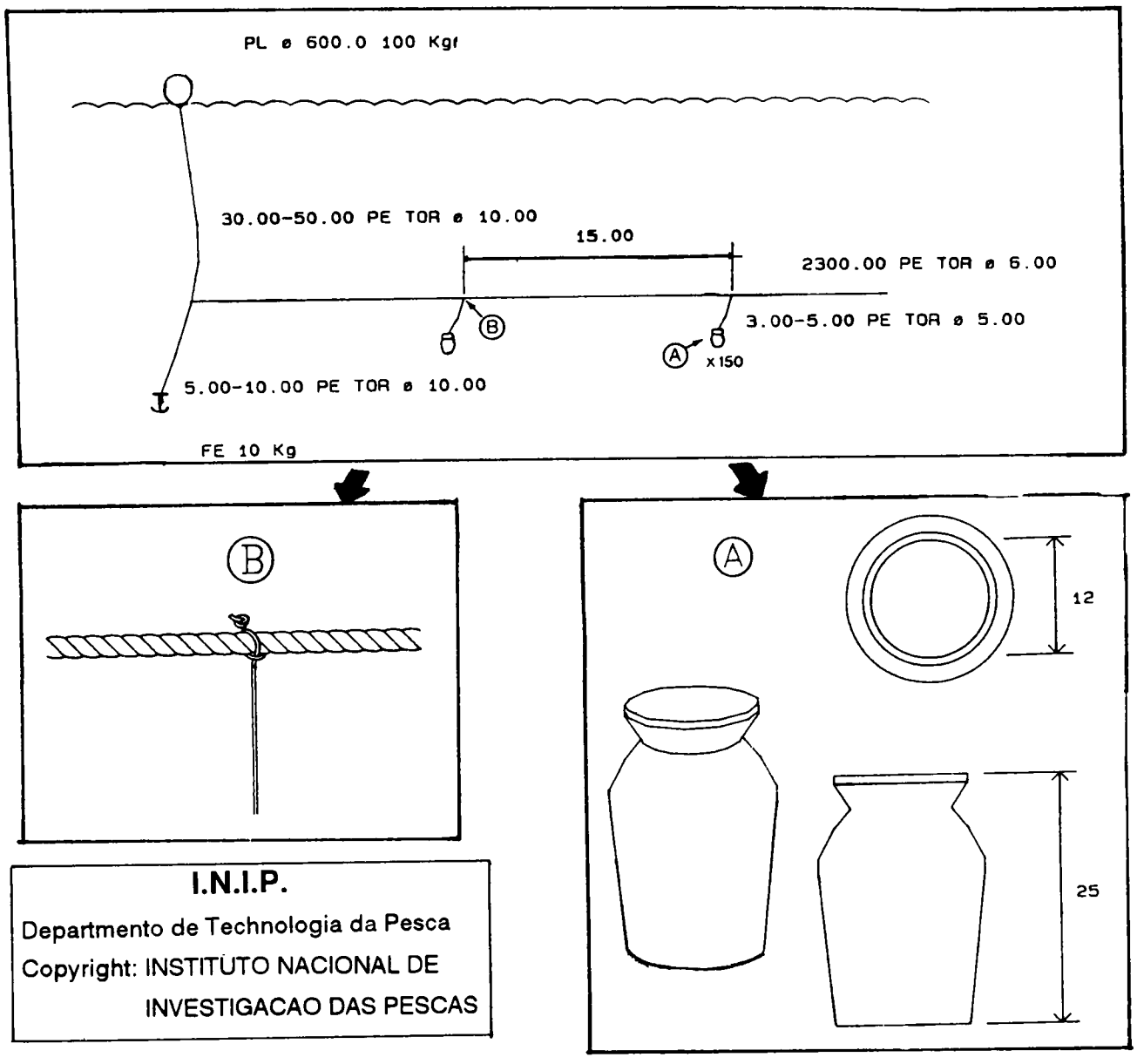


Fig. 2. Traps for octopus.



Ref: PEP-DTP; Date: 1990/10/17	Type: Longline; Species: Black Scabbard fish; From: INIP/DTP.

Fig. 3. Pots for octopus.

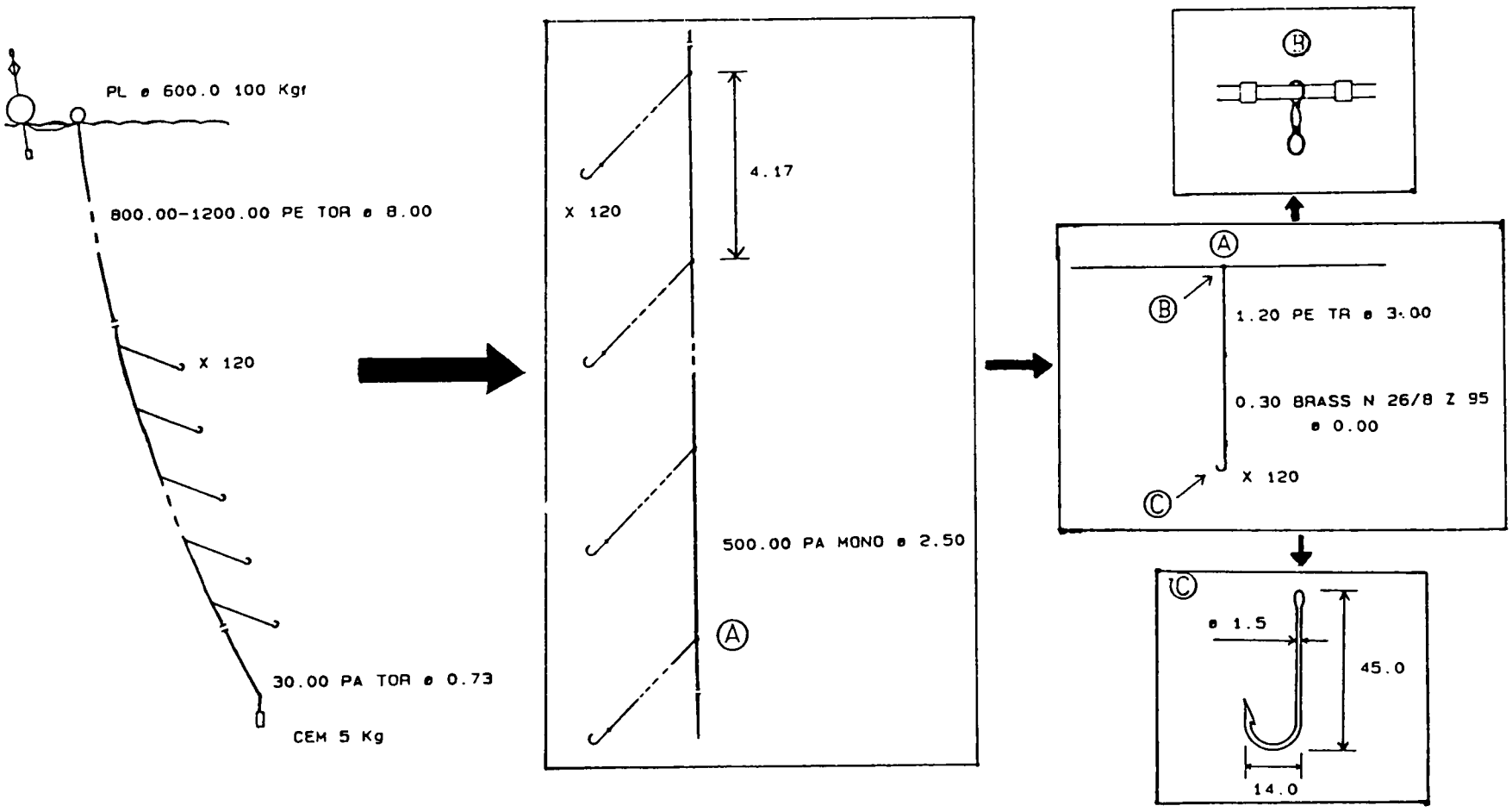
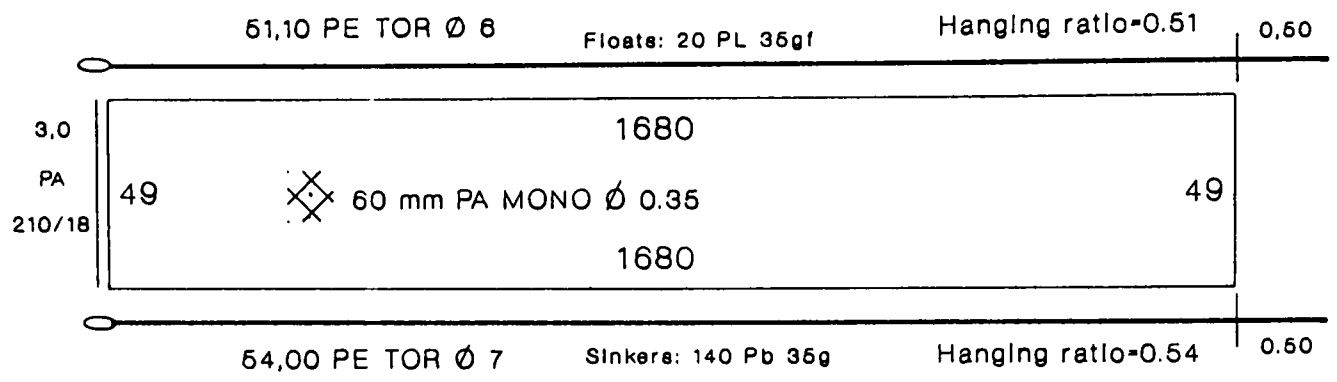


Fig. 4. Longline for black scabbard fish.



Species: Pout (*Trisopterus luscus*)
Origin: INIP
Ref.: Gillnet selectivity experiments on pout

Port.- Rede de emalhar
Engl.- Gillnet

Fig. 5. Gilnet for pout.

SC/O90/G57

Incidental Catches of Harbour Porpoises (*Phocoena phocoena*) in Danish Waters, 1986–89

Carl Chr. Kinze

Zoological Museum, University of Copenhagen, Universitetsparken 15, DK-2100 Copenhagen Ø, Denmark

ABSTRACT

Incidental catches of harbour porpoises (*Phocoena phocoena*) were studied for the years 1986–89 by means of a salvage programme, an interview survey and a small scale reporting scheme. Data were obtained on 152 animals. Most were taken in large-mesh gillnets (mesh size 70–120mm) set for cod, turbot, lumpfish and plaice, throughout Danish waters. An estimated maximum take of 750 porpoises from a single harbour in northern Jutland (Hanstholm) indicates a considerable total take. The catch consists mainly of subadult animals. Behavioural reactions of the porpoises to presence of fishing gear are discussed and may indicate that the animals have a capability of learning to avoid net entanglement.

KEYWORDS: INCIDENTAL CAPTURE; HARBOUR PORPOISE; BEHAVIOUR; FISHERIES; NORTH ATLANTIC

INTRODUCTION

There have been bycatches of harbour porpoises in nets in Danish waters since at least the 19th century (Melchior, 1834; Tauber, 1892). They were formerly of minor importance compared to a directed fishery that operated at several sites (see review by Kinze, 1994). The directed catch, which was estimated to be 97% of the total take (Tauber, op. cit.), ceased temporarily in 1892. It resumed during both world wars, in 1916–19 and 1941–44. Bycatches have occurred continuously throughout the period. Since the Second World War, the Baltic stock of the harbour porpoise has experienced a marked decline, and incidental catches in monofilament nets have been identified as a major threat to the population (Andersen, 1982).

Clausen and Andersen (1988) studied porpoises caught incidentally in Denmark during 1980–81. My studies began in 1986 (Kinze, 1987; 1989a). The aims of the present study were to determine (1) which fishing gear catches porpoises, (2) the sex and age distributions of the catches; (3) the timing of the catches relative to seasonal life history cycles of the porpoise and (4) to compare the findings with those of Clausen and Andersen (1988).

Although the Danish Fisheries Research Institute has recently (1993) carried out a survey to estimate cetacean bycatches, the results are preliminary (Larsen, 1995) and are discussed by Lowry and Teilmann (1994).

MATERIALS AND METHODS

Information on incidental catches was compiled from three sources: (1) a salvage programme to collect stranded and incidentally caught animals (run by the Zoological Museum of Copenhagen and yielding data on size, age, sex, date and type of fishing gear involved); (2) an interview survey at four fishing ports in western and northern Jutland (Hvide Sande, Thorsminde, Thyborøn and Hanstholm, Fig. 1) providing information on fishing gear and rough estimates of take; and (3) a small scale reporting scheme involving one vessel (from Hanstholm) and giving exact information on incidental catches.

Information on the Clausen and Andersen results came from their (1988) paper and their raw data in the archives of the Zoological Museum.

RESULTS

Numbers and season

Records of 152 incidental catches were compiled. The salvage programme collected 94 incidentally caught specimens between January 1986 and December 1989. The single-vessel survey out of Hanstholm recorded an incidental catch of 58 porpoises between April 1988 and August 1989 (47 during the one-year period May 1988 – April 1989). Complete data on fishing effort were not available, but the catches seemed to occur year round, with the possible exception of the winter months December – February. The salvage programme collected the bulk of the specimens during the spring quarter (March-May), while the single-vessel survey recorded greater numbers taken during the summer months, especially in August (Table 1).

Table 1

Incidental catches of harbour porpoises by months.

Month	Collected 1986/89	Special survey	Collected 1980/81
January	2	0	2
February	1	0	1
March	13	0	-
April	25	8	-
May	8	3	-
June	7	14	-
July	10	7	-
August	5	26	2
September	6	0	42
October	9	0	30
November	7	0	59
December	1	0	13
Total	94	58	149

Sex and age distributions

Of the 94 specimens collected in the salvage programme, 52 were males. Of 55 specimens of known sex recorded in the single-vessel survey, 34 were males. Thus males made up 57.7% of the catches of known sex. Age was determined for the specimens from the salvage programme; in this sample there was a preponderance of immature animals (76.5% less than 3 years old, Fig. 2).

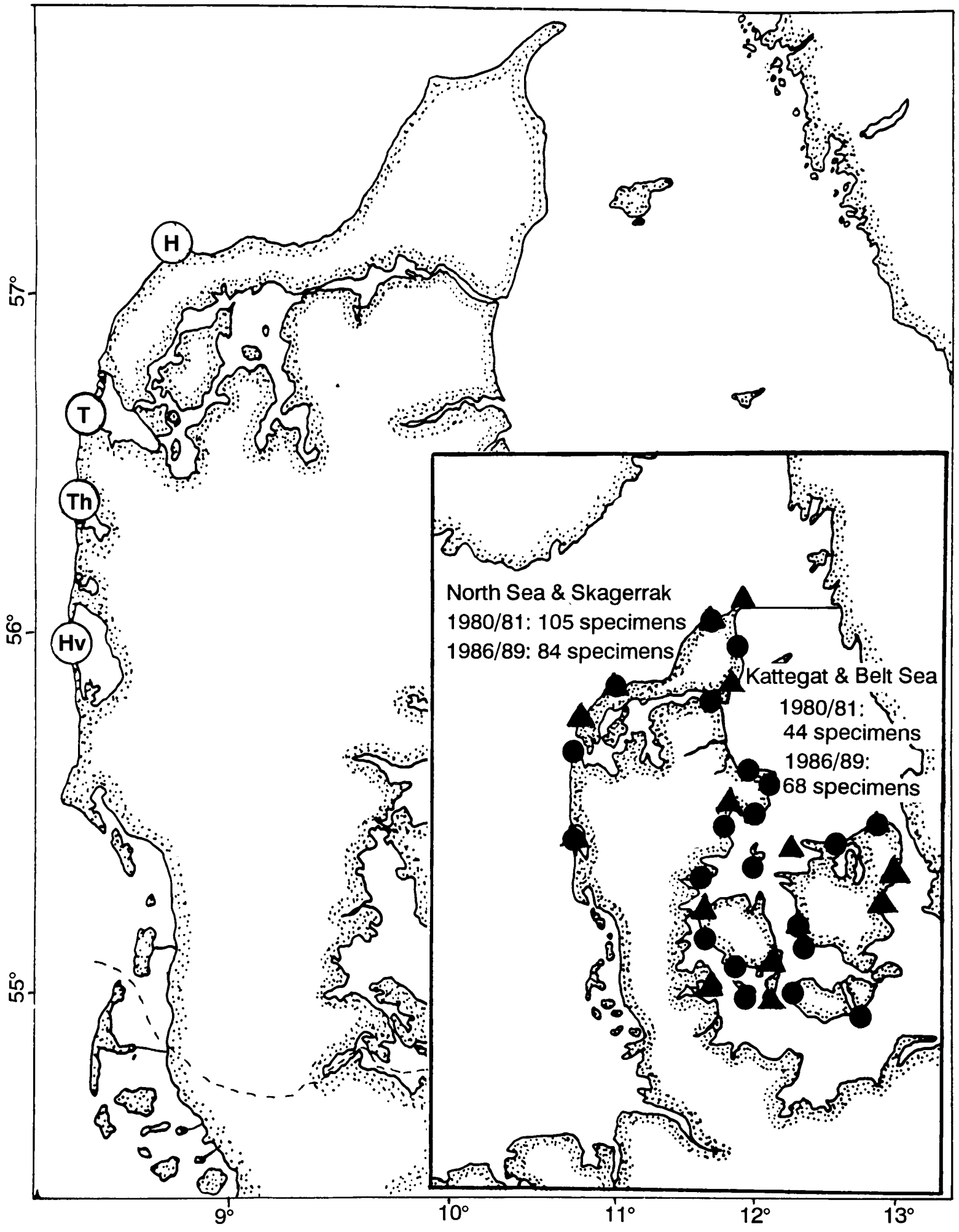


Fig. 1. Location of the four harbours covered by the interview survey (Main map, H=Hanstholm, T=Thyborøn, Th=Thorsminde, Hv=Hvide Sande) and geographical distribution of the harbours from which specimens were collected in 1980/81 (dots) and 1986/89 (triangles), respectively.

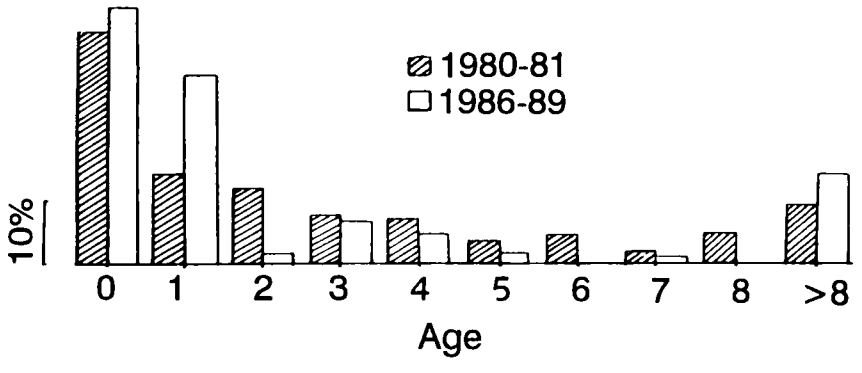


Fig. 2. Age distribution in the 1980/81 (n=148) and 1986/89 (n=94) samples given as percentages of the total sample.

Fishing gear

Of 152 animals recorded from the salvage programme and in the single-vessel survey, 147 were caught in large-mesh gillnets of 50–135mm mesh (Table 2). These nets were targeted on turbot (mesh size 110–135mm), lumpfish (70–120mm), plaice (65–90mm) and cod (50–85mm). The collected specimens nearly all came from cod and lumpfish nets. Incidental catches in cod nets occurred in all Danish waters during all or most of the year, while lumpfish nets caught porpoises only in Danish inner waters in the spring.

The interview survey revealed that in North Sea waters, incidental catches occurred mainly in cod nets (50% of the 'yes' answers) and turbot nets (33%) and to a lesser extent in plaice nets (17%). The single-vessel survey off Hanstholm documented a take in turbot nets. Only five of the collected specimens were not taken in gillnets. Of these, four were taken in trawls (Table 2). None were reported taken in trawls in the interview survey; 13 of 15 'no' answers were by trawlermen.

Table 2

Distribution of incidental catches by fishing gear.

Gear	1986/89	%	1980/81	%
Gillnets	89	95	111	75
Cod	22		90	
Lumpfish	34			
Plaice	11		21	
Other Flatfish	3			
Salmon	3			
Unspecified	16			
Trawls	4	5	28	19
Other	1		10	6
Total	94		149	

Size of the catch

Interviews with fishermen yielded the following rough estimates:

Maximum reported catch per vessel per season – 100–200
Maximum reported catch per cruise – 50
Maximum reported catch per day – 25
Maximum reported catch per net set – 8

The monitored vessel out of Hansholm caught 47 porpoises during a one-year period. There are about 15 vessels fishing with the same gear out of Hansholm. If an annual take per boat of about 50 porpoises is assumed, this means that the annual take for this port alone can be roughly estimated at about 750 animals.

Comparison with the 1980/81 data set

Clausen and Andersen (1988) reported on specimens collected from September to February, while the present study was based on specimens collected year round (1986–89). The 1980/81 sample included 105 specimens from the northern North Sea and the Skagerrak and 44 from Danish inner waters; for the present study the figures were 84 and 68, respectively (Fig. 1). In both samples there were more males than females. The age distributions were also similar, with age classes 0–2 accounting for 62.8% and 76.5% of the earlier and later samples, respectively (Fig. 2). The more recent sample had a higher proportion of age class 1 animals. The distribution of net types was also similar, with large-mesh cod nets accounting for the bulk of the catch (Table 2).

Clausen and Andersen's (1988) estimate of an annual incidental catch of 3,000 and my rough estimate of 750 for a single port agree in that they both indicate that large numbers may be taken.

DISCUSSION

Impacts

The results presented here and those of Clausen and Andersen (1988) indicate that large numbers of harbour porpoises have been taken incidentally in Danish waters for at least the period in question. However, the numerical estimates must be considered preliminary, because they are based on small samples of the fisheries. The porpoises are taken mainly on the bottom, in large-mesh gillnets. The entangled animals are predominantly immature, and males slightly outnumber females.

Since the present study has been completed, the Danish National Forest and Nature Agency has established a reporting system for incidental catches; 92 harbour porpoises were reported in 1991 and 119 in 1992 (Larsen, 1993: 1994). In addition, the Danish Fisheries Research Institute placed observers on 51 fishing trips in 1993, who reported a total of 117 harbour porpoises taken in cod and turbot nets (Larsen, 1995). Relatively crude extrapolation from this confirms the results of our study that several thousand harbour porpoises may be taken by Danish vessels each year (but see Lowry and Teilmann, 1994).

This apparently large incidental catch may be having a severe impact on the population(s). Unfortunately, our knowledge of the stock identity of harbour porpoises in this region is poor; it is thought likely that there may be several populations in the North and Baltic Seas (e.g. Kinze, 1985; 1990; Yurick and Gaskin, 1987; IWC, 1992). Similarly, there are few estimates of population size, apart from in the Lofoten-Barents Sea, the northern North Sea (Børge and Øien, 1994) and some Danish and German waters (Heide-Jørgensen *et al.*, 1993). Fortunately, this issue is being addressed and a multi-national survey in the North and Baltic Seas was carried out in summer 1994, although the results are not yet available.

Apart from the numbers caught, the age and sex compositions of the catch are important in assessing likely impact on populations. Certain life stages may be relatively more vulnerable to entanglement. The end of the weaning period (at eight months of age, according to Møhl-Hansen, 1954) and the onset of the lumpfish fisheries may co-occur in Danish waters; this may lead to frequent entanglements of newly weaned, inexperienced calves. It may also put accompanying adult females at risk if they try to rescue their calves. The 1986/89 data set includes as least one case of a presumed cow-calf pair caught in the same net.

The possibility of higher catches of specific age classes due to age-related segregation must also be taken into account. Subadult males are thought to segregate from other age/sex classes in offshore Canadian waters (Gaskin and Blair, 1977) and may be caught incidently in disproportionate numbers. On the other hand, females frequenting more inshore shallow-water calving grounds may in effect avoid fishing operations during the calving season.

Entanglement

An early study of the echolocation abilities of the harbour porpoise found that it could not detect thin nylon monofilament threads (Møhl and Andersen, 1973). However, this study was conducted on captive animals in an artificial environment with conditions little resembling those in the wild. More recent work has shown that harbour porpoises and other species should be capable of detecting monofilament nets at a considerable distance and even under severe weather conditions (Au and Jones, 1991).

Even though monofilament nets are theoretically detectable by porpoises, the echo from fish in a net may mask the return from the monofilament webbing and therefore be dangerous to inexperienced animals. Pence (1986) found the knots in a net to give the best echo; therefore small-mesh nets (with more knots) should be more easily detected than large-mesh nets. Most incidentally entangled porpoises in Denmark are taken in large-mesh nets; the animals typically have 'mesh-marks' on the head.

As noted in IWC (1994) several modifications of gillnets have been attempted but have yielded inconclusive results. Silber (1989) tested net modifications on free-ranging harbour porpoises and found higher frequency of avoidance for the nets with the best passive acoustic properties but was unable to achieve complete deterrence. The position of the net in the water column has an influence on entanglement; for example Piatt and Nettleship (1987), who found off Newfoundland that most animals were caught at 10–20m while Lindstedt and Lindstedt (1989) found highest catches of harbour porpoises in Swedish waters at 20–60m. Virtually all Danish gillnets are set in water shallower than 60m; even bottom nets are well within the diving depth of the harbour porpoise (maximum dive time about six minutes and maximum depth about 80m – Gaskin *et al.*, 1974).

A feature of the data presented here is the high proportion of sub-adult animals. One explanation is that entanglement may be related to experience of the animals and their behaviour around gillnets. Although all age-classes may be attracted to gilled fish in the nets (Gaskin, 1984), younger, less-experienced adults may be more vulnerable to entanglement (i.e. the age structure of the catch may not be representative of the population). An alternative explanation may be that the large proportion of young animals in the catches reflects segregation and immigration of young animals from other areas. This does not seem likely, however, because size distributions are similar in neighboring waters of Sweden, Norway and Britain (Lindstedt and Lindstedt, 1989; A. Bjørge, pers. comm.; S. Northridge, pers. comm.). Ostensibly unselected samples taken in drive fisheries or shot at sea in Baltic and Greenland waters have a larger proportion of older porpoises (Møhl-Hansen, 1954; Hammond, 1987; Kinze, 1989b).

Changes in body length distribution over time have been detected in incidental catches in Canadian waters (Read and Gaskin, 1988); this might be accounted for by learning on the part of the porpoises. Initially a gillnet fishery there caught animals of all size classes. After 10 years, the relative numbers of smallest and largest animals had declined. All mammals have a pronounced ability to learn by experience (Ewer, 1968), and a process of learning to avoid nets or to avoid entanglement should be expected to occur in harbour porpoises as a response to exploitation. If the porpoises learn by experience, one might expect decline in relative frequency of the smallest calves (because they are being kept out of the nets by their mothers) and the the largest (oldest) animals (because they have learned to avoid the nets).

Some porpoises may learn to avoid nets through direct experience of entanglement with subsequent escape or release. Others may learn indirectly through hearing distress calls from entangled individuals (Amundin and Amundin, 1971). In addition, harbour porpoises have an acute sense of taste (Kuznetsov, 1979), and glandular secretions, urination, or defecation of entangled animals could deter the approach of conspecifics; this is thought to occur in white whales, *Delphinapterus leucas*, in the White Sea (Yablokov *et al.*, 1972).

Young mammals spend a relatively greater proportion of time in exploration than adults do (Ewer, 1968). Recent studies of behaviour of the harbour porpoise in Danish waters (Kinze, 1988; 1990) found that subadults approached a research vessel very readily, while adults, especially those accompanied by calves, kept their distance.

All types of fishing gear seemingly have sufficient acoustic return to make them detectable by harbour porpoises. However, some gear may exclude the possibility of learning on the part of the porpoises, either because they remove all the animals in the area, or because the fishing operation is very complex and unpredictable from the animal's perspective.

Pair trawls may be less selective than gillnets, because members of all age classes may by chance be in the path of the mouth of the net when the fishing vessel turns or when the net falls. This may account for differences in size distribution found in animals caught in cod nets and in trawls (Clausen and Andersen, 1988). However, such gear accounts for only a minor fraction of the total incidental catch.

CONCLUSION

Considerably more information is needed before the impact of the incidental catches in Danish waters can be assessed; the available data indicate that large numbers of harbour porpoises, mainly subadults are taken in Danish fishing gear, mostly in various types of gillnets. The existing monitoring and reporting systems need strengthening and the 1994 multi-national survey results should be examined in conjunction with further studies on stock identity.

ACKNOWLEDGEMENTS

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A Review of the Passive Fishing Nets and Trap Fisheries in the Mediterranean Sea and of the Cetacean Bycatch

Antonio Di Natale

Aquastudio, via Trapani 6, 98121 Messina, Italy.

and

Giuseppe Notarbartolo-di-Sciara

Tethys Research Institute, Via G. Giusti 5, 20154 Milano, Italy

ABSTRACT

Cetacean mortality in passive fishing gear in the Mediterranean has not previously been the subject of a systematic study. Data on passive fishing nets and traps are here presented for the majority of the principal national Mediterranean fisheries, including geographic information, a description of vessels, crew, gear, operations, economics and history, total landings, effort, interaction with cetaceans and, in addition, occasional bycatches of the endangered monk seal. Although data on total bycatch, species composition and CPUE are lacking, it is well-known that cetaceans are incidentally caught in great numbers in fisheries in this region. Pelagic driftnets are responsible for the greatest proportion of the cetacean bycatch, although catches in coastal gillnets and traditional tuna traps also occur. Many of these fisheries are illegal but continuing. Recommendations for the conservation of cetaceans in the Mediterranean are made.

KEYWORDS: MEDITERRANEAN; INCIDENTAL CAPTURE; FISHERIES; MANAGEMENT; FIN WHALE; SPERM WHALE; MINKE WHALE; CUVIER'S BEAKED WHALE; PILOT WHALE - LONG-FINNED; RISSO'S DOLPHIN; STRIPED DOLPHIN; COMMON DOLPHIN; BOTTLENOSE DOLPHIN; ROUGH-TOOTHED DOLPHIN; KILLER WHALE; MONK SEAL

INTRODUCTION

Fishing is deeply rooted in the Mediterranean tradition and has formed an important component of local coastal economies since ancient times. As a consequence, the density of small-scale artisanal fishing operations in the Mediterranean is among the highest in the world (Northridge and Di Natale, 1991). Passive fishing nets are perhaps the most widespread gear used and this has led to the evolution of a large number of technological variants, sometimes extremely specialised and almost species-specific. This includes the use of pelagic driftnets for the capture of swordfish (*Xiphias gladius*), first recorded during the 2nd Century BC by the Roman historian Oppianus (Sisci, 1988).

Such high fishing pressure is inevitably a cause of conflict with marine mammals: one pinniped species, the almost extinct monk seal (*Monachus monachus*); and about 20 cetacean species. The most common cetaceans in the Mediterranean are: the fin whale *Balaenoptera physalus*, the sperm whale *Physeter macrocephalus*, Cuvier's beaked whale *Ziphius cavirostris*, the long-finned pilot whale *Globicephala melas*, Risso's dolphin *Grampus griseus*, the common dolphin *Delphinus delphis*, the striped dolphin *Stenella coeruleoalba* and the bottlenose dolphin *Tursiops truncatus* (Cagnolaro *et al.*, 1983; Di Natale, 1987). Apart from the recent survey to estimate the population size of striped dolphins in the western Mediterranean (Forcada *et al.*, 1994), little is known about their population size.

Of the many types of passive fishing nets used in the Mediterranean, the following are the most important in terms of their interactions with marine mammals: (1) bottom gillnets and trammels; (2) traditional tuna traps and (3) surface pelagic driftnets. Although interactions with these have directly and indirectly led to the near extinction of the monk seal (Ronald and Duguy, 1979), until a few decades ago cetaceans appear to have been little affected. This scenario was drastically changed after World War II mainly by two technological innovations; the use of synthetic net filaments and the introduction of power engines in fishing boats, which has enabled the development of large pelagic driftnet fleets.

PEOPLE CONTACTED

The following persons were contacted and provided information on national fisheries in Mediterranean waters: M. Balilli, D.E. Gaskin, F. Gorica, S. Memia, E. Hajderi (Albania); M. Adjal, G. Kadari, F. Zenasni (Algeria); M. Hadjichristophorou (Cyprus); A. Ezzat (Egypt); B. Lliorzou, J. Maigret (France); A. Aguilar (Gibraltar); E. Lefkathitou, S. Tselas, G. Tserpes, P. Megalofonou (Greece); A. Ben-Tuvia, M. Ben-Yami, M. Ton (Israel); N. Miyabe (Japan); N.K. El Kebir (Libya); L. Attard, J. Manduca, R. Sisci (Malta); J. Maigret (Monaco); A. Fahfuhi, A. Lamrini, A. Srour (Morocco); G. Plotoaga (Romania); A. Aguilar, J.L. Cort, J. Mejuto Garcia, J.M. de la Serna Ernst (Spain); K. Ben Mustafa, M. Fundun-Ktari, S. Najal, J. Zaouali (Tunisia); F. Aksiray, F. Altunel, M. Demir, M. Salih Celikkale, J. Tanyolac (Turkey); M. Ivashin, Y. Mikhalev, L. Popov, A. Rovnin, A. Yablokov (USSR); V. Alegria Hernandez (Croatia); R.C. Griffiths, J. Majkowski, M. Savini (FAO Fisheries Department); P. Miyake (ICCAT); J.C. Rey Salgado (EEC Direction General XIV).

LITERATURE REVIEW

Most of the available information concerning Mediterranean traditional tuna traps and surface pelagic driftnets is reported in ICCAT-SCRS[1] documents (Anon., 1990; 1993; In press). Coastal gillnet fisheries are poorly

[1] International Commission for the Conservation of Atlantic Tunas.

described and there have been no reviews updating the report of Dremière and Nédélec (1977). However, Di Natale *et al.* (1990) present an overview of all fishing activities in Italy, including traditional tuna traps, surface pelagic driftnets and coastal gillnets. This supplements the review of artisanal fishing gear, including gillnets, of Di Natale (1988). Although French Mediterranean artisanal fisheries were reviewed by Farrugio (1988), the information is incomplete. It is of concern that no regular monitoring or quantitative description of the environmental impact of passive fishing nets in the Mediterranean has been made (Northridge and Di Natale, 1991).

This lack of regular extensive monitoring is also true for the specific problem of the interactions between cetaceans and fisheries. Anecdotal evidence of cetacean incidental captures in fishing gear in the Mediterranean is contained in several stranding reports from France (e.g. Duguy, 1985; 1986; 1987; 1989) and from Italy (e.g. Anon., 1987; 1988a; 1989); early incidental catches are reported by Di Natale (1987), Mangano (1984), Mojo and Cavallaro (1972), Podestà and Magnaghi (1989); information was reviewed by Di Natale and Mangano (1982; 1983a; 1983b; 1983c) and Duguy *et al.* (1983). A summary of such incidents recorded along the Italian coasts between 1986 and 1989 is given by Notarbartolo-di-Sciara (1990). More recent, general reviews are provided by Scialabba (In press), Northridge and Di Natale (1991), Northridge *et al.* (1991) and Di Natale (1990b). Di Natale (1990a; b; 1992), Di Natale and Mangano (1990), Di Natale *et al.* (1993; In press; In press-a; b) explore in more detail the situation in Italy.

SYNOPSIS OF THE FISHERIES

Overview

The only Mediterranean countries that do not seem to have any fisheries in which passive nets cause cetacean mortality are Libya and Monaco.

Traditional tuna trap data are available for Italy and Tunisia; although Libyan and Croatian tuna traps exist, no cetacean accidental captures have been reported. Other coastal traps set for smaller pelagic schooling fishes are found in several Mediterranean countries (Italy, Romania, Turkey and ex-Yugoslavia), but there are no data on whether cetacean bycatches occur.

Pelagic driftnet data are reported here for Algeria, France, Greece, Italy, Malta, Morocco, Spain and Turkey. Albania*, Cyprus and ex-Yugoslavia presently do not have driftnet fleets.

The information on coastal gillnet fisheries provided by Dremière and Nédélec (1977) for Bulgaria, Cyprus, Egypt, France, Israel, Romania, Spain, Tunisia, Turkey and ex-Yugoslavia, is now obsolete. We were only able to obtain updated information for Algeria, France, Greece, Italy, Spain and Tunisia.

No recent information could be obtained for: Albania* (gillnets), Bulgaria (all fisheries), Cyprus (gillnets), Egypt (all fisheries), Gibraltar (all fisheries), Israel (all fisheries), Lebanon (all fisheries), Malta (gillnets), Morocco (gillnets and tuna traps), Romania (all fisheries), Spain (tuna traps), Syria (all fisheries), Tunisia (driftnets), Turkey

* It is believed that 'a few' boats have started to use driftnets in Albania after contact with Italian fishermen but no details are available.



Fig. 1. Sea floor profile and topography of the Mediterranean and Black Seas.

(gillnets), USSR (all fisheries), and ex-Yugoslavia (gillnets and tuna traps). We suspect, however, that fishing activities in Albania, Egypt, Gibraltar, Lebanon and Syria are not important with respect to cetacean incidental captures.

To our knowledge, no driftnetting in the Mediterranean is being carried out by countries from outside the region (Anon., 1990; 1993).

The following fisheries are described in more detail: (A) Algerian gillnet; (B) Algerian surface pelagic driftnet; (C) French Mediterranean gillnet; (D) French Mediterranean surface pelagic driftnet; (E) Greek gillnet; (F) Greek surface pelagic driftnet; (G) Italian gillnet; (H) Italian surface large pelagic driftnet; (I) Italian surface small pelagic driftnet; (J) Italian traditional tuna trap; (K) Maltese surface pelagic driftnet; (L) Moroccan Mediterranean surface pelagic driftnet; (M) Spanish Mediterranean gillnet; (N) Spanish Mediterranean surface pelagic driftnet; (O) Tunisian gillnet; (P) Tunisian traditional tuna trap; (Q) Turkish surface pelagic driftnet.

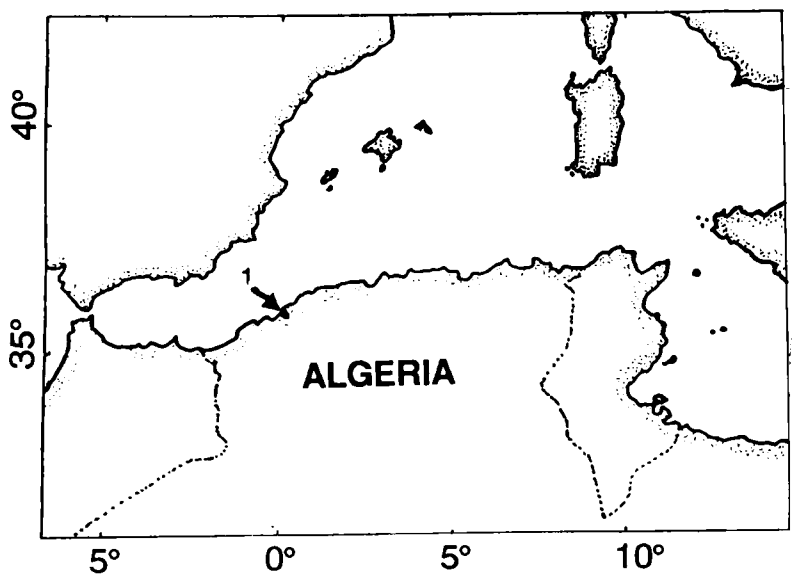

Fig. 2. Position of the Algerian harbour in which the experimental driftnet boat was located. (1) Oran.

(A) Algerian gillnet fishery

There is relatively little information for this fishery, with respect to ports, vessels, operation, catch and effort data or economics. The available information is summarised below.

Target species

European hake (*Merluccius merluccius*), common sole (*Solea vulgaris*) and other benthic species are taken.

Area of operation

The fishery is carried out in Algerian coastal areas, but not within 3 n.miles of the coast.

Gear

Although no detailed information is available, the gillnets used have a stretched mesh size from 20–30mm to 350mm.

Interactions with marine mammals

One or two dolphins (species not specified) are reported as 'commonly' taken but there are no estimates of the annual bycatch. An awareness campaign is being carried out by CERP (Centre d'Etudes de Recherche Appliquée et de Documentation pour la Pêche et l'Aquaculture, Bou-Ismail), because cetaceans are protected by the Algerian law. Occasionally a monk seal is entangled in gillnets (perhaps one per year).

(B) Algerian surface pelagic driftnet fishery (experimental)

Ports/operation area

The fishery is centred near Oran (1°16'W, 35°04'N; Fig. 2) and operates in coastal waters.

Target species

Swordfish (*Xiphias gladius*) and tuna-like fishes are targetted.

Vessels and crew

A wooden cabin vessel, 9m long, with a 10 tonne displacement, was used in an experimental fishery in 1990 with a crew of four Algerian fishermen. Since then, the fishery has expanded to ten vessels.

Gear

In the experimental fishery, a multifilament driftnet with a stretched mesh size of 37cm was used. The float size was 40cm and the spaces between floats were 5m. Beacons consisted of battery operated lamps and radio transmitters. The total net length was 2km and the net depth was 3m. It is assumed that the vessels now operating use similar gear.

Operations

Trips last from 12–15 hours. The net is set in waters less than 40m deep, usually during the night (0100–0200hrs) and retrieved the next morning after 8–9 hours soaking time.

Economics and history

The catch is typically kept fresh and landed daily; ex-vessel prices are about 10 US$/kg. The fish is sold fresh on the domestic market. A total annual landing of 400kg is reported from the experimental fishery. The expanded fishery is still relatively small.

Interactions with cetaceans

Although there are no official data, the common dolphin is potentially at risk of capture. Algerian law forbids the capture, trade and transportation of cetaceans.

This experimental driftnet fishery operated for a short time under the control of Algerian fishery scientists from 1990. Moderate commercial development of driftnetting followed and up to ten boats.

(C) French Mediterranean gillnet fishery

Ports/operation area

Vessels operate from ports found all along the French Mediterranean coasts, both on the mainland and in Corsica. All boats operate within the French Mediterranean coastal area, approximately within 18km of the coast.

Target species

A large number of benthic and pelagic species are targetted.

Vessels and crew

The fleet is heterogeneous. Boats have a wooden or fibreglass hull and range in length between 3 and 14m (Fig. 3c). There are no official data concerning the total number of vessels but it is thought that over 1,000 boats are in operation, crewed by 1–3 French fishermen, sometimes helped by Maghrebian fishermen.

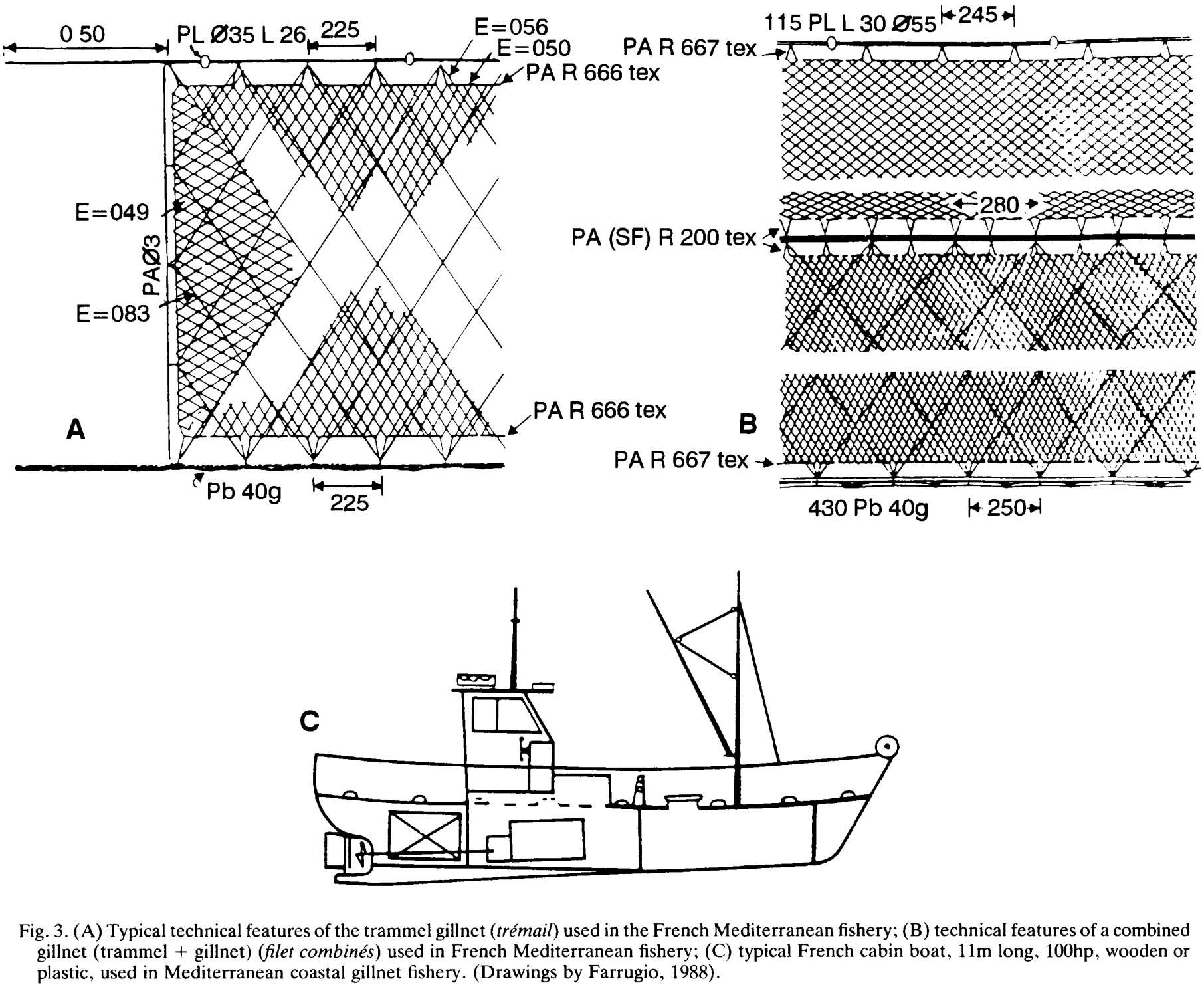

Fig. 3. (A) Typical technical features of the trammel gillnet (*trémail*) used in the French Mediterranean fishery; (B) technical features of a combined gillnet (trammel + gillnet) (*filet combinés*) used in French Mediterranean fishery; (C) typical French cabin boat, 11m long, 100hp, wooden or plastic, used in Mediterranean coastal gillnet fishery. (Drawings by Farrugio, 1988).

Gear
Trammels follow a traditional design, as in most Mediterranean countries. Combined nets are also used (Figs 3a and 3b). Monofilament and multifilament nylon or polyamide gillnets are used with a stretched mesh size of 25–80mm and a maximum length of 50m per panel. Net depth is reportedly 1.2m. Each boat typically uses 10–40 panels, but some reach a maximum of 50–200 panels.

Operations
Trammels and combined trammels are generally set during the night and retrieved the following morning. By contrast, the set gillnets used in the hake fishery are set in the morning and retrieved during the day. No other information is available.

Economics and history
Fish is normally kept fresh, landed daily and sold in the domestic market. No data on total landings or effort are available.

Interaction with cetaceans
Anecdotal reports concerning four striped dolphins, one common dolphin, four bottlenose dolphins, four Risso's dolphins and two minke whales (*Balaenoptera acutorostrata*) are given by Duguy *et al.* (1983). Two rough-toothed dolphins (*Steno bredanensis*) have been reported by Granier (1970) and Duguy and Cyrus (1973). Further information from the French Mediterranean stranding record is given by Duguy (e.g. 1985; 1986; 1987; 1989). Cetaceans are protected by French law.

Comment
This fishery is among the most important in the French Mediterranean but it is not yet adequately monitored.

(D) French Mediterranean surface pelagic driftnet fishery

Ports/operation area
Ports on the mainland coast (Gulf of Lions) and Corsica are used (Fig. 4) and the fishery is carried out in adjacent waters.

Target species
The swordfish (*Xiphias galdius*), albacore (*Thunnus alalunga*) and other tuna-like fishes are targetted.

Vessels and crew
In 1990, only 12 driftnet boats were thought to operate in the French Mediterranean, all with a French crew. Two large boats operated in the Gulf of Lions; the remaining 10 smaller vessels operate in Corsican waters (Anon., 1990). The number of large vessels has since increased to 10.

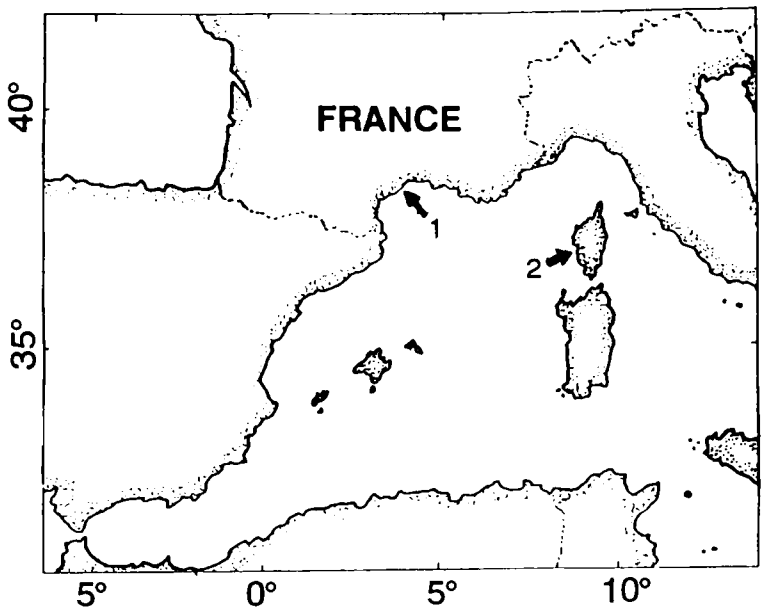

Fig. 4. Position of the French Mediterranean harbours in which driftnet boats are located. (1) *Gulf of Lions*; (2) Corsica.

Gear
Driftnets are made of nylon multifilament with a stretched mesh size of 36–42cm. In 1990, net length was 12–15km in the larger boats (Gulf of Lion) and 2.5–3km in the smaller (Corsica). Current European legislation forbids the use of driftnets greater than 2.5km. Nets are set in deep waters at sunset and retrieved before dawn the following morning. One of the boats operating in Corsica occasionally set the net on the bottom.

Interactions with cetaceans
Anecdotal information concerning four striped dolphins and one minke whale is given by Duguy *et al.* (1983). Additional information from the stranding record in the French Mediterranean is given by Duguy (1976; 1985; 1986; 1989). Sperm whales, long-finned pilot whales and Risso's dolphins are also suspected to be part of the bycatch. Cetaceans are protected by French law.

Comment
In March 1993, France, Italy and Monaco signed a Declaration to establish a marine mammal sanctuary in the Ligurian Sea. Unfortunately, although accepted by the French Ministry of the Environment, it has not been accepted (or enforced) by the Ministry of Fisheries. This is a matter of some concern (e.g. see Anon., 1994).

(E) Greek gillnet fishery

Ports/operation area
Ports are found all along the Greek mainland and islands coasts and operations occur in all Greek coastal waters.

Target species
A large variety of benthic and pelagic species are targetted.

Vessels and crew
Little information is available. The fleet is large (about 20,000 vessels) and heterogeneous. Most boats are small and their hull is wooden. The crew usually comprises 1–5 Greek nationals.

Economics and history
The catch is landed fresh, and sold on the domestic market. There are no data on gear, methodology or catch and effort.

Interactions with marine mammals
Smaller delphinid species (striped, common and bottlenose dolphins) are suspected to be part of the gillnet bycatch. Cetaceans are protected by the Greek law, but this appears to be weakly enforced. Unknown numbers of monk seals are known to be captured accidentally by gillnets (Northridge, 1984).

Comment
Given the socio-economic importance of this fishery, accurate monitoring of the marine mammal bycatch is strongly recommended, particularly with respect to the endangered monk seal.

(F) Greek surface pelagic driftnet fishery

Ports/operation area
The main ports are Kefallonia (Ionian Sea) and Kithyra (southwestern Aegean Sea) and operations take place in adjacent waters (Fig. 5). Small mesh driftnets are used everywhere, but mostly in eastern waters.

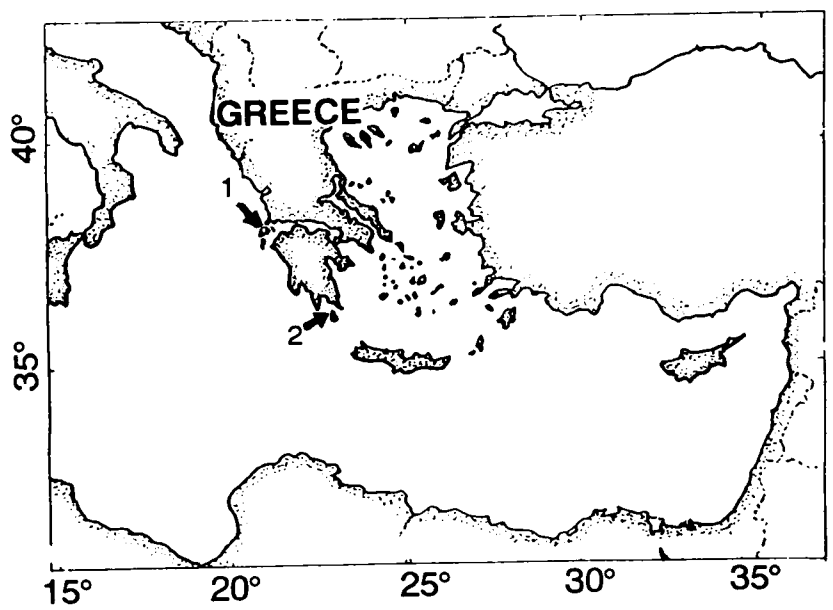

Fig. 5. Position of the Greek harbours in which driftnet boats are located. (1) Kefallonia; (2) Kithyra.

Target species
The target species is the swordfish (*Xiphias gladius*). Small driftnets catch small tunas.

Vessels and crew
In 1990, the fleet consisted of five 7–8m long wooden cabin cruisers with a crew of 2–4. The number of vessels using small mesh driftnets is unknown.

Gear
The nets are made of nylon polyfilament, with a stretched mesh of 36–42cm width, a maximum length of 3–5km (in 1990 – European legislation now makes nets of >2.5km illegal) and a depth of up to 28m. In small driftnets, stretched mesh size is around 8–9cm.

Operations
The fishery occurs in summer, when the weather is calm. The net is set before sunset and the soak time is approximately 4 hours. There are no data available for the small-scale fisheries.

Economics and history
Fish are landed fresh and sold on the domestic market with the ex-vessel price being about 8 US$/kg. Driftnetting began in 1989, with technology imported from Italy. No data are available for the small-scale fisheries.

Interaction with cetaceans
Although there are no official data, it is suspected that striped and common dolphins are caught. Cetaceans are protected by Greek law.

Comment
The swordfish fishery was started only after the Italians began operating in Greek waters and thus cannot be regarded as locally traditional. There are no monitoring programmes in effect. The Greek Government has not confirmed the existence of this fishery.

(G) Italian gillnet fishery (trammels)

Ports/operation area
Ports are found all along the Italian coasts and operations occur in Italian coastal and shelf waters.

Target species
Wrasses (Labridae), mullets (Mugilidae and Mullidae), rockfishes (Scorpaenidae), groupers and combers (Serranidae), dentexes and seabreams (Sparidae) and weevers (Trachinidae) are the principal target species.

Vessels and crew
The fleet is large (over 15,000 vessels) and heterogeneous. Boats may be made of wood, fibreglass or aluminium and are 4–16m in length. Crews are Italian and range in size from 1–4.

Gear
Most nets are made of nylon or polyammide polyfilament although a few nets are of nylon monofilament. The average mesh size (stretched) is 14–15mm (lower part of the net), 13–14mm (upper part) and 220mm (wall) long. Mesh size varies geographically. Panel length is highly variable from boat to boat; modal length is 350–400m. Each vessel usually carries 1–6 panels, although some can carry up to 20 panels. Most beacons are made of makeshift recycled plastic material. Nets are retrieved by hand or by net hauling gear (1– or 2–wheel).

Operations
Trips normally last between 3 and 5 hours. Nets are generally set on the bottom within a depth range of 5–200m. Nets are set in the afternoon and retrieved the following morning.

Economics and history
The catch is landed fresh (when it may be refrigerated) and marketed locally; prices vary between 7 and 21 US$/kg depending on prey species. There are no data on catch and effort.

Interaction with marine mammals
Although few entrapments are reported, this is probably because many go unreported rather than that they are rare. Bottlenose, Risso's and striped dolphins, and sperm whales are reportedly caught in gillnets, mostly in Sicily and Puglie. Cetaceans are used, removed or released by cutting the net; the proportion of live/dead bycatch is unknown. The bycatch is normally discarded. The Italian Ministry of Merchant Marine has funded research on this subject. The impact of this fishery on cetaceans is likely to be low. The once abundant (>40 years ago) monk seal, *Monachus monachus*, used to become commonly entangled in trammel nets. Rare reports of such occurrences still existed in the recent past in Sardinia.

Comment
More detailed research on the interactions between coastal cetacean species and fisheries should be carried out. Although cetacean mortality in this fishery seems relatively minor, fishermen's complaints and animosity towards cetaceans is common along the Italian coast, and may lead to directed mortality.

(H) Italian surface large pelagic driftnet fishery
The description of the fishery below refers mainly to the period before it was banned by the Italian Government on 30 July 1990. In 1991 the ban was lifted (see Discussion) and Aguilar and Silvani (1994) report that some 600–700 boats operate throughout the Mediterranean using illegal (>2.5km) nets. Most of the pre-ban information given below is thus probably still valid, although details are difficult to obtain.

Ports/operation area
The fishery took place out of more than 101 ports located along the western Italian coast (Tyrrhenian Sea), the coasts of Sicily and the Ionian coast of Calabria (Fig. 6). Our best estimate is that 20% of the fleet operated in all Mediterranean regions, 70% in Italian Seas (both coastal and offshore) and 10% only in Italian coastal areas.

Target species
Swordfish (*Xiphias gladius*) and albacore (*Thunnus alalunga*) are the targetted species.

Vessels and crew
The total number of vessels was about 800 just before the ban and is estimated now at about 650 vessels. The fleet was extremely heterogeneous, with no 'typical' vessel. All but one steel-hulled vessel had wooden hulls. Only about 40 smaller coastal boats lacked a cabin. About 5% of the vessels were less than 5m long, 15% were between 6 and

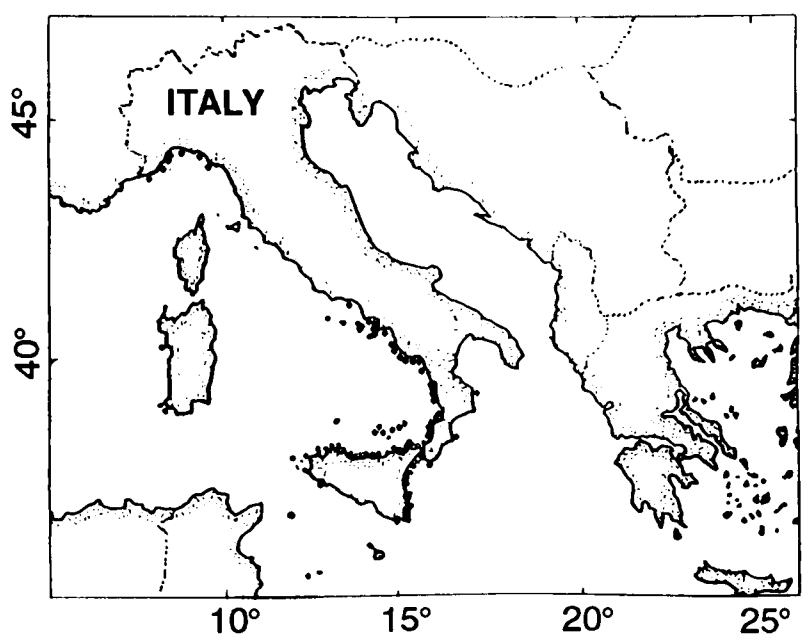

Fig. 6. Position of the Italian harbours in which driftnet boats are located.

12m, 65% were between 12 and 20m whilst the remaining 15% exceeded 20m. Most boats were between 20 and 40 GRT (range: 2–60 GRT). Crew number ranged from 2 to 6, almost all of whom were Italian (about 1% Tunisians). The fish capacity of each boat varied between 0.3 and 80 tonnes (modal value unknown). Half of the boats were not equipped with refrigeration facilities and landed the catch fresh, 40% put the catch on ice or in non-freezing refrigerators while 10% froze the fish on board.

Gear

Most of the nets were of nylon or polyamide twisted polyfilament. A few nylon monofilament nets were in use in the coastal fisheries. Mesh size (stretched) varied from 16–52cm, with most swordfish nets being from 36–42cm and albacore nets from 16–20cm. Twine size was between 48 and 60. Panel length ranged from 2 to 22.5km. Most nets were about 15km long, and 70–80 meshes (28–32m) deep. Each vessel carried only one panel. In spring some of the vessels operating in the southern area carried a larger mesh panel for swordfish and a smaller mesh panel for albacore. Driftnets were equipped with small floats, 10–15cm long and 5–6cm wide. Float spacing was variable, depending on mesh and twine size, and panel depth. Beacons were heterogeneous and largely makeshift, consisting of flashing lights, oil lamps, orange plastic inflatable buoys or black plastic flags (made of trashbags); different beacon types were often used on the same gear. Artisanal 3-wheel hydraulic hauling gear was commonly used, normally one per vessel (rarely two). In historic times driftnets were made of natural fibre (originally linen and later hemp and cotton). Synthetic fibres were introduced after 1950.

Operations

Fishing normally occurred between April and September in coastal and offshore waters (100 to >3,000m) and usually in deep (>1,000m) waters. Fishermen generally attended their nets during the night. Trip lengths ranged from 1 day in the coastal fishery to 2–5 days in the Italian offshore fishery or 8–20 days in further Mediterranean regions. The number of trips per vessel varied widely between 20 and 100 trips per year. Driftnets were usually set in a zig-zag pattern, beginning at 1700–1800hrs and ending at 2000–2100hrs. The soaking time was 3–4 hours. Nets were retrieved between 0100–0300 and 0700hrs or later. Catch size varied greatly, depending on geographic area, oceanographic conditions, weather conditions and moon phase; the mean catch was 96kg of commercial species per set.

Economics and history

The Italian driftnet fishery has a very ancient tradition, dating back to at least 177 B.C. (Sisci, 1988). Systematic research on this subject was initiated only in 1984 (Di Natale *et al.*, 1987); but between 1987 and 1990 the fleet increased by about 57% in the studied areas (Di Natale, 1990c). More recent data are reported by Di Natale *et al.* (1992). There is no official record of swordfish landings separated by gear (long line, driftnet or harpoon). Fish is sold fresh and frozen in the domestic market. A few tons are smoked and packed. Processors are capillarily distributed in most landing locations and in all major inland cities. Ex-vessel price ranged from 6.50 to 19.50 US$/kg, for a total ex-vessel value range of 30,000–300,000 US$/year.

Total landings

About 8,000 tonnes of swordfish and 1,700 tonnes of albacore (our unofficial estimate) are landed annually. Other commercial species comprise up to 1,800 tonnes.

Effort data

Catch per unit effort (CPUE) data exist only for 1985 and 1986 (C = catches in kg, E = (net length/100) × number of days fished). In 1985 the CPUEs were 1.04kg (swordfish) and 6.76kg (albacore). In 1986 they were 0.90kg (swordfish), 3.05kg (albacore).

Interaction with cetaceans

Several cetacean species are known or suspected to have been entangled in the Italian driftnets. These include: fin, minke, sperm, Cuvier's beaked and long-finned pilot whales and Risso's, bottlenose and striped dolphins. The many unidentified specimens on record may include the rarer common and rough-toothed dolphins. No official data on cetacean bycatches in driftnets exist. Although the stranding record provides some information, it heavily underestimates incidental mortality (Notarbartolo-di-Sciara, 1990). A conservative estimate of 10 cetaceans accidentally caught per vessel per season would mean a total annual bycatch in the Italian driftnet fishery of more than 8,000 cetacean specimens (mostly striped dolphins, but including at least 30 sperm whales). This estimate may be reduced in the light of more recent assessments based on observers data (Di Natale *et al.*, 1992). The uncertainty of the bycatch data and the lack of information on the sizes of the populations involved, makes it impossible to assess the impact of driftnetting on the local cetacean populations.

Cetaceans observed are usually entangled in the upper third of the net. Most cases involved passive entanglements although a few records of active entanglements (involving adult sperm whales entangled while attempting the rescue of a calf) have been reported. Cetacean removal techniques depended mostly on their size: the smaller species were brought on board to facilitate operations, and the tail and flippers were often cut to speed up removal. The larger whales were left entangled, dead or alive, and the entangling portion of the net was cut off from the main net. Very few specimens were disentangled and released alive. Most of the smaller specimens were found drowned, or were deliberately killed if found alive. Adults of the larger species (e.g. sperm whales) are always alive when the net is retrieved.

Cetaceans have been protected in Italian waters since 1980. Marketing of cetacean products is unlawful in Italy and thus the carcasses are generally discarded by the fishermen. However, occasionally dolphin meat is used as longline bait and there is a limited illegal market for dried dolphin fillet (*musciame*), considered a delicacy in Liguria and Tuscany. In 1989, three research projects were funded by the Ministry of Merchant Marine aimed at reducing cetacean bycatches. This included an observer programme and gear modification experiments. A 24 hour nationwide answering service, maintained by the Centro Studi Cetacei with the support of Europ Assistance, has been active since 1986 and has resulted in the rescue of several specimens: 8 sperm whales (33% of the total reported), 4 pilot whales and 3 striped dolphins were found entangled, rescued and released alive at sea by volunteers between 1986 and 1989 (Notarbartolo-di-Sciara, 1990).

Although there are no reports of monk seal

entanglement in pelagic driftnets in Italian waters, Italian vessels have been seen fishing in Greek waters, where the monk seals barely survive (Aguilar and Silvani, 1994).

Comment
The current illegal fishery is a major cause for concern and enforcement is poor (see Discussion). However, an exception is the Sanctuary in the Ligurian Sea (see *Comment* under (D) above), where enforcement is strict and large scale driftnets banned.

(I) Italian surface small pelagic driftnet fishery

Ports/operation area
Vessels operate from ports all along the coast and operate in adjacent coastal waters.

Target species
Bullet tuna (*Auxis rochei*), little tuna (*Euthynnus alletteratus*), skipjack tuna (*Katsuwonus pelamis*), Atlantic bonito (*Sarda sarda*), chub mackerel (*Scomber japonicus*) and Atlantic mackerel (*Scomber scombrus*) are the target species.

Vessels and crew
This is an opportunistic small-scale fishery, for which there are no official data. The total number of vessels is unknown. The fleet is heterogeneous; most boats have wooden hulls, ranging in length from 4 to 14m. Crews comprise 2–3 Italian nationals.

Gear
About 90% of the nets are made of nylon or polyamide polyfilament; the remainder are nylon monofilament. Stretched mesh size ranges between 4 and 9cm. Panel length ranges from 0.2–1.5km and the depth is 3–8m. Each vessel carries only one panel. Beacons are makeshift recycled plastic bottles and containers, and pieces of styrofoam. Most nets are retrieved by hand; a few boats use artisanal 1-wheel hydraulic gear.

Operations
Trips are usually made daily, but vary considerably in length depending on the abundance and concentration of the target species. Nets are set mostly over the continental shelf. No other details are known.

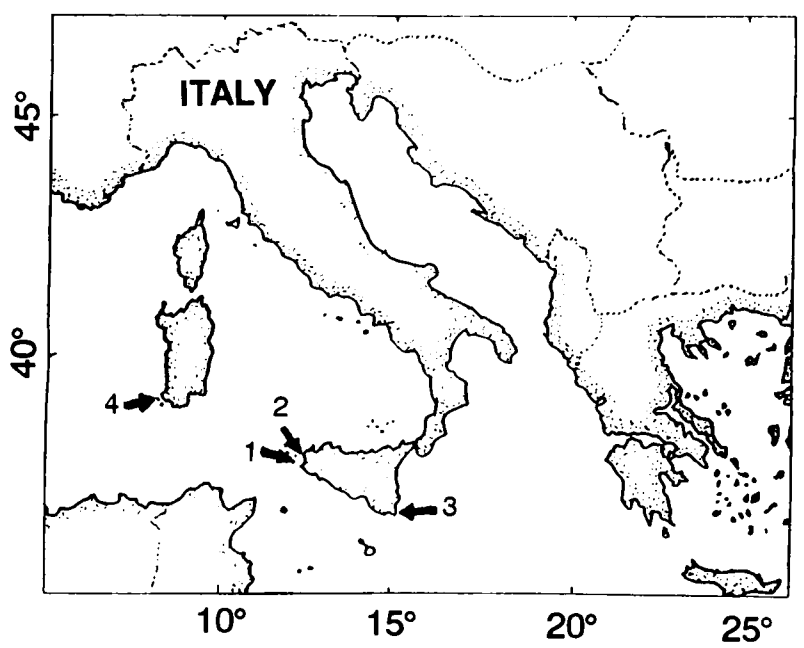

Fig. 7. Position of the Italian traditional tuna traps. (1) Favignana; (2) San Cusumano; (3) Porto Palo; (4) Carloforte.

Economics and history
With the exception of a small amount of mackerels canned in Southern Italy, fish is landed and sold fresh. The market is strictly domestic and processors are evenly spread along the coast and the landing locations. Ex-vessel prices range from 2 to 6 US$/kg. There are no catch or effort data.

Interaction with cetaceans
No official statistics exist and no scientific research or organised monitoring has ever been carried out. However, some species are known to have been involved including Risso's and bottlenose dolphins. The total number of incidental captures is thought to be low and the impact of the fishery on cetacean populations minimal. Entangled specimens are normally released alive at sea. In Liguria, Tuscany and off the smaller islands cetaceans are killed and filleted for the black marketing of *musciame*.

Discussion
Although we believe incidental mortality is probably low, a systematic investigation of this fishery should be carried out.

(J) Italian traditional tuna trap fishery

Ports/operation area
The main ports are San Cusumano, Favignana, Porto Palo di Capo Passero (all in Sicily) and Carloforte in Sardinia (Fig. 7) and operations are coastal and localised.

Target species
The bluefin tuna (*Thunnus thynnus*) is the target species.

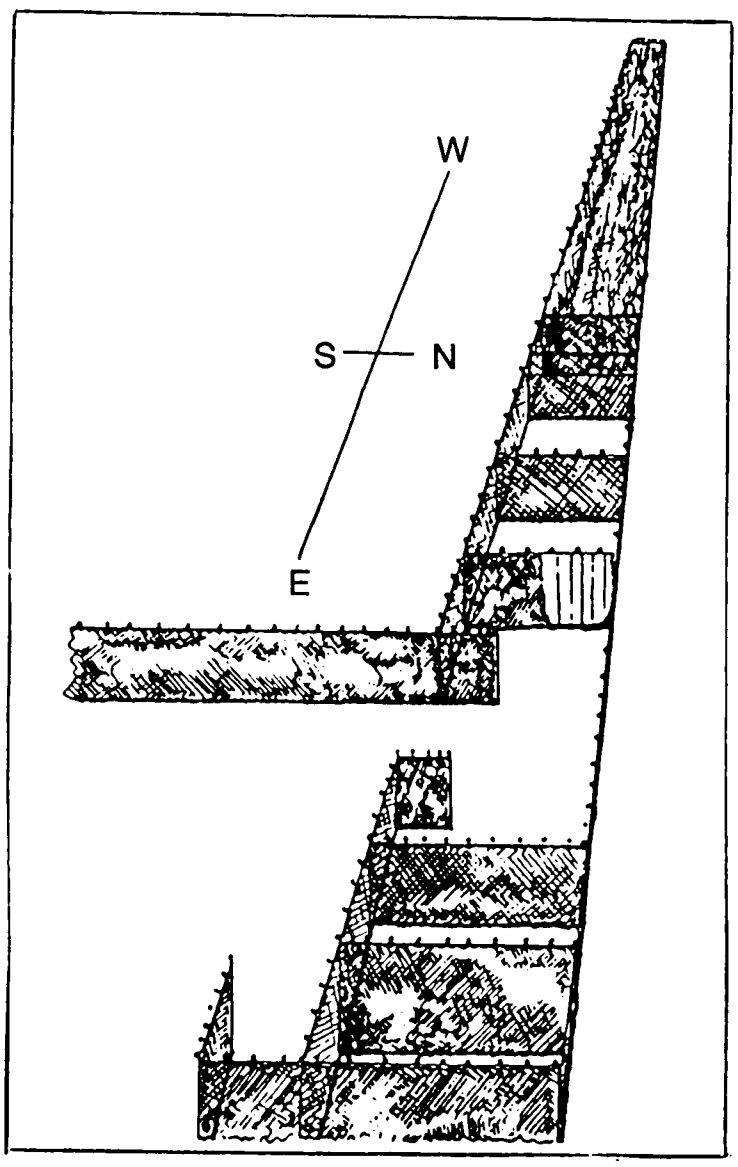

Fig. 8. Sicilian traditional trap (from: Sarà, 1983).

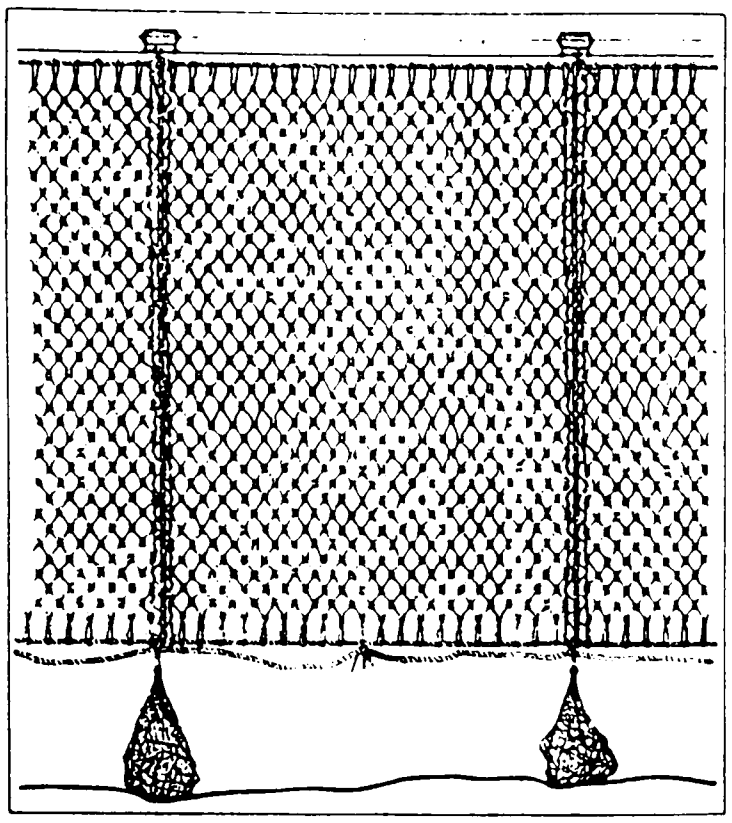

Fig. 9. Hanging scheme of the tuna trap in Favignana, Sicily (from: Sarà, 1983).

Vessels and crew
This is a land-based fishery using a number of support vessels towed in place by a motorboat. The boats used to carry the net and for all operations are typically made of wood. Crew numbers vary from 30 to 70. Fishermen are all Italian.

Gear
Nets are made of nylon or polyfilament polyamide with a stretched mesh size of from 20 to 120cm (Figs 8–10). Panel lengths and depths vary from trap to trap.

Operations
Tuna traps are usually set in May and retrieved at the end of June, in coastal waters shallower than 50m. The nets span from the sea surface to the bottom and are anchored in place. Fishing 'events' occur between 2–9 times per season, depending on the number of tunas entrapped. Each operation is concluded by the killing (*mattanza*) of all tunas entrapped in the last part of the trap, called the 'death chamber'.

Economics and history
This is one of the most typical Mediterranean fisheries and is of ancient origin. Up until the end of the 19th Century it was quite widespread along the coast of the Italian mainland and islands (Sarà, 1983; Consolo, 1987). Today several environmental and socioeconomic factors have strongly reduced its use and its activity is government supported as a national cultural heritage. Fish is sold canned, frozen (fillets for Japan), salted (ovaries, fillets and entrails) or fresh (for local consumption). The market is partly domestic and partly foreign (mostly Japan), but the relative proportions are unknown. Processing factories are located in the immediate vicinity of the tuna traps. Ex-trap price is about 4.5 US$/kg.

Total landings
About 250 tonnes/year of bluefin tuna and 1 tonne/year of swordfish are caught. The total catch has been increasing since 1985 after a serious decline in the previous decade.

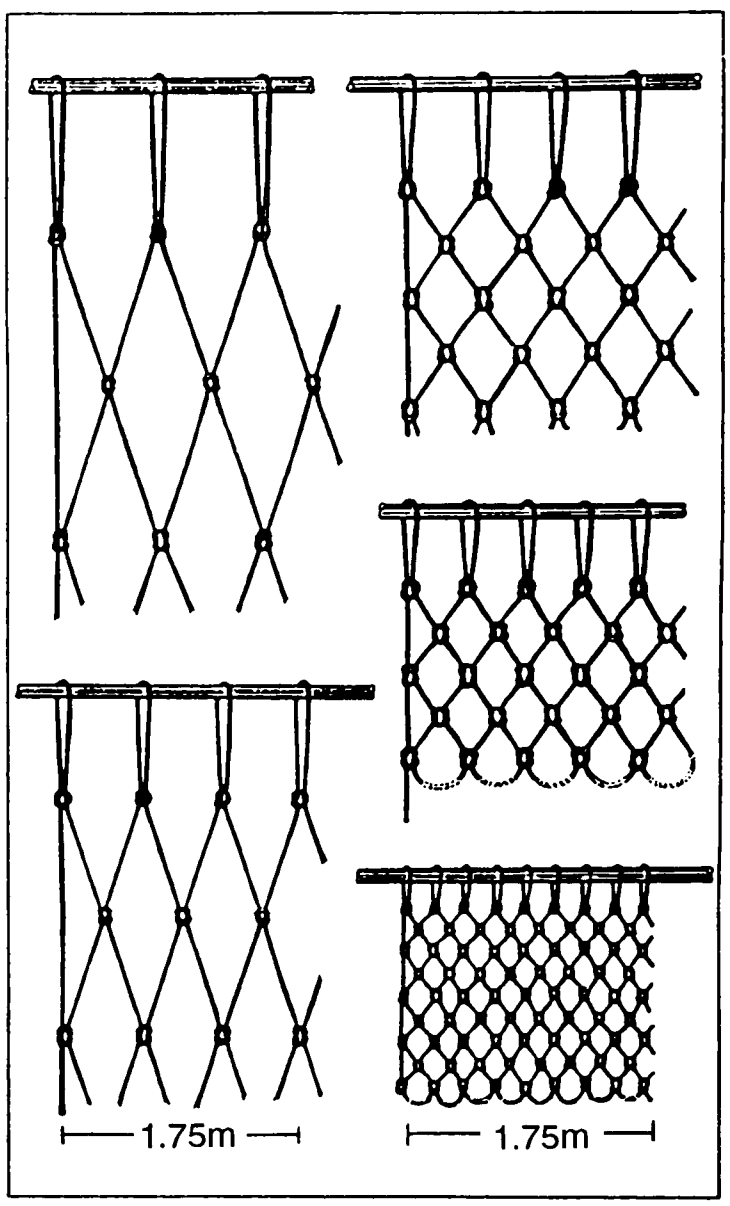

Fig. 10. Various meshes used in the tuna trap in Favignana, Sicily. The reference measure (*una canna*) is 1.75m (from: Sarà, 1983).

Effort data
1990 CPUE indices are available only for the two most important tuna traps (Favignana and San Cusumano). The total CPUE = 14,736, bluefin tuna = 14,694; swordfish = 42.2) where the catch is in kg and the effort is the total number of *mattanze*).

Interaction with cetaceans
One killer whale was captured in 1972 near Scopello, Sicily (Di Natale and Mangano, 1983a). Bottlenose dolphins are known to occur in the bycatch, although they are never reported. All cetaceans are alive when trapped and killed afterwards. The impact on cetacean populations is supposedly negligible.

(K) Maltese surface pelagic driftnet fishery

Ports/operation area
The two ports are Valletta and Marsaxlokk (Fig. 11) and operations occur throughout the Maltese Archipelago.

Target species
The swordfish (*Xiphias gladius*) is the target species.

Vessels and crew
In 1990, five wooden cabin cruisers, 12 to 16m long, crewed by 3–7 Maltese fishermen operated. We were unable to obtain more recent information.

Gear
Nets of 5–12km made of either nylon polyfilament or monofilament are used. They are equipped with radio transmitters as beacons. Mesh size (stretched) ranges from 20 to 42cm. A net-hauler is available on board.

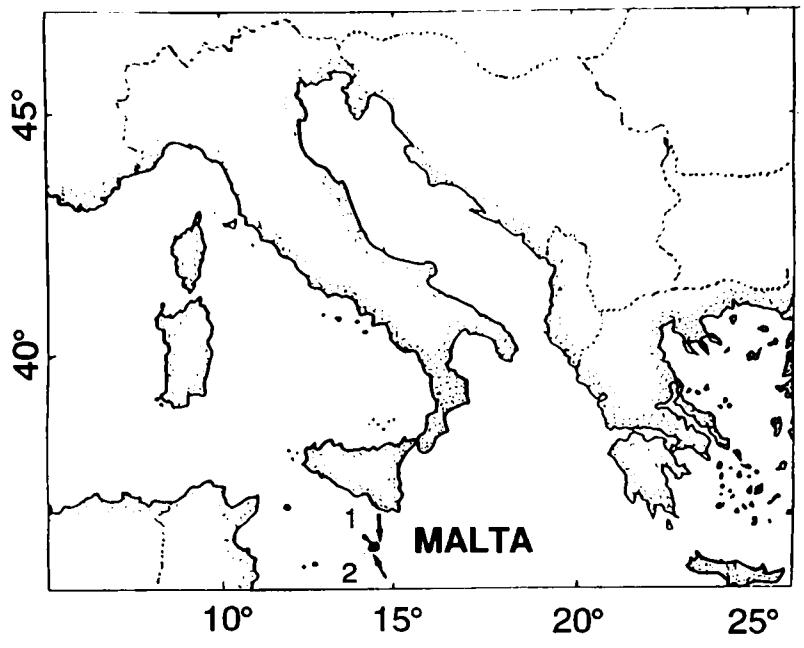

Fig. 11. Position of the Maltese harbours in which driftnet boats are located. (1) Valletta; (2) Marsaxlokk.

Operations
Fishing occurs in summer in water deeper than 200m. Trips last for 1–2 days. Nets are set at 1500–1900hrs and retrieved at 0200–0600hrs. The soaking time is thus 7–16 hours.

Economics and history
This fishery, which began in 1989, is likely to increase in the future. Fish is sold fresh on the domestic market. The 1990 ex-vessel price was about 6.20 US$/kg. No information on catch or effort is available.

Interaction with cetaceans
There are no official data but common, bottlenose and striped dolphins are potential bycatch species. Dolphins caught by other methods (harpoon and gun) are used as bait for shark longline fisheries.

Discussion
Information was gathered from three different sources, two of which refer to 1989 and one to 1990. It seems likely that some foreign boats may have reflagged with Maltese flags, with the purpose of creating a local swordfish industry in 1991, but we have been unable to obtain more recent information on this.

(L) Moroccan Mediterranean surface pelagic driftnet fishery

Ports/operation area
Aguilar and Silvani (1994) report that the main ports are Cabo de Agua, Nador, Al-Hoceima and Tangier. Operations occur in coastal waters and the Alboran Sea (Fig. 12).

Target species
Tuna-like fish species are targetted, as well as swordfish.

Vessel and crew
According to Anon. (1990), the fleet consisted of 30–40 wooden boats, all crewed by Moroccan and Spanish fishermen. More recently, Aguilar and Silvani (1994) stated that at least 200 vessels operate in the Alboran Sea for swordfish using variable length nets, many over 2.5km. Little operational or catch data are available. The fleet appears to have stabilised at this number since 1992.

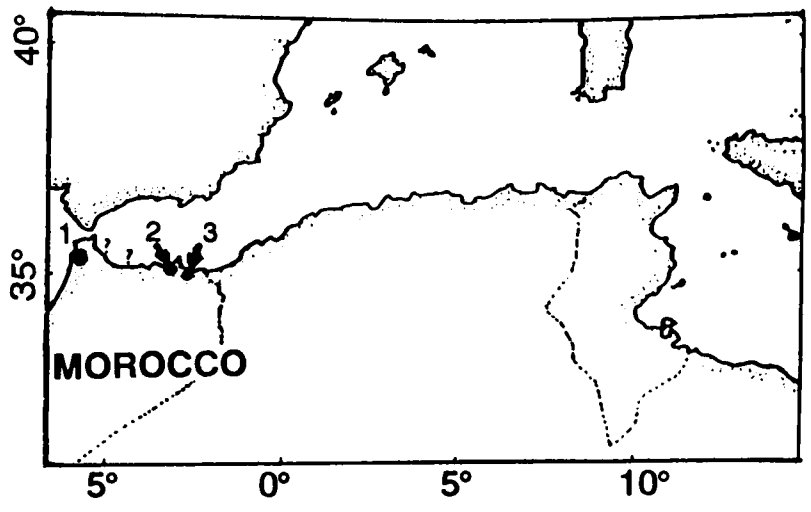

Fig. 12. Area of possible location of Moroccan Mediterranean driftnet boats. (1) Tangier; (2) Al-Hoceima; (3) Nador.

Interaction with marine mammals
No official data exist but it is thought that many stranded dolphins have died as a result of fishery interactions, including striped, bottlenose and common dolphins; monk seals are also found in the area (Aguilar and Silvani, 1994).

Discussion
A scientific programme to monitor the activities of this fleet was apparently established (Anon., 1990) but no regulations exist and no data have been published to our knowledge.

(M) Spanish Mediterranean gillnet fishery

Ports/operation area
Operations occur all along the Spanish Mediterranean mainland coast and on the islands from numerous ports, and extends over the continental shelf.

Target species
A large variety of benthic species are targetted in this fishery.

Other information
Apart from the fact that Spanish fishermen are involved, there is very little information on this fishery. The catch is largely sold fresh on the domestic market although a small part is exported to France.

Interaction with cetaceans
Anecdotal reports concerning 1 common dolphin and 1 bottlenose dolphin are given by Duguy *et al.* (1983). Cetaceans are protected under Spanish law.

Discussion
Although this fishery activity is rather widespread along the Spanish Mediterranean coast, there is a paucity of information available. This should be remedied.

(N) Spanish Mediterranean surface pelagic driftnet fishery
In October 1990, the Spanish government banned the use of swordfish driftnets. Thus the fishery described below is now illegal but still continues to some extent (Aguilar and Silvani, 1994).

Ports/operation area
The boats are based in Algeciras and Tarifa and fish in that area and the Alboran Sea (Fig. 13).

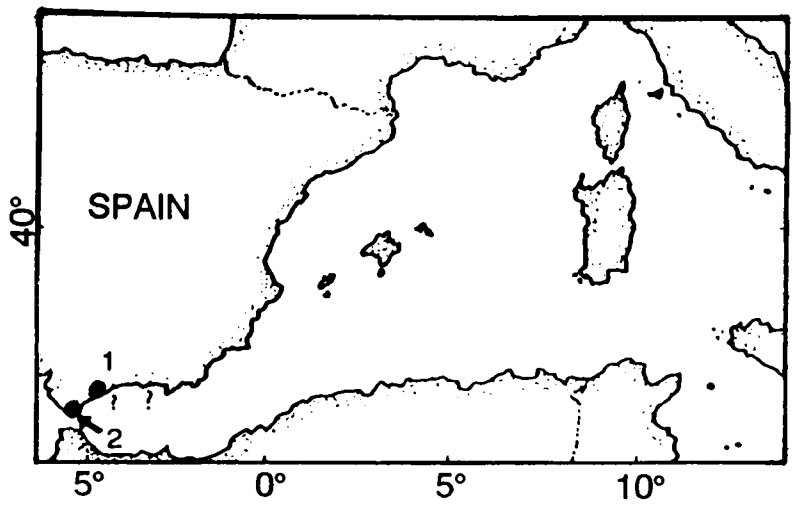

Fig. 13. Area of possible location of Spanish Mediterranean driftnet boats. (1) Algeciras; (2) Tarifa.

Target species
Swordfish (*Xiphias gladius*) and tuna-like fishes are targetted.

Vessels and crew
About 30 wooden boats operate most of which are 15m long. The crew comprises 4–5 Spanish fishermen. Spanish driftnet boats, legally operating in the Atlantic, encroach illegally into the Mediterranean Sea on an irregular basis. The number of vessels appears to be slowly decreasing.

Gear
Little data exist but panels are up to 5km long. Each vessel carries only one panel.

Operations
Operations take place from July to September.

Economics and history
Fish is sold mostly fresh on the domestic market. Refrigerated or frozen fish is exported to France and Italy. Ex-vessel prices range between 5 and 10 US$/kg.

Interaction with cetaceans
Only bottlenose dolphin bycatches are reported in the literature (Duguy *et al.*, 1983), but many more species are suspected to be involved. As a measure to reduce bycatches, observers had occasionally been placed on board driftnet vessels by the Instituto Español de Oceanografia (Anon., 1990).

Discussion
Spanish pelagic driftnetting in the Mediterranean is not considered in official Spanish reports, since these fishermen are considered 'pirates'.

(O) Tunisian gillnet fishery

Ports/operation area
Vessels operate from all along the coast and throughout Tunisian coastal waters.

Target species
A large variety of benthic species are targetted.

Vessels and crew
The total number of vessels is unknown. The fleet is apparently heterogeneous, but all boats have a wooden hull. Crews are all Tunisian.

Gear
The nets are made of polyamide monofilament and the panel length is about 100m. Each vessel carries 20–30 panels. Stretched mesh sizes are reported to be between 44–250mm. Little other operational information exists.

Interaction with cetaceans
One bottlenose dolphin was reported entangled in November 1980 in a trammel net north of Tunis (Ktari-Chakroun, 1981). No other information is available.

Discussion
There is no monitoring of this fishery. Gillnetting is widespread among Tunisian fishermen and interactions with cetaceans, particularly bottlenose dolphins are considered common. Local fishermen see dolphins as competitors and try to kill them when possible (K. Ben Mustapha, pers. comm.). In recent years large mesh driftnetting appears to have developed rapidly. It is reported that the Government is intending to introduce a total ban, largely to protect cetaceans and the monk seal.

(P) Tunisian traditional tuna trap fishery

Port/operation area
The fishery operates out of Sidi Daoud (Fig. 14) and occurs in the Gulf of Tunis.

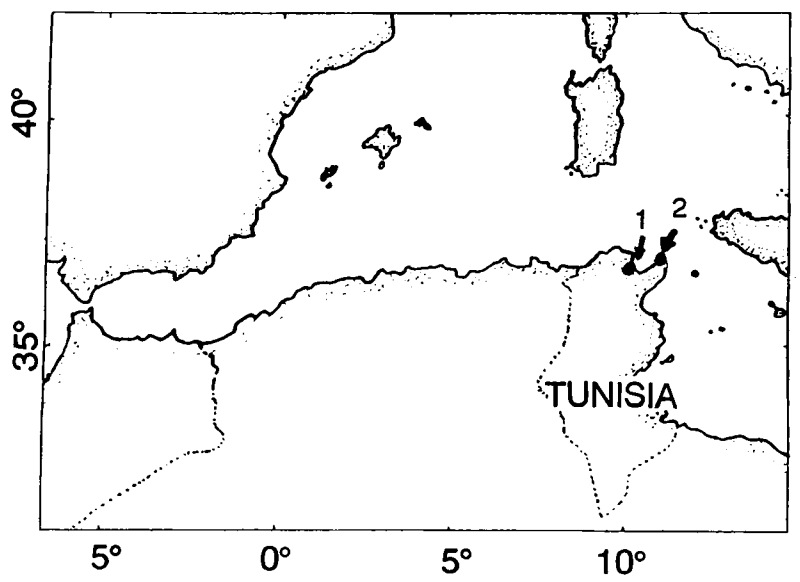

Fig. 14. Location of the Tunisian traditional tuna trap. (1) Tunis; (2) Sidi Daoud.

Target species
The bluefin tuna (*Thunnus thynnus*) is the target species.

Vessels and crew
This is a land-based operation using a number of support vessels, all crewed by Tunisian fishermen. The net is towed in place by a motorboat.

Economics and history
The only available information is that 83 tonnes of tuna were landed in 1988 (Anon., 1990). No official monitoring of the fishery exists.

Interaction with cetaceans
A minke whale and a common dolphin were captured, respectively, in May 1976 and in June 1980 (Ktari-Chakroun, 1980; 1981). Both animals, alive when trapped, were killed by the fishermen.

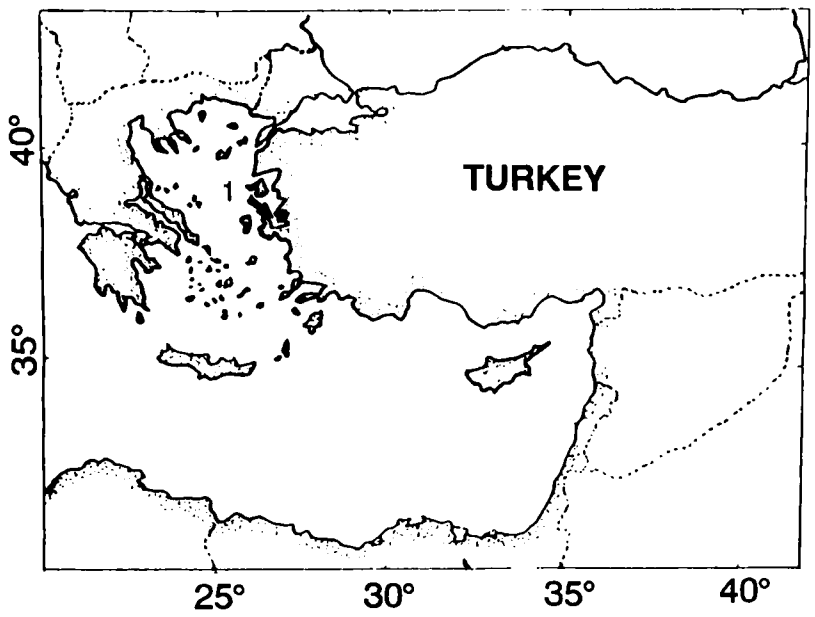

Fig. 15. Position of the Turkish area in which driftnet boats are located. (1) Izmir.

(Q) Turkish surface pelagic driftnet fishery

Ports/operation area
Vessels operate in the eastern Aegean Sea from Izmir and the Aegean coast south of it (Fig. 15).

Target species
The swordfish (*Xiphias gladius*) is the target species.

Vessels and crew
The fleet consists of 14 wooden boats, one about 16m long and the rest 7–8m long. The boats are crewed by 2–4 Turkish fishermen. In 1990 there was an Italian instructor.

Gear
The nets used are made of nylon polyfilament, with a stretched mesh size of 42cm. The smaller boats use a net 2–3km long and 28m deep whilst the larger boat uses a net 10km long and 30m deep. Only the largest vessel has hydraulic hauling gear.

Operations
The smaller boats make 50–70 trips per year, whereas the larger vessel made only 12 trips in 1990. Nets are set at 1800–1900hrs and retrieved at 0200–0400hrs. The fishing season lasts from February to June. The fishery is strongly limited by the typical summer meteorological conditions of the area (*meltemi* winds).

Economics and history
The Turkish swordfish driftnet fishery began in the mid 1980s (exact date unknown) and has increased since technology was imported from Italy in the late 1980s. Fish are sold fresh on the domestic market and 557 tonnes were landed in 1988. The fishery appears to have stabilised in the 1990s, but officially the Government does not admit that driftnetting occurs.

Interaction with cetaceans
There are no official reports but it is thought that bottlenose, striped and common dolphins may be involved. No cetaceans were reportedly caught by the largest vessel during the 1990 fishing season. We have been unable to obtain more recent information.

(R) Turkish gillnet fishery

Ports/operation area
The fishery operates in the eastern Aegean Sea.

Target species
Benthic species are targetted.

Available information
An unknown number of wooden boats, manned by Turkish fishermen are involved. The nets used are made of polyamide polyfilament, 365–550m long and 1–3.65m deep. The stretched mesh size is 20–300mm. The fish are landed fresh.

Interactions with marine mammals
No official data exist but smaller species (bottlenose, striped and common dolphins) are suspected to be incidentally taken. The endangered monk seal is known to be accidentally killed by coastal trammel nets.

DISCUSSION AND RECOMMENDATIONS

Tuna traps
This fishery activity is now only a remnant of the past, and has a traditional rather than an economical relevance. Its significance, as far as cetacean mortality is concerned, is negligible.

Coastal bottom gillnets
This fishery is extremely widespread throughout the Mediterranean and may result in mortality of coastal species such as the bottlenose dolphin and the monk seal. Given the perilous state of the monk seal (Durant and Harwood, 1992), any mortality is serious but the fishery probably has only a small impact, if any, on the bottlenose dolphins. However, given its widespread use, closer monitoring of the situation is recommended. In addition, both bottlenose dolphins and monk seals in the Mediterranean are known to take fish from the bottom setnets and damage gear; this induces human hostility towards these species, which may lead to directed mortality (Anon., 1988b).

Pelagic driftnets
There are two principal categories of driftnets in the Mediterranean: driftnets used to catch large pelagic scombriform fishes (swordfish and albacore) and driftnets used to catch smaller pelagic schooling fishes. It appears that only the former has a significant impact on cetaceans, mostly because of the great lengths of the nets (Di Natale, 1990b; 1992; Di Natale *et al.*, 1993); pelagic driftnetting has been responsible for a large number of cetacean deaths throughout the Mediterranean (Notarbartolo-di-Sciara, 1990; IWC, 1992). Of all cetacean specimens stranded in Italy between 1986 and 1988, for which the cause of death could be established, 83% had died in driftnets (Cagnolaro and Notarbartolo-di-Sciara, 1992).

Until July 1990, the largest pelagic driftnet fleet in the Mediterranean was the Italian fleet, reaching about 90% of the total (by number of vessels, Fig. 16). Although the situation changed dramatically after pelagic driftnetting for swordfish and albacore was outlawed in Italy in 1990 (Fig. 17), since then it has been confused by several 'bans' and reallowances, established by both the Government and the Administrative Courts; the situation now seems to be even

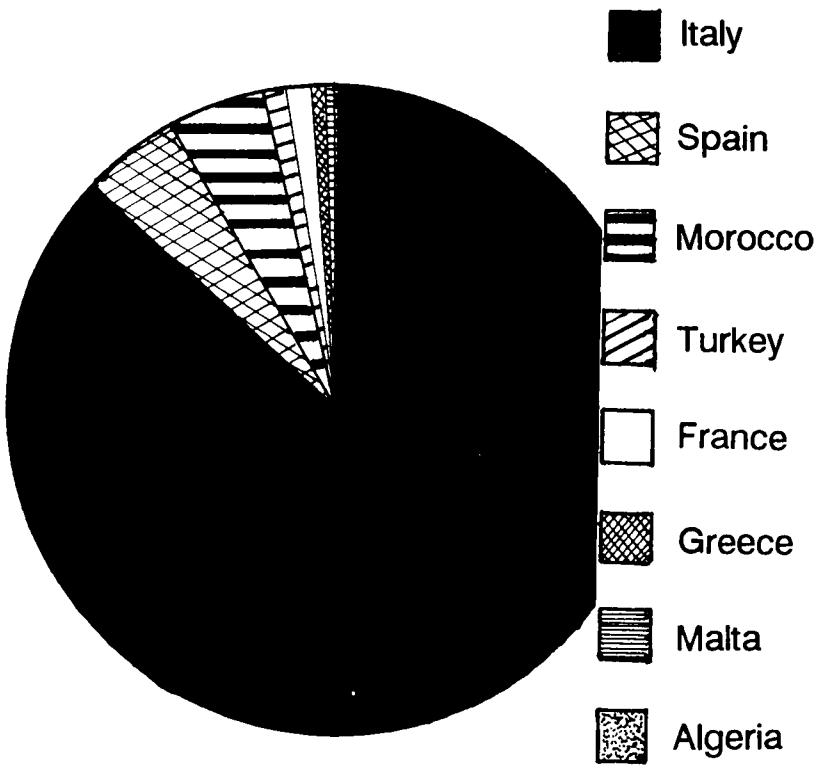

Fig. 16. Mediterranean pelagic large driftnet fleets (by number of vessels).

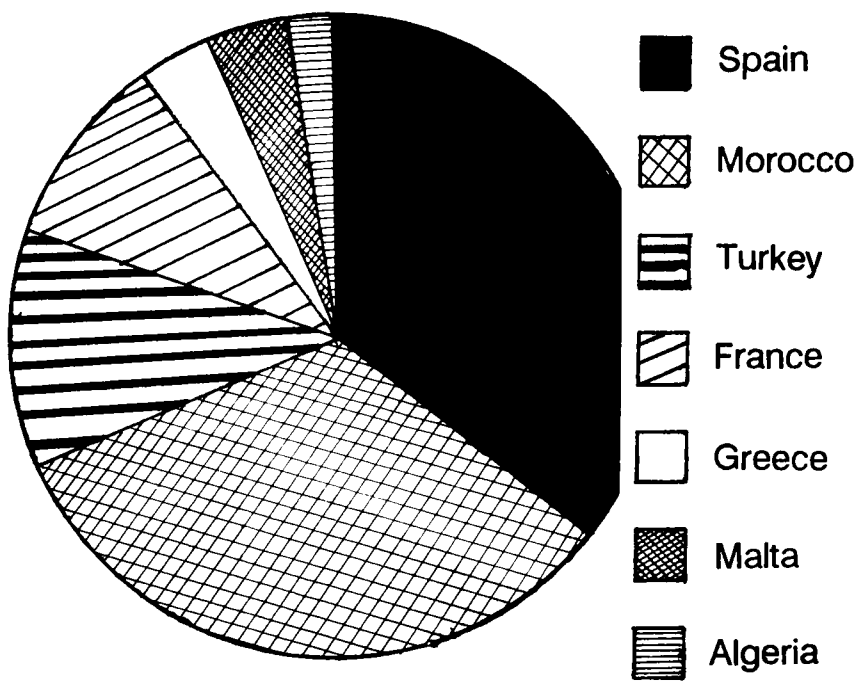

Fig. 17. Mediterranean pelagic driftnet fleets (by number of vessels, excluding the Italian fleet).

worse than before 1990 (Aguilar and Silvani, 1994). The collection of information on this subject is often very difficult for political reasons. In particular the IWC Scientific Committee has drawn attention to the situation of the striped dolphin. IWC (1994) expressed concern that incidental catches of this species were unsustainable. This was followed by a series of recommendations for research and management action (IWC, 1992, p. 207; IWC, 1995, Item 15.5). We reiterate those recommendations.

If the problem of bycatches is to be properly addressed, research is needed:

(1) to obtain reliable estimates of bycatches for all fisheries in the region;
(2) to obtain reliable estimates of cetacean population size;
(3) to better understand the stock structure of cetaceans in the Mediterranean.

It is clear that urgent action is required, in terms of enforcing existing regulations banning the use of driftnets >2.5km, carrying out the Action Plan for Cetaceans established by the 1991 meeting of the Barcelona Convention in Cairo and perhaps, most importantly, adopting a legally binding approach to the conservation of cetaceans in the Mediterranean under the auspices of the Convention on the Conservation of Migratory Species of Wild Animals. A draft agreement is under discussion at present (November 1994).

ACKNOWLEDGEMENTS

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Bycatch and Bycatch Reduction of the Harbour Porpoise (*Phocoena phocoena*) in Danish Waters

Nicholas Lowry

DIFTA, North Sea Centre, PO Box 59, 9850 Hirtshals, Denmark

and Jonas Teilmann

Danbiu ApS, Toragevej 2, 2920 Charlottenlund, Denmark

ABSTRACT

The harbour porpoise (*Phocoena phocoena*) is the only cetacean incidentally caught in significant numbers by the Danish fishing fleet and there is some concern that the populations in Danish waters may be in decline. The main catches are in the extensive fleet of vessels fishing dermersal gillnets. Recently, this bycatch has been quantified by a rough estimate of up to 7,000 bycaught harbour porpoises and public and political awareness of the issue is increasing. This paper reviews the Danish passive gear fishery and the level of the bycatch of harbour porpoises. Methods with potential for reducing this bycatch are briefly discussed.

KEYWORDS: NORTH ATLANTIC; BALTIC; INCIDENTAL; CAPTURE; FISHERIES; HARBOUR PORPOISE.

INTRODUCTION

The harbour porpoise (*Phocoena phocoena*) is the only cetacean that is known to be resident in Danish waters (e.g. Jensen, 1946; Clausen and Kinze, 1993). This primarily coastal species has a circumpolar distribution in the Northern Hemisphere from the Cape Verde Islands at 15°N to Thule at 78°N (Gaskin, 1984; personal observation).

Several studies have considered the status and distribution of the harbour porpoise in Danish and adjacent waters and concluded that its numbers may have declined and its distribution narrowed (e.g. Andersen, 1982; Smeenk, 1987; Clausen and Andersen, 1988). These assumptions are mostly based on information from historical catch statistics (e.g. the extensive Danish fishery up to the 2nd World War is reviewed by Kinze, In press), and scattered information from strandings and incidental sightings.

In recent years there has been increasing international interest and concern about the bycatch of small cetaceans in fishing gear (e.g. IWC, 1994a). In northern Europe, the harbour porpoise is the species most frequently caught in fishing gear and concern about the problems this may cause for the populations have been widely expressed (e.g. IWC, 1992; 1994a).

Few studies have tried to assess the magnitude of the bycatch in fishing gear, or to obtain estimates of species abundance – two factors critical to the management of the harbour porpoise. Some preliminary work has been done to attempt to find solutions to entanglements in fishing gear, but so far no commercially useful solutions have been developed.

This paper presents current information on the Danish gillnet fishery and the bycatch in fishing gear in inner Danish waters and the North Sea. The final section briefly reviews possible ways of reducing bycatches.

SUMMARY OF DANISH PASSIVE GEAR FISHERIES

This section summarises the situation of Danish fisheries in the 1990s. Information for previous years is given in Coviconsult (1988), Flintegård (1986) and Kinze (1990).

Gillnet fishery

Denmark has the largest gillnet fleet of any member state of the European Community (EC). In 1992, a total of 1,549 vessels were registered as prosecuting gillnet fisheries and 3,198 people were directly employed. The distribution of these vessels by area and as a proportion of the total number of vessels in the fleet is shown in Fig. 1. The most important species for gillnetters are (by value) cod, plaice, sole, turbot, hake, pollack and lumpsucker, with at least 30 other species of fish represented in the catches. The relative tonnage of the most important species by area is given in Table 1. The total value of the catch is at least 600 million Danish kroner (about $US100,000,000).

Gear and fishing strategies

In all gillnet fishing, the nets are constructed individually and tied together into 'strings' or 'fleets', each end of which is marked by an anchor and a buoy (IWC, 1994b). The number of nets carried by a boat and the number of nets in a string varies according to the size of the boat, the fishery, and how the net is hauled. There are approximately 50–80 nets for a vessel of 10 BRT (1 man), 100–200 nets for a vessel of 10–15 BRT (2 men) and 350–400 nets for a vessel of 20 BRT (4–5 men). The total length of the nets set by Danish gillnetters in the North Sea each day is about 5,000–10,000km. Strings vary in size depending on the fishery, but are typically 5–15 nets. In the Danish fishery, there are large numbers of both small boats operating in coastal waters that make day trips and of larger boats that work further offshore and make trips of 5 to 14 days. Operational strategies are variable depending on the particular fishery and the prevailing conditions during the day. Typically, it involves setting the net, leaving it overnight and returning the next day to haul and clean the net before resetting. This lets the net fish over two changes of tide (or two day/night changes in the Baltic where there is little tide) which is when the greatest catches occur. The exceptions to this are nets for turbot, which are left for 2–8 days before hauling, and the sole fishery, in which the soak time is often only 6 hours. Soak times are shorter during periods of high water temperature or where there are

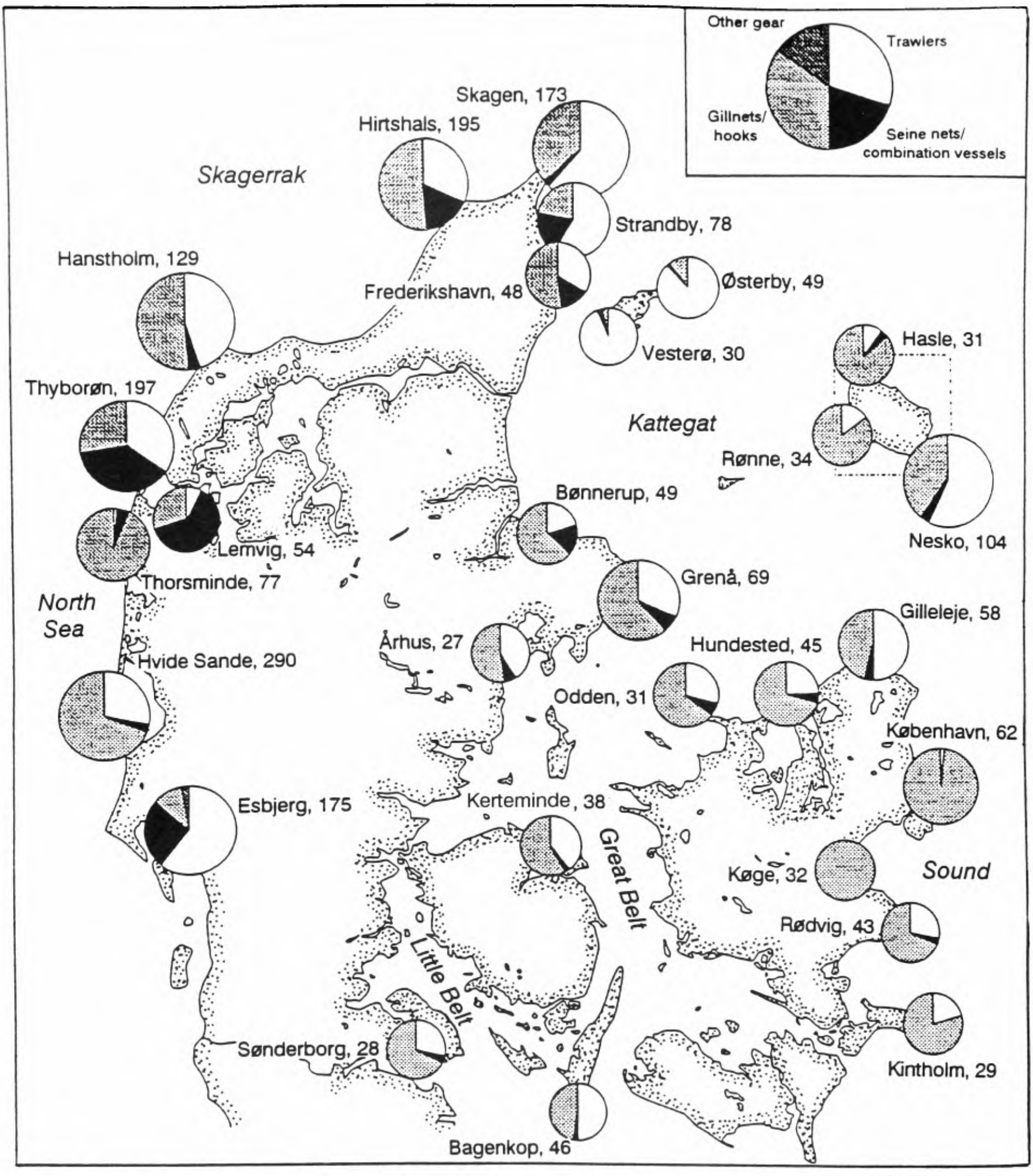

Fig. 1. Map of Denmark. Number of Danish fishing vessels by type and home port 1992 (*Yearbook of Danish Fishery Statistics, 1992*).

problems with, for example, lice or crabs attacking the fish, weed clogging the net or a high bycatch of unwanted species.

Cod fishery

The nets used in cod fisheries are generally made of nylon monofilament or multimono. They range from 110 to 180mm mesh size (all mesh sizes are given as inside mesh opening). Meshes are generally larger in the North Sea than the Baltic. Height ranges from $15\frac{1}{2}$ to $35\frac{1}{2}$ meshes, and length is generally 1,000 meshes. Hanging ratios (length of headline/length of netting) are of the order of 35–50%. Lead-cored ropes are used for the footrope, with plastic floats (65–125g lift) used on the headline. Fishing occurs in all Danish waters, notably the central North Sea (Fig. 2) and the Baltic, and is year round.

Table 1

Danish gillnet fishery (incl. traps and lines) catch (tonnes) by area and species in 1992 (only those with a total catch of over 600 tonnes). Source: *Yearbook of Danish Fishery Statistics 1992.*

	North Sea	Skagerrak	Kattegat and Isefjord	Belts and Western Baltic	Sound and Eastern Baltic
Cod	9,849	3,796	573	2,500	7,628
Plaice	6,358	1,290	583	95	35
Sole	1,100	75	314	35	32
Turbot	682	60	35	159	81
Herring	181	0	69	238	1,336
Hake	1,056	371	6	0	0
Lumpfish	6	7	512	262	95
Pollack	476	453	14	3	1
Other species	1,823	604	991	879	1,406
Total	21,531	6,656	3,097	4,171	10,614

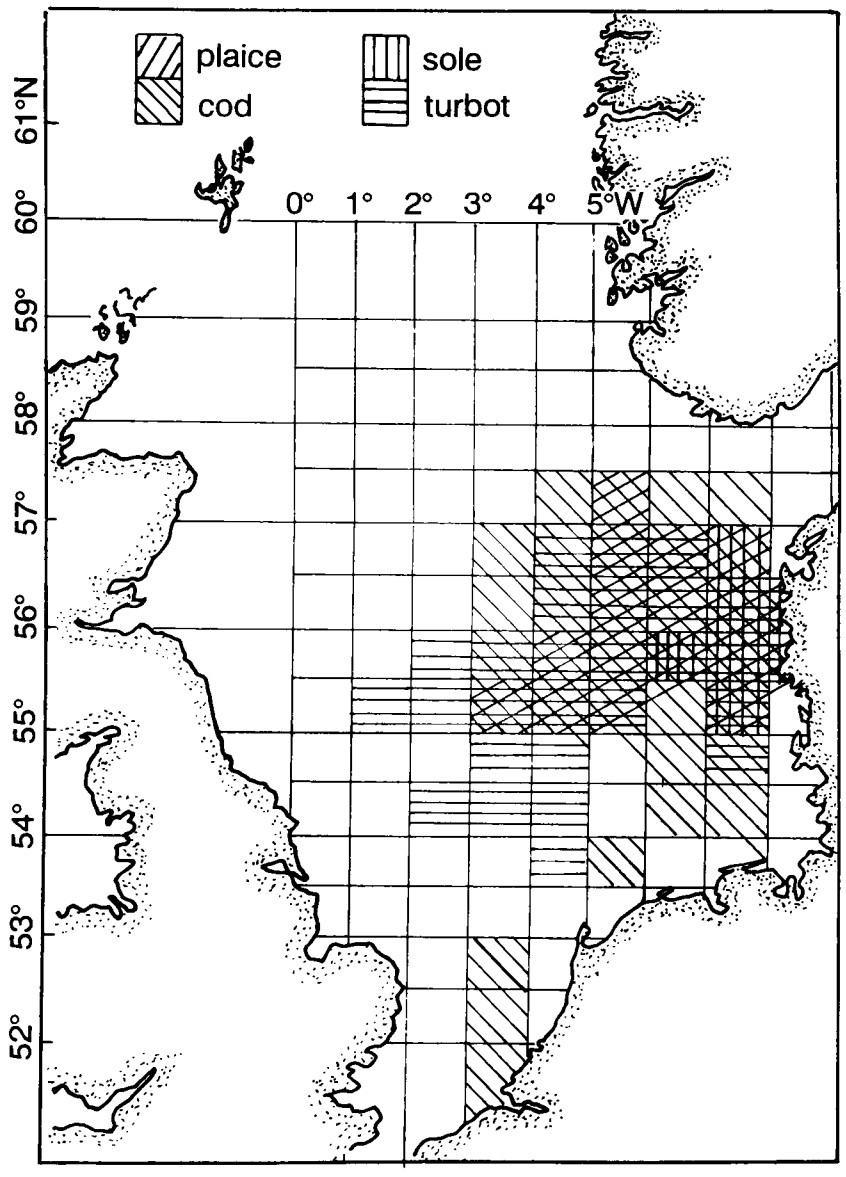

Fig. 2. Map showing areas of highest catches of cod, plaice, sole and turbot, taken by Danish gillnetters in the North Sea (based on information in Vinther, 1994). Smaller catches are taken outside these areas.

Flatfish fisheries

Turbot nets are mainly monofilament, with large mesh sizes (up to 270mm); nets are $6\frac{1}{2}$ to $10\frac{1}{2}$ meshes high. The footrope is lead cored. There is a great deal of variation in the flotation used, varying from floating polypropylene ropes to floats of the type used in the cod fishery. All Danish waters are fished, but most effort occurs in the North Sea (Fig. 2) and Western Baltic.

In the sole fishery, monofilament gillnets with mesh sizes of around 100mm are usually used. Nets are 1000 meshes long and $9\frac{1}{2}$ to $16\frac{1}{2}$ meshes high. Hanging ratios are around 30%. The footrope is lead cored and the headrope is usually polypropylene, which is sufficiently buoyant that little or no other flotation is needed. The main fishing area is off the North Sea coast of Jutland (Fig. 2). The fishery has low quotas and only takes place in the spring and early summer. About half of the fishery uses trammel nets. These nets use monofilament or multimono inner meshes of 120mm with outer meshes of 600mm and the nets are $1\frac{1}{2}$-2 outer meshes deep. Hanging ratios are about 40% of the inner net and higher for the outer. Headlines with $20gm^{-1}$ braided in floats are used.

Trammel nets account for about 90% of the plaice fishery. The nets used are similar to those used in the sole fishery, except for a slightly larger inner mesh size, about 150–170mm. The plaice fishery occurs mainly in the North Sea (Fig. 2), Skagerrak and Kattegat. The fishery is year round but location moves with migration of plaice; the peak occurs during the northward migration from April to October.

Other species

The lumpsucker fishery uses similar nets to the turbot fishery, mainly in the Kattegat, the Belts and the Sound. The fish are caught mainly for the lump caviar industry, so the fishery only occurs during spring.

The gear used in the hake fishery is similar to that used in the cod fishery, although the nets have a smaller mesh size and greater height. The fishing area is mainly off the coast of Northern Jutland during the summer.

Driftnet fishery

There are few Danish driftnet fisheries. The major fishery is the fishery for salmon in the Baltic Sea. Kinze (1990) summarised the available information. In the late 1980s, 50–70 driftnetters operated using net panels mounted to a headrope equipped with floaters. The nets are made of polyester multifilament (terylene) which (twine diameter, 0.5mm) nets of 300–350 meshes long and 40–50 meshes deep (mesh size 160mm) with no footrope or an unweighted footrope are used. Usually, some 30 nets are set in a straight line at sunset and hauled just before sunrise (maximum soak time 15 hours). A maximum of 600 nets per vessel per operation is allowed. In 1992, driftnets accounted for about half of the total Danish salmon catch (308 tonnes out of 656 tonnes), worth over 15m Danish kroner (about $US2,500,000). Herring driftnets (small mesh, 45mm) are used only in the Sound, by small vessels.

Pound nets

Pound nets used to be commonly used in Danish waters but numbers have decreased recently (Kinze, 1990). Land fixed pound nets are used in the autumn for eels. This provides the most important part of the poundnetters' income. In spring, the nets are set further offshore for herring and mackerel.

LEVELS OF BYCATCH

Gillnet fisheries

The bycatch of porpoises in the Danish fisheries has, until recently, been poorly documented, although concern was expressed as early as 1983 about the status of the stocks of harbour porpoise in the North Sea and Baltic, due to the apparently large bycatch in the Danish gillnet fisheries

(Andersen and Clausen, 1983; IWC, 1984). Kinze (1994) reported an estimated 750 harbour porpoises from a single harbour (Hanstholm) on the northwest coast of Jutland. Clausen (1990) suggested a conservative estimate of 1–3,000 for the total Danish fishery and Clausen and Andersen (1988) stated that they believed that up to 3,000 animals were taken in the wreck net fishery alone, with a total figure of 'several thousand'. However, these estimates were largely based on information from strandings, animals handed in by fishermen or interviews, and then subject to necessarily simplistic extrapolations. Such results are vulnerable to a number of sources of error and cannot be considered reliable (e.g. see IWC, 1994a; Lien *et al.*, 1994b).

The only systematic study to estimate Danish bycatch numbers is being carried out by DIFMAR (Danish Institute for Fisheries and Marine Research). Bycatches are counted directly by observers on board Danish gillnet vessels fishing in the North Sea. Vinther (1994) presents preliminary results from this survey. In 1993, bycatch statistics were obtained for between 1 and 3% of the total annual fleet effort (51 trips, about 20 vessels from 20–60 GRT, 1,546km nets) for the fisheries and vessel classes involved (sole, turbot and cod fisheries). A total of 117 bycaught porpoises were recorded.

However, a number of problems have been recognised in this study. In particular, these centre around how representative the coverage was of the total fleet and the total fishing area. They can be summarised as follows.

(1) Only vessels greater than 10GRT were sampled. Thus only medium and large gillnet vessels operating in offshore waters were covered. In fact, vessels less than 10GRT account for over 40% of the total fleet tonnage and 25% of the catch.
(2) The directed plaice and hake fisheries (36% of effort of vessels over 10GRT) were not covered.
(3) As in all surveys of this kind, animals which are caught and die but fall out of the net during hauling are usually missed by observers (e.g. Frady *et al.*, 1994). Similarly animals which escape but are fatally injured will not be counted.

Despite these problems, Vinther (1994) extrapolated their data to obtain an estimated total Danish bycatch figure of 4,629 porpoises for 1993 in the sole, turbot and cod fisheries in the North Sea. However, given the clustered distribution of the sampled animals, an estimate stratified by area (which would have resulted in a lower estimate) may have been more appropriate. Vinther (1994) also estimated that approximately 7,000 porpoises were incidentally caught in 1993 for the total Danish North Sea gillnet fleet. While this is the best available estimate, it must be treated with caution until more extensive surveys with a scientifically based sampling strategy are carried out.

Although the data for the North Sea are uncertain, data for the inner Danish waters are almost nonexistent. A brief review by Kinze (1990) noted that bycatches are taken in gillnets in these waters but no estimates of the size of this bycatch are available.

Other fisheries

Although salmon driftnets caught relatively large numbers of harbour porpoises (e.g. 50 specimens collected in a single year) in the 1960s and earlier (Lindroth, 1962), only one was reported between 1986 and 1990 from the Danish fleet (Kinze, 1990).

Catches in pound nets, which are set to catch herring and salmon, are also occasionally recorded (Kinze, 1990), but probably only represent between 1–7% of the total (Clausen and Kinze, 1993), and many of these animals are released alive and apparently unharmed.

In addition to the bycatches in passive gear, it is known that there are some harbour porpoises caught in midwater trawls (van Utrecht, 1978; Andersen and Clausen, 1983; Northridge and Lankester, 1990). The total trawl bycatch appears to be much less than that in static gear, although some individual hauls produce large numbers. Reliable data are sparse but the few studies in Danish waters suggest that the catch in trawls may represent 2–19% of the total bycatch (Clausen and Kinze, 1993).

Effect on harbour porpoise population(s)

In order to properly assess the impact of the bycatches on harbour porpoises, the following information is required:

(1) reliable estimates of bycatches for all countries in the region;
(2) knowledge of harbour porpoise stock identity and migration patterns;
(3) reliable estimates of population size.

Bycatch estimates

As we have shown, estimates of bycatch numbers in Danish fisheries are poor for the North Sea and almost non-existent for inner Danish waters and the Baltic. Information on bycatches for other fleets fishing in these and adjacent waters is also poor.

In Norway, the main bycatch was thought to be in the salmon driftnet fishery (96 recorded in 1988) and this influenced the banning of driftnets. However, the data available are insufficient for assessing the total mortality in Norwegian fisheries (Bjørge *et al.*, 1991).

German data are also limited (see review by Benke, 1994). From 1987–94, annual reported catches in the western part of the German Baltic ranged from 6–26, mainly between May to November coinciding with the observed migration pattern through Danish waters. In the German North Sea, the level of bycatch is unknown. The situation in Swedish waters is summarised by Berggren (1994).

In Britain, there are few available figures on bycatches in the gillnet fishery, but catches occur regularly in set nets along the east coast (Northridge and Lankester, 1990). A scheme to record bycaught and stranded animals, co-ordinated by the Institute of Zoology in London, is now in place (Anon., 1992).

In Poland, approximately 1 harbour porpoise per year has been recorded (sighted, stranded or caught) since the second world war (Skora *et al.*, 1988; Skora, 1991).

Stock identity and migration patterns

Harbour porpoises migrate seasonally through the Danish Belt Seas into the western Baltic (e.g. Möhl-Hansen, 1954) and this regular migration allowed the long history of direct exploitation in Danish waters (Kinze, In press). As several authors have noted, the abundance of the harbour porpoises in these areas, particularly in the Baltic seems to have declined and/or the distribution narrowed (e.g. Clausen and Andersen, 1988).

Although there is evidence of several population units in the Baltic/North Sea region, stock identity is poorly understood at present (IWC, 1992, p.209). If the impact of

bycatches is to be determined, improving our knowledge of stock structure in these waters should be accorded high priority.

Population size

Until recently, little was known about the numbers of harbour porpoises in these waters. The first quantitative work was carried out in Danish and German waters by Heide-Jorgensen *et al.* (1992; 1993). However, in July 1994, a major multi-national survey of the Baltic and North Sea area was undertaken (Anon., 1994). Although analyses of the results are not yet complete, this survey should provide a useful base for attempting to evaluate the effect of bycatches on harbour porpoise stocks.

Implications for the fishing industry

The cost to gillnet fishermen in terms of damage to gear and loss of catch caused by entanglement of marine mammals can be high; annual losses of $2,000,000 were estimated for Newfoundland, but this included damage by seals and large whales (Lien *et al.*, 1988). The losses experienced by Danish fishermen cannot be quantified from the available data but in general they do not consider the losses to be significant. The main impact on the Danish fishing industry is probably in the form of the negative publicity which is associated with the bycatch of marine mammals. Public pressure has had a major impact on fisheries around the world in terms of changed fishing practices (e.g. the tuna fishery in the eastern tropical Pacific – see IWC, 1992), closed seasons (e.g. New Zealand – Dawson, 1991a) and even complete bans (e.g. driftnetting in many areas including the North Pacific – see Nagao, 1994). All these measures may, of course lead to losses of income to the fishing industry and in some cases lead to fishermen losing their livelihood. However, it should be noted that changes in fishing gear and practices may have unforeseen ecological consequences that should be monitored, such as reducing the average length of the target fish species caught or increasing bycatches of non-marine mammal species (e.g. Joseph, 1994).

The increasing public awareness of the bycatch of harbour porpoises in gillnets in Denmark is likely to result in more pressure being put upon the fishermen to reduce this bycatch, and may result in legislation closing areas to fishing or in regulation of gear types. Current US legislation in the western North Atlantic states that the deaths of harbour porpoises must be significantly reduced towards zero in the near future (Read, 1994). One beneficial effect of this is that it has resulted in co-operation between fishermen and scientists to attempt to achieve this (Fullilove, 1994). It is important that the fishing industry, biologists and gear technologists work together to find solutions to bycatch problems which will minimise the difficulties to the industry, without losing the practical benefits of gillnets as a gear type (IWC, 1994a).

POSSIBILITIES FOR BYCATCH REDUCTION

A major difficulty in attempting to reduce cetacean bycatches is our lack of knowledge of why cetaceans become entangled (IWC, 1994a). In simple terms, it is not known if porpoises get entangled in the gear because they do not know it is there (detection) or if they do know it is there but do not perceive it as a threat (classification). Much of the early work on modifying gear relied on the trial-and-error approach, rather than an understanding of the physiology of the animals and the entanglement process.

Acoustic devices

A considerable body of work now exists that shows that cetaceans are at least theoretically able to detect gillnets acoustically (e.g. Au and Jones, 1991; Dawson, 1991b; Au, 1994; Goodson *et al.*, 1994a). At present there are two schools of thought concerning the utility of using acoustic devices (either 'passive' or 'active') to reduce cetacean bycatches (IWC, 1994a). Some authors (e.g. Dawson, 1991b; 1994) believe that this approach is unlikely to succeed, whilst others (e.g. Goodson *et al.*, 1994a; b; Hatakeyama *et al.*, 1994) believe that the approach has considerable potential. It is not appropriate to enter into this debate here but merely to note that there is some evidence from field trials that is encouraging for both acoustic enhancement of nets (Goodson *et al.*, 1994b) and the use of a commercially available buzzer (Lien *et al.*, 1994a). As yet, however, there remain problems of sample size in determining their effectiveness and in the practical deployment of modified gear in an actual fishery.

Other alterations to fishing gear

Net height

Vinther's (1994) data from the North Sea suggested that the catch rate per hour may be correlated with the net height (and hence area of mesh), but no such correlation was observed in the Gulf of Maine (Frady *et al.*, 1994). As yet the evidence is equivocal and from the fishermen's perspective, any change in the net height will only be acceptable if it is not associated with a significant reduction in the catch of the target species.

An approach which may have some potential to reduce bycatches in flatfish fisheries is to reduce the effective fishing height of the net by reducing the amount of flotation. It is known that the effective height of the net during fishing is less than the rigged height and varies due to tidal flow (Stewart, 1988). Fishermen do not consider that it is important to have great flotation on nets for flatfish (many sole nets have almost no flotation) and it is thought that these nets are effective when almost flat on the bottom due to the habits of the target species. However, it is likely that this approach would reduce catches of groundfish species.

Mesh size

All mesh sizes pose some risk to porpoises, but there is no clear evidence that different mesh sizes result in different bycatch rates (e.g. Frady *et al.*, 1994). Any change in mesh sizes will of course affect the size of fish caught and perhaps the species composition of the catch; this will probably be unacceptable to fishermen.

Hanging ratio

The hanging ratio for most demersal gillnets used in the North Sea, Baltic and in the Western Atlantic, is approximately 30–50%. The hanging ratio has an effect on whether fish are gilled or tangled in the net (more are gilled, fewer tangled with tighter hanging ratios). This is especially the case for the flatfish fisheries that use very slack nets and catch many fish by entanglement. This may be relevant to porpoises, with more tightly stretched meshes causing the porpoises to 'bounce off' the netting without getting entangled (Dawson, in Frady *et al.*, 1994). However, increasing the hanging ratio would be likely to cause a decrease in target species catch rates.

Bridle changes

It has been suggested that widening the gaps between nets in a string may reduce cetacean bycatches (Frady *et al.*, 1994) but this would probably only be viable if the cetaceans perceive the nets and require a gap to go through. It may be useful as a supplement to the use of passive acoustic reflectors in driftnets (Goodson and Mayo, 1994).

Changes in fishing strategy

Frady *et al.* (1994) found a lower than expected bycatch in over 90 fathoms depth. If the animals have shallower areas available in which they prefer to forage, then minimum depth restrictions may be useful in reducing bycatches.

Frady *et al.* (1994) also found evidence that harbour porpoises forage more in areas of high bottom relief and this might be useful in identifying areas with high porpoise activity in order that they may be closed to fishing. It may cause a conflict among fishermen however, by moving gillnetters onto grounds which are usually fished by trawlers. This may result in a loss of gear and a reduction in catch.

CONCLUSIONS

For centuries, thousands of harbour porpoises were hunted for domestic purposes in Denmark; this direct hunt ceased after the second world war (Kinze, 1994). Since then, increasing fishing effort has caused an increasing conflict with the harbour porpoise. The DIFMAR study (Vinther, 1994) in the North Sea has shown that this problem is far larger than was previously thought, but the estimates are still unreliable. Despite our present inability to adequately quantify the impact of bycatches on harbour porpoises, the available information makes it clear that bycatches in fishing gear now appear to represent the main threat to the harbour porpoise.

Methods to reduce bycatches of marine mammals can be grouped into those which involve stopping fishing (either by closed areas, seasons or restricting gear types) and those which involve modifying fishing gear and/or practice. Our knowledge of the areal and temporal variation in harbour porpoise stocks is insufficient to recommend specific closed areas or closed seasons which will reduce bycatches. The most promising gear modifications appear to be those involving passive or active acoustic approaches. Tests of these approaches are so far inconclusive but show potential. Further development work and thorough testing of their effectiveness and practicality is needed.

Governments in the region have accepted that fishing operations pose a potential threat to cetaceans, particularly the harbour porpoise. In September 1994, the first meeting of the parties to ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas) took place. The parties, including Denmark, passed a Resolution on the implementation of a conservation and management plan for the region. This included a number of priorities for action including: reduction of pollution; reduction of direct and indirect interactions with fisheries (including reliable estimation of bycatch numbers and research on gear and fishing method modification); reduction of 'disturbance'; and monitoring, status and population studies (ASCOBANS, 1994). It is to be hoped that Governments fulfil their own guidelines in these matters.

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Bycatches of the Harbour Porpoise (*Phocoena phocoena*) in the Swedish Skagerrak, Kattegat and Baltic Seas; 1973–1993

Per Berggren

Department of Zoology, Stockholm University, S-106 91 Stockholm, Sweden

ABSTRACT

The harbour porpoise is the only cetacean common to Swedish waters. This paper reviews data on harbour porpoise bycatches in the Swedish Skagerrak, Kattegat and Baltic Seas between 1973 and 1993. Bycatches in various fisheries are the major threat to harbour porpoises in Swedish waters. Gillnet fisheries are responsible for more than 80% of all incidental takes. Although bycatches occur year round in all areas, 51% were collected during three months; March, April and May. Bycatches occur in water depths between 0 and 100m, suggesting that depth restrictions for fisheries are not likely to reduce catches. In the Skagerrak Sea, 47.5% of the bycatches were taken in gillnets set for spiny dog fish in water depths between 40–80m; in the Kattegat Sea 72% were taken in gillnets set for cod in depths between 20–60m and in the Baltic Sea, 53.8% of the bycatches were taken in surface driftnets for salmon. It is not possible to quantify the threat bycatches represent to harbour porpoises in Swedish waters in the absence of reliable estimates of bycatches or abundance and uncertainty over stock identity. However, the existence of bycatches is a serious cause for concern and immediate action is needed.

KEYWORDS: INCIDENTAL CAPTURE; NORTH ATLANTIC; HARBOUR PORPOISE; FISHERIES.

INTRODUCTION

The harbour porpoise is the only cetacean common to Swedish and Baltic waters (e.g. see Aguayo L, 1978). There are reports of Polish (Skora *et al.*, 1988) and Danish (Kinze, 1995) fisheries for harbour porpoises as early as the 14th century. Anecdotal evidence suggests that all countries with a Baltic Sea coastline were engaged in harbour porpoise hunts to some extent during the 19th century. However, the only documented records of catches are from Danish waters in the 19th and early 20th centuries, when the annual hunt in the Danish Belt Seas in some periods averaged more than 1,000 animals (Andersen, 1982; Kinze, 1995). Catch numbers gradually decreased by the end of the 19th century, but whether this was due to a reduction in population size or a decreasing demand for porpoise meat and blubber is unclear. There have been no directed catches since the 2nd World War. There is no information to indicate a similar hunt in the Swedish Kattegat and Skagerrak Seas.

Every year, large numbers of harbour porpoises (*Phocoena phocoena*) are incidentally caught in fishing gear around the world (IWC, 1994). In most of these areas, population sizes have not been estimated and only minimum estimates of numbers of bycatches are available, based on the opportunistic collection of bycaught specimens. In a few cases, the development of independent observer schemes has made it possible to better estimate the total bycatch of animals (Smith *et al.*, 1993; Berrow *et al.*, 1994; Vinther, 1994) but unless the schemes are carefully designed and of adequate scale, the resultant estimates may still be unreliable (e.g. see Lowry and Teilmann, 1994). In perhaps the best studied area, the Gulf of Maine in the Northwest Atlantic, between 2 and 5% of the estimated population size has been estimated to be killed by incidental capture in the bottom set gillnet fishery (Smith *et al.*, 1993). Modelling exercises have shown that harbour porpoise stocks have limited potential to replace even moderate takes (Barlow, 1986; Woodley and Read, 1991).

Swedish fisheries are no exception to the general pattern and this paper reviews data on the harbour porpoise bycatch in Swedish coastal waters between 1973 and 1993. Data up to 1988 were discussed briefly in Lindstedt and Lindstedt (1989). The data presented here have been divided up into three geographical areas: the Skagerrak Sea, the Kattegat Sea and the Baltic Sea (Fig. 1), based on oceanographic and habitat differences between these areas and, as discussed later, the possible existence of a separate harbour porpoise stock in the Baltic Sea.

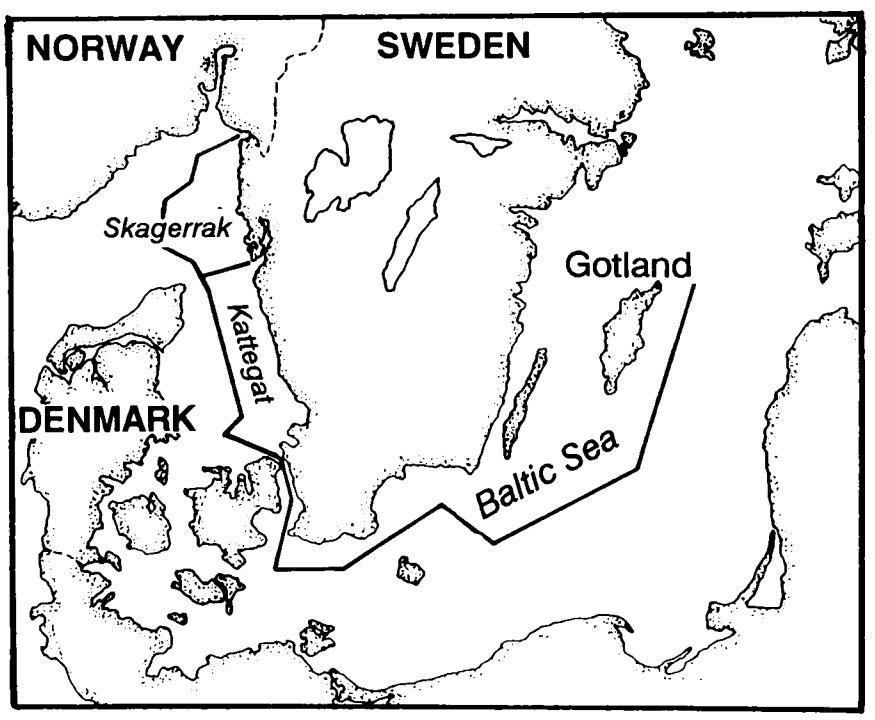

Fig. 1. Map showing the Skagerrak, Kattegat and Baltic Seas; areas where harbour porpoise bycatches occur in Swedish waters. The discontinuation of the line to the north of the island of Gotland in the Baltic Sea signifies no reports of bycatches beyond this point in the last two decades.

The areas were divided according to Fonselius (1994). The border between the Skagerrak and Kattegat Seas is between Skagen, Denmark and Pater Noster, Sweden, while that between Kattegat and the Baltic is the island of Saltholm in Öresund.

Legal status of the harbour porpoise in Swedish waters

The harbour porpoise has been protected in Sweden since 1 July 1973. Hunting Ordinance paragraph 33 states that any harbour porpoise found stranded, or that is incidentally killed, is state property and should (according to para. 36) be reported to the police as soon as possible. Para. 37 states that a report shall include information as to where and when the animal was killed or found dead. The police should, after receiving a report, ensure that the animal is properly handled according to regulations set by the Swedish Environmental Protection Agency (SEPA; para. 36). Para. 35, that allowed professional fishermen to kill trapped and entangled porpoises and keep them, was abolished in 1992.

MATERIALS AND METHODS

The Museums of Natural History in Sweden have collected and kept records of bycaught harbour porpoises for more than 100 years. However, only a few animals per year were collected prior to their protection in 1973. Following this, the collection of specimens became more systematic. The National Natural History Museum of Stockholm was the main collector of animals between 1973 and 1988. It also performed post-mortem analyses and collected samples for future analyses.

In June 1988, a scheme that attempted to collect all bycaught and stranded harbour porpoises was started. Requests for animals were sent to fishermen with a promise of a SEK 150 (approx. US$25) reward for every animal submitted. This scheme continued until January 1992. In total, 504 harbour porpoises were collected in the Kattegat, Skagerrak and Baltic Seas between June 1988 and December 1991. Most of these were collected by the National History Museum of Gothenburg.

In Sweden, protected fauna and flora are managed by SEPA and in 1992, SEPA stipulated that all reports of harbour porpoises bycaught or found stranded be sent to them. They also set new guidelines to the effect that only animals from the Baltic Sea should be collected whilst those found in the Kattegat and Skagerrak Seas should merely be reported. For this purpose, in the summer of 1993, SEPA distributed a new combined information folder and reporting form for the recording of sightings, strandings and bycatches of harbour porpoises. The folder was distributed to all fishermen, the coastguard, police, county and municipal officials and others. Following the decision not to collect animals from any areas but the Baltic Sea, and the lack of follow-up on the distributed folder, there was a drop in the number of reported bycatches and strandings in the Kattegat and Skagerrak Seas to levels similar to the Baltic Sea; approximately 5 animals per year.

When submitting bycaught porpoises, fishermen also provided information on the bycatch location, the type of gear used and the water depth in which the gear was set.

At the time of writing no effort data are available for the different fisheries. It is thus not possible to provide any detailed analyses of bycatches by gear type or relative effort.

RESULTS

A summary of the number of harbour porpoises collected by the Museums of Natural History between 1973 and 1988 and at the Natural History Museum in Gothenburg between 1988 and 1991, and the relative frequency of bycatches and strandings is shown in Table 1. Reported and collected animals are given for 1992 and 1993.

Table 1

Number of harbour porpoises collected from bycatches and strandings during the two periods of 1973-1988 and 1988-1991. The records for 1992 and 1993 are for reported and, in the case of the Baltic, collected animals.

	1973-1988	1988-1991	1992	1993
Bycatches	169 (65%)	297 (59%)	6	9
Strandings and floaters	70 (27%)	201 (40%)	6	6 *
Unknown	21 (8%)	6 (1%)	-	-
Total	260	504	12	15

* Including 3 collected from the Baltic.

The relative distribution of collected bycatches by month (Fig. 2) for the three years, January 1989 to December 1991 (n=270) shows that bycatches occur year round in all areas. During that period, most (70%) catches occurred in the Kattegat Sea followed by the Skagerrak (22%) and the Baltic (8%) Seas. There was a peak in bycatches in April and 51% of the bycatches were collected during the months of March, April and May.

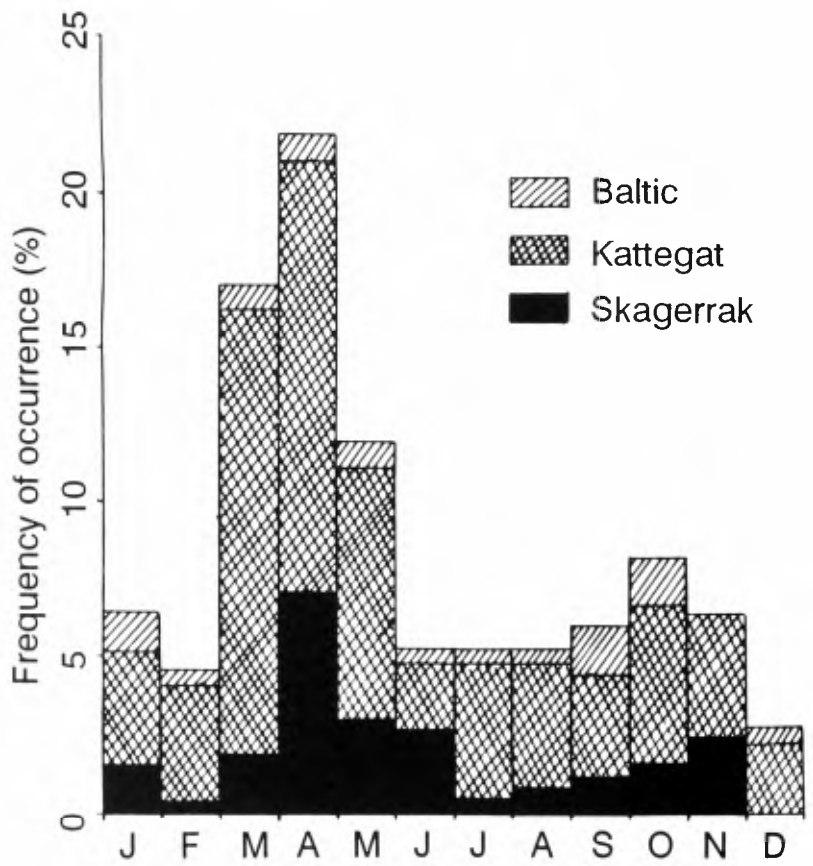

Fig. 2. The relative frequency of harbour porpoises caught by month for the Skagerrak, Kattegat and Baltic Seas between 1989 and 1991. A total of 270 specimens were collected.

The relative frequency of harbour porpoise bycatches in various gear used for the period 1989–1991 in the Skagerrak, Kattegat and the Baltic Seas is shown in Fig. 3. Gillnet fisheries are responsible for more than 80% of the bycatches in all three areas. In the Skagerrak Sea (n=59), 47.5% of the bycatches collected were in gillnets set for spiny dogfish while in the Kattegat Sea (n=175), 72% taken were in gillnets set for cod and in the Baltic Sea

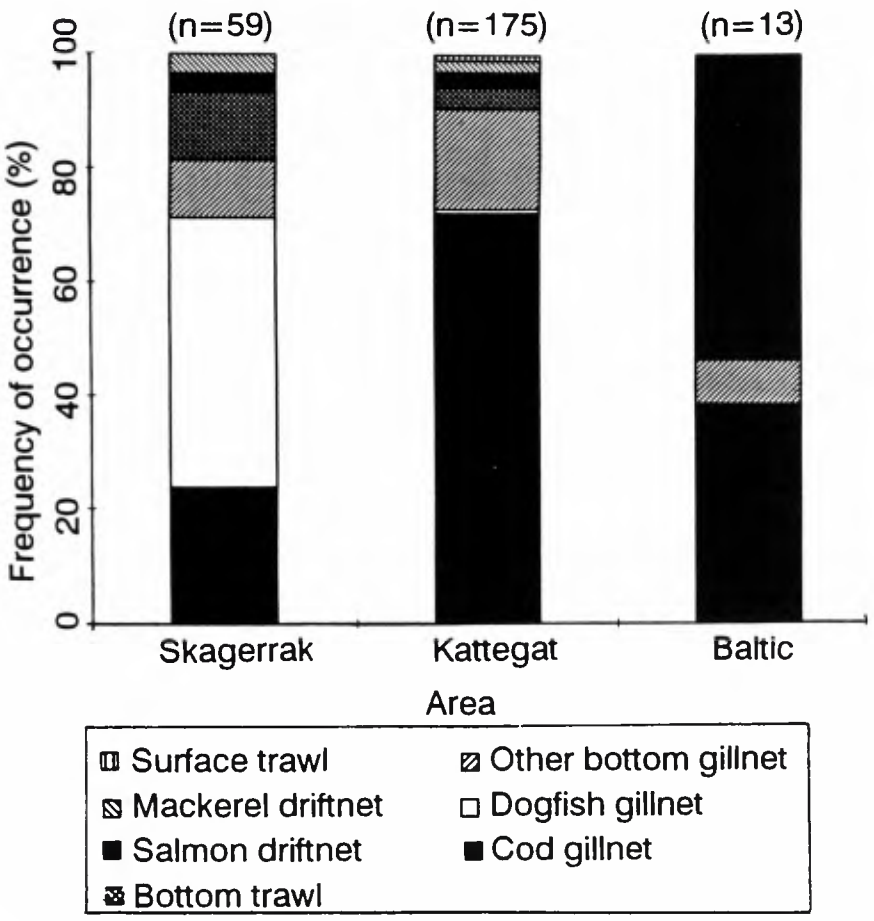

Fig. 3. The relative frequency of harbour porpoises bycaught in different types of fishing gear for the three areas studied; The Skagerrak, Kattegat and Baltic Seas between 1989 and 1991.

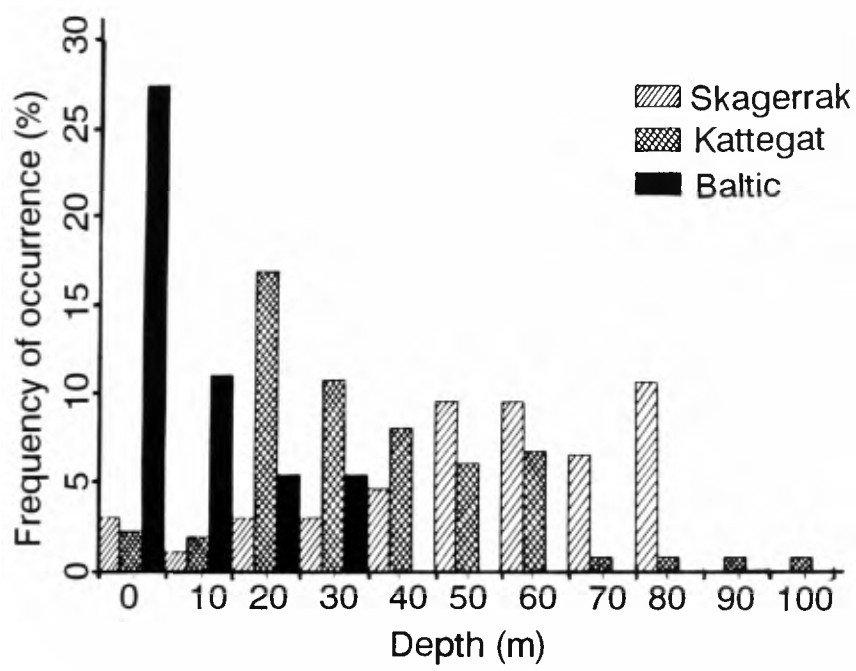

Fig. 4. The relative frequency of water depths in which 48 harbour porpoises were bycaught in the Skagerrak Sea between 1989 and 1991; 47 harbour porpoises were bycaught in the Kattegat Sea between 1989 and 1991 and 9 harbour porpoises were bycaught in the Baltic Sea between 1989 and 1991.

(n=13), 53.8% of the bycatches were in driftnets for salmon. Mesh size varied between 40–180mm for the different fisheries.

Water depth

Fig. 4 shows the depth distribution of bycatches between 1989–1991. In the Skagerrak Sea (mean depth 218m), 79% of the bycatches (n=48) occurred in water depths between 40–80m whilst in the Kattegat Sea (mean 25m), 86% (n=147) were between 20–60m. In the Baltic Sea (mean depth 67m) most (78% n=9) catches were in shallow waters between 0 and 10m.

Age distribution

Fig. 5 shows the age distributions of collected harbour porpoises from Swedish waters that have been aged at the time of preparation of this paper (November 1994). We are currently ageing the samples at the University of Stockholm. No preference was given as to which animals were aged first.

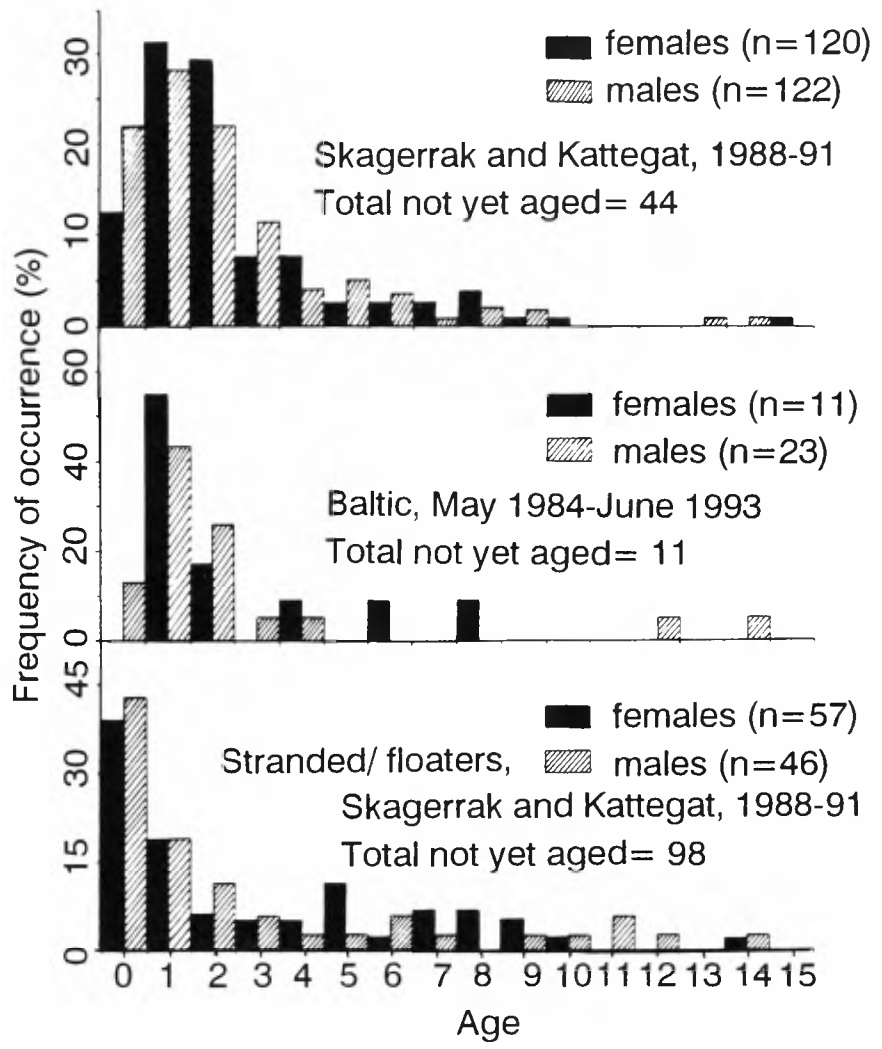

Fig. 5. The relative representation of age classes of harbour porpoises (a) bycaught in the Swedish Skagerrak and Kattegat Seas between 1988 and 1991; (b) bycaught in the Swedish Baltic Sea between 1984 and 1993; and (c) found dead, stranded or floating in the Skagerrak and Kattegat Seas during 1988–1991.

DISCUSSION

Impact of bycatches

In order to assess the impact of bycatches on a population or populations, the following information is needed:

(1) an estimate of the total bycatch (from more than one nation where appropriate);
(2) an understanding of stock identity and migration;
(3) an estimate of population size for the relevant population(s).

Of course it must be recognised that other threats than bycatches (e.g. pollution, habitat degradation) may have a negative impact on harbour porpoises in these waters.

Estimation of bycatches

Sweden does not have an independent observer scheme to monitor bycatches aboard fishing vessels. The information presented in this paper is insufficient to allow a reliable estimate of the bycatch of harbour porpoises in Swedish waters to be made. The changes to the legal and reporting situations described above have also made interpretation of the available data problematic.

On average, about 17 harbour porpoises were collected annually in Swedish waters between 1973 and 1988, compared to 150 animals per year between 1988 and 1991. This approximately tenfold increase in the number of animals collected can largely be attributed to the increased effort made to collect animals during the latter period, as a result of the scheme established in June 1988. It is clearly inappropriate to interpret the difference between the two collection periods as either an indication of an increase in the abundance of harbour porpoises or an increase in the actual bycatch. This view is supported by the fact that only 12 and 15 animals were reported bycaught or stranded in 1992 and 1993, with the advent of the SEPA guidelines.

These changes in numbers are consistent with the findings of the first attempt to study the Swedish bycatch problem by Lindstedt and Lindstedt (1987), who carried out a questionnaire survey of 68 fishermen. They found that the fishermen had officially reported only 13% of their actual bycatches to the authorities between 1973 and 1986.

Despite our inability to estimate total bycatch, however, the 1988–91 data do provide an absolute minimum estimate of the number of bycaught animals in Swedish waters.

Bycatches by other fleets that may have an impact on harbour porpoise population(s) affected by Swedish fisheries are discussed in Kinze (1990), Lowry and Teilmann (1994), Benke (1994), Skora *et al.* (1988) and Skora (1991).

Stock identity and migration

The stock identity of harbour porpoises in the Baltic/North Sea region is poorly understood, although there is some evidence suggesting that there may be several population units (IWC, 1992; p. 209).

Preliminary results from morphometric studies (Börjesson and Berggren, 1993) indicate that harbour porpoises collected in the Baltic and Skagerrak Seas belong to separate stocks. Andersen (1982) described a migration of harbour porpoises into the Baltic Sea in early spring and out of the area during late autumn, based on anecdotal notes and catch statistics. Incidental takes in Swedish fisheries however, show that at least some harbour porpoises spend winter months in the Baltic proper (Fig. 2). Anecdotal records also show that during severe ice winters, bottom trawl fisheries in the Baltic Sea catch a large number of animals that have apparently drowned under the ice (Hanström, 1960). This supports the view that some animals stay in the Baltic Sea year round. Fig. 2 also shows that some animals remain in the Skagerrak and Kattegat Seas year round.

In the absence of better information on stock structure, a conservative management approach would be to treat harbour porpoises in these areas as separate 'units'.

Population size

There is little information on either the historic or current population abundance of harbour porpoises in Swedish waters. Berggren and Pettersson (1995) compared results from a questionnaire survey that strongly indicated that the number of sightings of harbour porpoises in Swedish waters had significantly declined since the 1950s.

In July 1994, a major multinational survey of the North Sea/Baltic Sea region was undertaken (Anon., 1994). This survey, however only attempted to cover the western part of the Baltic Sea and poor weather led to poor coverage in that area. However, even a crude examination of the results reveals considerably lower densities in Baltic waters, supporting the generally held view that the numbers in the Baltic may have declined and its distribution narrowed (e.g. Kinze, 1995). There are plans to survey the whole of the Baltic Sea in summer 1995. The analyses of the 1994 data are not yet complete but the results should provide a useful base for attempting to assess the impact of bycatches in the surveyed area, including the Skagerrak and Kattegat Seas.

Possible measures to reduce bycatches

It is not appropriate here to discuss in detail the various approaches that have been suggested to try and reduce cetacean bycatches (e.g. see Dawson, 1994; Goodson *et al.*, 1994; IWC, 1994), but merely to note that no effective method of modifying gear has yet been developed. In this section I will simply examine the limited data available for the Swedish fishery and explore any potential for reducing bycatches (I have not commented on any effect on fishery yields).

Seasonal restrictions

Fig. 2 showed that the peak months for bycatches in the Skagerrak and Kattegat Seas were from March-May. Fig. 3 reveals that 81.4% of the Skagerrak and 90.3% of the Kattegat Sea bycatches occurred in the bottom set gillnets. Clearly in the absence of fishing effort data it is not possible to determine the strength of the seasonality factor i.e. whether it is merely a direct reflection of effort, but the possibility of reducing bycatches by restricting bottom set gillnet effort in the spring warrants further attention.

Depth restrictions

Fig. 4 shows that bycatches are taken in nets set at all depths down to 100m in the Kattegat and Skagerrak Seas. This suggests that depth restrictions are unlikely to reduce bycatches in these Seas. In the Baltic, over half the bycatches occur in the salmon driftnet fishery in depths of 0–10m.

Age distribution of the samples

Fig. 5 shows the age distributions of the animals aged thus far. In all areas, animals between 0–2 years predominated. This is not an unknown feature in several areas and may be a result of a number of factors including lack of experience or greater curiosity in juveniles (e.g. see IWC, 1994). The samples revealed no apparent difference in mortality between males and females.

Yearlings of both sexes were the most common age class found stranded in the Skagerrak and Kattegat Seas. This indicates that for whatever reason females are not always successful in raising their young. Of the older animals found stranded, some will probably have died of natural causes and others will be animals that have been caught and then fallen out of nets, or been dumped at sea by fishermen. That the latter occurs is supported by fresh net marks found on some stranded animals.

CONCLUSIONS AND RECOMMENDATIONS

The data presented in this paper do not allow for an evaluation of how serious a threat bycatches are to harbour porpoises in the Swedish Skagerrak, Kattegat and Baltic Seas, since no reliable estimates of either bycatches or abundance exist yet, and stock identity is uncertain.

However, the level of bycatches appears to be the most serious threat to harbour porpoises in Swedish waters, although other factors such as habitat degradation and pollution should also be regarded when assessing the status

of this species in the Skagerrak, Kattegat and Baltic Seas. This is particularly true if the animals in the Baltic represent a separate population; even the low level of bycatches may be sufficient to prevent recovery.

I recommend that the following action should be taken:

(1) immediate efforts should be made to reduce bycatches;
(2) reliable estimates of bycatches (through a scientifically designed observer programme) should be obtained;
(3) estimates of the abundance of harbour porpoises in Swedish and adjacent waters should be obtained;
(4) the question of stock identity should be addressed.

ACKNOWLEDGEMENTS

I would like to thank Patrik Börjesson, Julia Carlström and Magnus Kull of the Harbour Porpoise Project at the Department of Zoology, Stockholm University for preparing some of the data. The Museum of Natural History in Gothenburg and the National Museum of Natural History of Stockholm for access to their collections. World Wide Fund for Nature (WWF-Sweden) for research and collection grants 1988–1994. Thanks are also due to the Swedish Environmental Protection Agency (SEPA) for grant 12407. Greg Donovan and an anonymous reviewer made useful comments on the manuscript.

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A Note on Cetacean Bycatches in German Waters

Harald Benke

Forschungs–und Technologiezentrum Westküste der Universität Kiel, Werftstr. 10, D-25761 Büsum, Germany

ABSTRACT

This note summarises available information on bycatches of harbour porpoises in German waters since 1987. Most information is for the cod set net fishery in Schleswig-Holstein. More recently, information on catches in the North Sea fishery has come to light. It is not yet possible to reliably estimate the actual bycatch numbers.

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; HARBOUR PORPOISE; NORTH ATLANTIC; BALTIC

INTRODUCTION

This short note summarises briefly, available German bycatch information. A more comprehensive review will be presented at a future date. Although a number of cetacean species are found in German waters (Benke and Siebert, 1994), the harbour porpoise (*Phocoena phocoena*) is by far the most common and the one for which a bycatch problem exists.

THE FISHERIES

The most important fishery in German waters with respect to harbour porpoises appears to be the set net fishery for cod. The fishery is concentrated in Schleswig-Holstein in an area between 54°32′N – 54°50′N and 9°52′E – 10°10′E and most effort is from August to March (Benke *et al.*, 1991). Nets are usually set overnight at depths of 5–40m (typically 7–13m). Monofilament triple nets with an outer mesh size of 300mm and an inner mesh size of 65–75mm are used. Typically, they are up to 600m long and 1.2m deep. Several hundred part-time and full-time vessels operate. Trammel net and trawl fishing also occur.

The main German fisheries in coastal North Sea waters are an otter trawl fishery for cod and flatfish, a beam trawl fishery for sole, plaice and brown shrimp and, seasonally, a small-scale set net fishery for sole (which is currently conducted by 12 vessels).

INTERACTIONS WITH HARBOUR PORPOISES

Investigations on harbour porpoise bycatches began in the late 1980s, centred at the University of Kiel. Contacts were made with local fishermen and authorities and a reporting and collection scheme was initiated. Between 1987 and 1990 a total of 41 bycaught harbour porpoises were recorded in coastal Baltic Sea waters off Schleswig-Holstein, 37 in set nets, with a peak between August and November (Benke *et al.*, 1991).

In 1990, a more comprehensive project to investigate harbour porpoises in German waters began, which included surveys to examine abundance and distribution (Heide-Jørgensen *et al.*, 1992; 1993). That programme was completed at the end of 1993 and a preliminary report is given in Bohlken and Benke (1993). Reported harbour porpoise bycatches between 1990 and 1993 are given in Table 1. The reported bycatch of harbour porpoises in the German North Sea fishery is low and there is circumstantial evidence (anecdotal records from fishermen) that it is underreported. The bycatch figure in the western Baltic is probably much closer to the true figure but has to be considered as a minimum estimate.

Table 1

Reported bycatches of harbour porpoises by German fisheries in the North and Baltic Seas.

Year	North Sea	Baltic Sea
1990	0	21
1991	4	26
1992	2	6
1993	6	5

It is not possible to estimate the total bycatch by German vessels from the available data but a number of projects to improve estimates of bycatches and to assess their impact are underway (Anonymous, 1994a, Appendices B and C). Germany participated in the multi-national survey to estimate harbour porpoise abundance in the North Sea in summer 1994 (Anonymous, 1994b) and is a signatory to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS, 1994; Donovan, 1994). Information on bycatches from other nations that might involve the same harbour porpoise population(s) is given in Kinze (1990), Berggren (1994) and Lowry and Teilmann (1994).

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Central America and Caribbean

Cetaceans and Gillnet Fisheries in Mexico, Central America and the Wider Caribbean: A Preliminary Review

Omar Vidal

Departamento de Ciencias Marinas and Centro do Conservación y Aprovechamiento de los Recursos Naturales, Instituto Tecnológico y de Estudios Superiores de Monterrey-Campus Guaymas, Ap. Postal 484, Guaymas, Sonora 85400, Mexico

Koen Van Waerebeek

Centro Peruano de Estudios Cetológicos, c/o Asociación de Ecología y Conservación, Vanderghen 560, Lima 27, Peru

and

Lloyd T. Findley

Centro de Investigación y Desarrollo de los Recursos Naturales de Sonora-Unidad Guaymas, Miramas 63 Plata Alta, Col. Miramas, Guaymas, Sonora 84150, Mexico

ABSTRACT

This paper reviews published and unpublished information on the mortality of cetaceans in gillnets in Mexico, Central America and the wider Caribbean. Data on this incidental mortality are provided from only nine of the 36 nations in the area (Colombia, the Dominican Republic, French Guiana, Honduras, Mexico, Panama, Surinam, Trinidad and Tobago, and Venezuela); the lack of mortality records from the other countries reflects poor or non-existent documentation. We surveyed those types of passive fishing gear which potentially or actually entrap cetaceans in this large area; these included gillnets with mesh sizes of 18 to 400mm. At least 14 species of cetaceans have been caught in fishing nets in this area: vaquitas, common dolphins, bottlenose dolphins, tucuxis, Atlantic spotted dolphins, spinner dolphins, clymene dolphins, Risso's dolphins, killer whales, pygmy sperm whales, botos, gray whales, humpback whales and balaenopterids. At least another five species are potentially at risk: pantropical spotted dolphins, striped dolphins, Pacific white-sided dolphins, false killer whales and short-finned pilot whales. Of special concern is the endangered vaquita in the northern Gulf of California, Mexico.

KEYWORDS: INCIDENTAL CAPTURE; NORTH PACIFIC; NORTH ATLANTIC; VAQUITA; COMMON DOLPHIN; BOTTLENOSE DOLPHIN; TUCUXI; SPOTTED DOLPHIN; CLYMENE DOLPHIN; RISSO'S DOLPHIN; KILLER WHALE; BOTO; PYGMY SPERM WHALE; GRAY WHALE; HUMPBACK WHALE; PANTROPICAL SPOTTED DOLPHIN; STRIPED DOLPHIN; WHITE-SIDED DOLPHIN; FALSE KILLER WHALE; PILOT WHALE–SHORT-FINNED.

INTRODUCTION

The problems of the incidental capture of cetaceans during fishing operations have been highlighted in recent years, e.g. Brownell *et al.* (1989). Data on the magnitude of such kills as a result of large-scale pelagic fisheries have been collected for certain regions, such as the eastern tropical Pacific tuna purse–seine fishery (e.g. Hall and Boyer, 1987; 1988; 1989; 1990) and the Japanese high-seas mothership salmon driftnet fishery (Jones, 1990). However, mortality due to small-scale artisanal fisheries, particularly coastal gillnet fisheries, remains largely unmonitored. The coastal distribution of many cetacean species, particularly dolphins and porpoises, renders them at risk from gillnet fisheries and the potential effect on their populations is a cause for concern among scientists, conservationists and fishery managers (IWC, 1994).

In this paper we review the limited available information on the incidental mortality of cetaceans in gillnets in Mexico, Central America and the wider Caribbean (Fig. 1). We document those types of passive fishing gear (gillnets and traps) which potentially or actually capture cetaceans in this area. The review is preliminary and covers only 26 of the 36 nations in the region. Much more effort will be required to fully assess the magnitude and impact of incidental captures on the populations of cetaceans in the region. Here we can only outline the problem and indicate the many gaps existing in the information from various countries and their fisheries.

Published records

Worldwide reviews of fisheries interactions with cetaceans have been prepared by Mitchell (1975) and Northridge (1984). Based on available literature, Northridge (1984) concluded that most gillnet and trap fisheries in the Caribbean region (FAO Marine Fishing Area 31) and in the Mexican and Central American Pacific region (FAO Area 77) are unlikely to involve interactions with marine mammals. We found only a few published reports dealing with cetaceans incidentally caught in gillnets in these two regions (Caldwell and Caldwell, 1971; Mitchell, 1975; O'Shea *et al.*, 1986; Engeman and Bromaghin, 1990; Ottley *et al.*, 1988; Vidal, 1989; 1990; In press; Agudo, 1990; Van Waerebeek, 1990).

As a result, much of the information we present on the fisheries in the countries involved comes from internal unpublished fishery reports provided by some of the individuals or organisations we contacted.

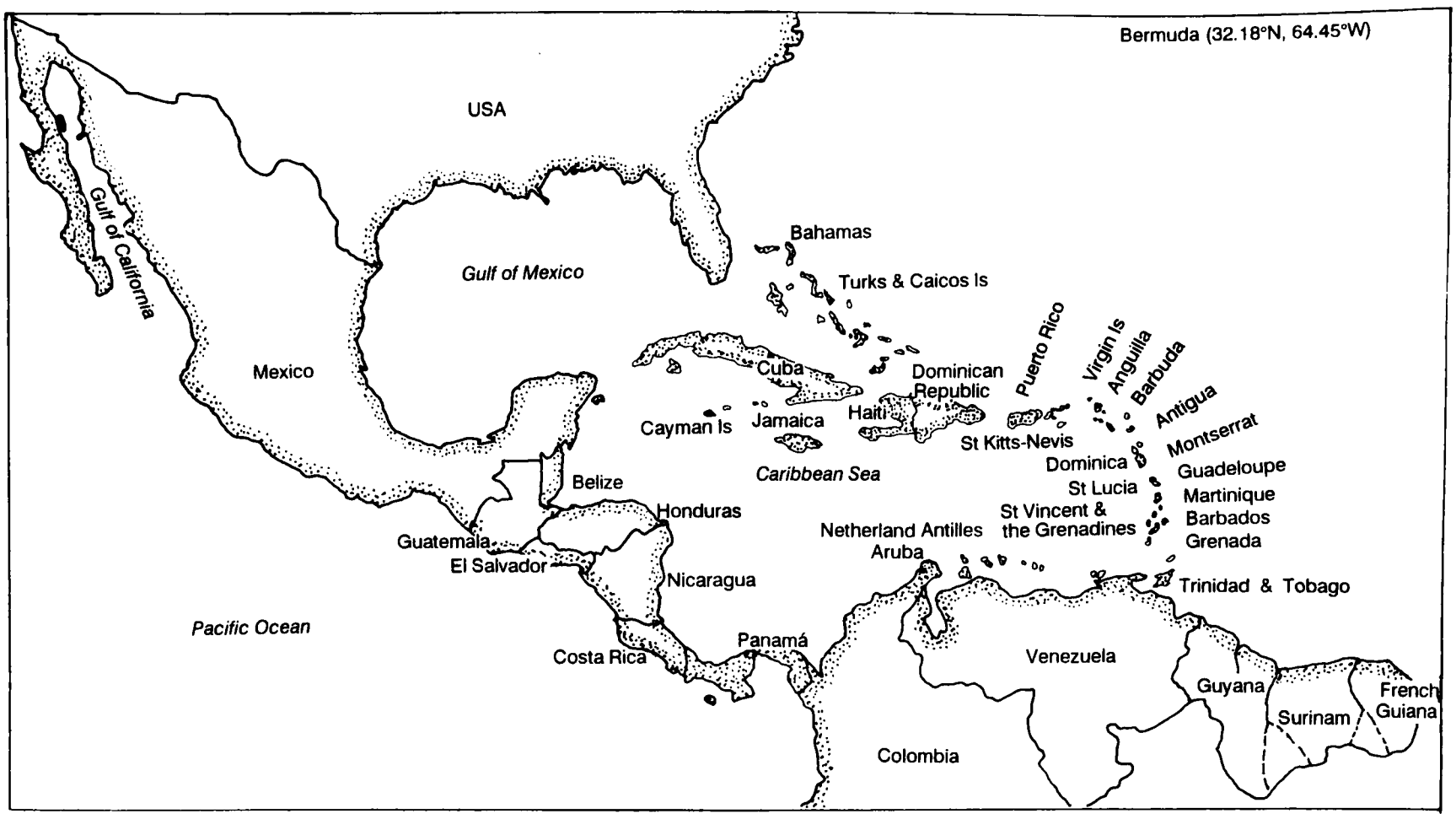

Fig. 1. Study area: Mexico, Central America and the wider Caribbean.

Table 1

Nations and overseas territories/departments within the study area (English spellings are used).

Mexico	Surinam	Guadeloupe, with St. Martin North	Haiti
Guatemala	French Guiana	and St. Barthelemy (France)	Turks and Caicos Islands (UK)
Belize	Trinidad and Tobago	Monserrat (UK)	Jamaica
El Salvador	Netherland Antilles*	Antigua and Barbuda (UK)	Cuba
Honduras	Grenada	St. Kitts and Nevis	Cayman Islands
Nicaragua	St. Vincent and the Grenadines	Virgin Islands (British)	Bahamas
Panama	St. Lucia	Virgin Island (USA)	Bermudas
Colombia	Barbados	Anguilla (UK)	
Venezuela	Martinique (France)	Puerto Rico (USA)	
Guyana	Dominica	Dominican Republic	

* Aruba, Curaçao, Bonaire, St. Maarten South, St. Eustatius and Saba.

METHODS

Published accounts of cetacean mortality in gillnets in the region are scarce or non-existent for most countries. Information was gathered in two ways. Firstly, over 150 letters soliciting information were sent to government agencies, universities and individuals (not necessarily involved in cetacean research). The replies received provided limited information (primarily related to the fisheries and not to cetacean interactions). Secondly, personal observations by the authors, cetacean research biologists and/or reliable local fishermen were used for Mexico, Colombia, Surinam, French Guiana and Venezuela. Difficulties in obtaining data may have been due either to its unavailability or the reluctance of the authorities to provide it for international scrutiny. Sources are identified for each country.

In our report, 'potentially at risk' means that incidental entanglement is strongly suspected but not actually recorded; 'risk' is inferred for coastal species previously reported killed in the same or similar kinds of fisheries.

The 36 nations and overseas departments within the study area and the 19 species of cetaceans involved in the survey are given in Tables 1 and 2, respectively, and shown in Fig. 1.

Table 2

Cetaceans mentioned in this survey.

Vaquita, *Phocoena sinus*
Tucuxi, *Sotalia fluviatilis*
Common dolphin, *Delphinus delphis*
Bottlenose dolphin, *Tursiops truncatus*
Atlantic spotted dolphin, *Stenella frontalis*
Pantropical spotted dolphins, *Stenella attenuata attenuata* and *S.a. graffmani*
Spinner dolphins, *Stenella longirostris longirostris, S.l. orientalis* and *S.l. centroamericana*
Striped dolphin, *Stenella coeruleoalba*
Clymene dolphin, *Stenella clymene*
Pacific white-sided dolphin, *Lagenorhynchus obliquidens*
Risso's dolphin, *Grampus griseus*
Killer whale, *Orcinus orca*
Short-finned pilot whale, *Globicephala macrorhynchus*
False killer whale, *Pseudorca crassidens*
Pygmy sperm whale, *Kogia breviceps*
Boto, *Inia geoffrensis* (also known as the Amazon river dolphin)
Gray whale, *Eschrichtius robustus*
Humpback whale, *Megaptera novaeangliae*
Unidentified balaenopterid whale, *Balaenoptera* spp.

ACCOUNTS OF CETACEAN-GILLNET INTERACTIONS BY COUNTRY

No data were available for Belize, Guatemala, El Salvador, Guyana, the Netherland Antilles, Haiti and Anguilla. [For data on Grenada, Montserrat, and St. Kitts and Nevis, see Antigua and Barbuda.]

Mexico[1]

Almost all available information on incidental mortality of cetaceans in gillnets in Mexico is limited to the northern Gulf of California, and, therein, to only one species, the vaquita, *Phocoena sinus* (Vidal, In press). However, since 1979, two of us (OV and LTF) have frequently found fresh carcasses of common and bottlenose dolphins (*Delphinus delphis* and *Tursiops truncatus*) on beaches of the central Gulf (coast of Sonora and Sinaloa) which showed signs of entrapment in gillnets (e.g. net marks on head and trunk, tip of dorsal fin and lobes of caudal fin cut away to allow for easier removal from the net, etc.). Interviews with local fishermen also substantiate incidental captures. Information is lacking on total numbers of dolphins killed, but recent findings suggest that incidental mortality could be relatively high locally. For example, 19 common dolphin carcasses were found between late February and late March 1990 along five kilometres of beach at a single location north of Estero de Tastiota, *ca* 60km NE of Guaymas, Sonora. Gillnets are one of the most common types of fishing gear used throughout the Gulf of California and we suspect that dolphins (of at least these two species) are often caught in other areas where gillnets are common (e.g. Los Cabos, La Ribera, La Paz, Loreto and Mulegé in Baja California Sur; Puertecitos, Bahía San Luis Gonzaga and San Felipe in Baja California (Norte) (BCN); El Golfo de Santa Clara, Puerto Peñasco, Desemboque, Puerto Lobos, Puerto Libertad, Bahía Kino, Guaymas, Bahía Lobos, Tobarí, Bahía Santa Bárbara, Yavaros, and Las Bocas in Sonora; and Estero de Agiabampo, Topolobampo, Bahía de Navachiste, Bahía Santa María, Altata, Mazatlán and Teacapán in Sinaloa). Common and bottlenose dolphins, as well as other small cetaceans, are probably caught in other areas of Mexico where gillnets are commonly used.

In addition, at least four entanglements of gray whales, *Eschrichtius robustus*, all in the Gulf of California, have been documented. Riley (1979) reported a gray whale near Punta Colorado, La Ribera, Baja California Sur (BCS), dragging a large gillnet wrapped mainly around its tail. This animal was released when the net was removed by fishermen. K. Balcomb (Center for Whale Research, Friday Harbor, WA, USA) presented a film (XIV International Meeting of the Mexican Society for the Study of Marine Mammals, La Paz, March 1989) on the lengthy efforts culminating in the release of a gray whale entrapped by a gillnet near Playa Palmilla, BCS. Finally, Vidal (1989) reported separate incidents (1978 and 1984) wherein two gray whales (a calf, and a small juvenile) were temporarily trapped in gillnets near Yavaros, Sonora; one of the two calving grounds for this species in the Gulf of California (Gilmore *et al.*, 1967; Findley and Vidal, In press). Both whales were eventually released by local fishermen. Vidal (1989) concluded that entanglements in gillnets are probably an important cause of mortality for gray whale calves in and near the calving grounds in the Gulf, as has been reported for other areas along the migratory route of the species (e.g. Brownell, 1971).

There are two major artisanal fisheries using gillnets in Mexico. We have no data on the fishery along the Gulf of Mexico coastline, other than that gillnets are extensively used. A summary of the available information on the Gulf of California fishery is given below.

Artisanal gillnet fishery of the upper Gulf of California

PORTS

The main ports are San Felipe and Puertecitos in Baja California (Norte) and El Golfo de Santa Clara and Puerto Peñasco in Sonora.

TARGET SPECIES

The main target species are: sierra, *Scomberomorus sierra*, and Monterey Spanish mackerel, *S. concolor* (Scombridae); totoaba and corvinas, *Totoaba macdonaldi* and *Cynoscion* spp. (Sciaenidae); striped mullet, *Mugil cephalus* (Mugilidae); several species of sharks including lamnids (white shark, *Carcharodon carcharias,* and shortfin mako, *Isurus oxyrinchus*), carcharhinids (lemon shark, *Negaprion brevirostris,* Pacific sharpnose shark, *Rhizoprionodon longurio*, and *Carcharhinus* spp., especially blacktip shark, *C. limbatus*, and dusky shark, *C. obscurus*), alopiids (bigeye thresher, *Alopias superciliosus*), sphyrnids (scalloped hammerhead, *Sphyrna lewini*) and triakids (brown smoothhound, *Mustelus henlei*, and sicklefin smoothhound, *M. lunulatus*); and rays including myliobatids (e.g. bat ray, *Myliobatis californica*, and cownose ray, *Rhinoptera steindachneri*), the stingray, *Dasyatis brevis*, and mobulas, *Mobula* spp.

AREA OF OPERATION

Operations occur throughout the entire area, generally close to shore, but often as far as Rocas Consag, a small rocky island in the central part of the (generally shallow) upper Gulf.

VESSELS AND CREW

Boats comprise *pangas* of (mainly) fibreglass, 6–8m long, with 2–3 local men. Boat numbers by port are: San Felipe, 260; El Golfo de Santa Clara, 226; and Puertecitos, 30; there is no information available for Puerto Peñasco. The fish are handled fresh and iced.

GEAR (GILLNETS)

Monofilament nylon nets of the following mesh sizes are used: 85mm (mackerels and corvinas); 100–150mm (sharks and rays) and 200–305mm (totoaba). Totoabas also have been frequently fished with the same nets from shrimp boats. Each *panga* carries 1–2 panels of the following lengths: mackerels and corvinas (459m), sharks and rays (680m) and totoaba (180m).

OPERATIONS

Trips usually last about five hours. Nets are set for either bottom, midwater or near surface fishing at depths between 7 and 40m. They are set (and usually retrieved) in the early morning. The soak time ranges from *ca* 12–24 hours.

[1] Since this review was completed, results of further work have been presented by Zavala-Gonzalez *et al.* and these are published in this volume, pp. 235–8.

ECONOMICS AND HISTORY

In general the fish is supplied to the domestic market, although some of the corvina, totoaba, shark and ray products are exported. The fish are processed fresh, iced, frozen or salt-dried (shark and ray fins, and shark skins and some meat). The important totoaba fishery began on a very small scale in the mid-1920s. From 1929, it responded to a growing USA market and improved its fishing methods, progressing from dynamiting and hook-and-line and primitive gillnetting to (especially after 1942) the use of efficient nylon gillnets (Flanagan and Hendrickson, 1976). Most totoaba fishing boats operated out of San Felipe, El Golfo de Santa Clara and Puerto Peñasco, which had been established near the main fishing areas which include the large Colorado River estuary (Arvizu and Chávez, 1972; Flanagan and Hendrickson, 1976). After a peak catch of 2,261 tons of totoaba meat in 1942, and despite intensified fishing effort, annual catches declined to a minimum of approximately 59 tons in 1975. Consequently, the Mexican government declared a complete ban on fishing the species (Flanagan and Hendrickson, 1976). However, illegal and 'experimental' fishing has continued at El Golfo de Santa Clara and around San Felipe (Vidal, In press; Lagomarsino, 1991). Comparable available information is lacking for the shark and ray gillnet fishery, but it has been growing rapidly in the upper Gulf of California since the early 1940s and continues to operate without controls.

EFFORT DATA

Little information exists for determining total fishing effort in the area. Vidal (In press) summarised available information for 1990 as follows: El Golfo de Santa Clara – 126 gillnets in use for sharks and rays (Feb.-Jul.), 125 for mackerels (Apr.-Sept.) and at least 30 for totoaba (Jan.-May); San Felipe – 300 for sharks and rays (Feb.-Jul.), 300 for mackerels (Apr.-Sept.) and at least 30 for totoaba (Jan.-May); Puerto Peñasco – 136 for sharks and 52 for smaller fishes (Sept. 1989-Jan. 1990); and Puertecitos – 30 for sharks (year-round).

INTERACTIONS WITH CETACEANS

Vaquitas, common dolphins and bottlenose dolphins are regularly caught. Fishermen report that vaquitas become entangled in the early morning, when the net is hauled and they are usually brought aboard. However, for the larger entangled dolphins, the fins are often cut-off to allow removal from the net when the carcass is shaken out and they are rarely brought aboard. Except for two reports by fishermen, all vaquitas were found dead in the net. Some fishermen from San Felipe reported eating vaquita meat. Sometimes, bottlenose or common dolphin meat is used as bait in hook-and-line fisheries, but dolphins are not actively pursued for this purpose in the area. Catch data since 1985 (minimum known catches) are shown in Table 3. The best monitored years were 1985, 1990 and 1991, the years with the highest catches as one might expect (data from Vidal, In press). At least 35 vaquitas are estimated to be killed each year in fishing activities (Vidal, In press). Detailed catch information is lacking for the other two cetaceans involved, although from second-hand information, Mitchell (1975) estimated that perhaps 50 bottlenose dolphins are taken yearly by the shark and totoaba fisheries, mainly north of San Felipe. We know of many unpublished records of both common and bottlenose dolphins entangled in gillnets in the upper Gulf (e.g. at least eight common dolphins between February to June 1984 near Puerto Peñasco, R. Boyer, Centro Intercultural de Estudios de Desiertos y Océanos, *in litt.*, 11 February 1988, Puerto Peñasco, Sonora).

All marine mammals are legally protected in Mexico.

Table 3

Summary of the incidental mortality of *Phocoena sinus* in fishing activities in the Gulf of California, 1985-1992 (Vidal, In press)*.

Year	No. individuals	Year	No. individuals
1985	35	1989	13
1986	>2	1990	36
1987	6	1991	22
1988	9	1992	5

* Mortality numbers are minima; the best monitored years were 1985, 1990 and 1991.

Considering the probable low population size and very limited range of the vaquita, the current (and potential) levels of incidental mortality due to fishing activities, the difficulties in implementing and enforcing long-term conservation measures quickly and other detrimental factors affecting the upper Gulf of California ecosystem, the vaquita is in immediate danger of extinction (Robles *et al.*, 1987; Vidal, In press). On 10 June 1993, the Mexican Government declared the Biosphere Reserve of the Upper Gulf of California and the Colorado River delta to protect the vaquita, the totoaba and their natural habitat (Vidal, 1993). At present, we have no systematically gathered information on the incidental mortality of the region's common and bottlenose dolphins but mortality is suspected to be high, and other fisheries (e.g. the purse-seine fishery for sardines, etc.) are possibly detrimental (Mitchell, 1975; Vidal *et al.*, 1993).

CONCLUSION

Cetaceans potentially at risk in Mexican waters are: humpback whales, *Megaptera novaeangliae* (Gulf of California and rest of Mexican Pacific); spotted dolphins, *Stenella attenuata graffmani* (Pacific); common dolphins (Gulf of California, Pacific and Gulf of Mexico); bottlenose dolphins (Gulf of California, Pacific and Gulf of Mexico); Pacific white-sided dolphins, *Lagenorhynchus obliquidens* (southwestern Gulf of California); the three subspecies of spinner dolphins (Perrin, 1990), *S. longirostris longirostris* (tropical and subtropical Pacific), *S.l. orientalis* (endemic to the eastern Pacific) and *S.l. centroamericana* (coastal waters of Mexico and Central America); and Atlantic spotted dolphins, *S. frontalis*, and *S. longirostris* (Gulf of Mexico).

There is an urgent need to monitor and to reduce the incidental mortality of the vaquita in fishing activities. Vidal (In press) identified the following research needs and management requirements for the conservation of this species: (1) reduce incidental mortality by enforcement of existing law prohibiting totoaba fishing activities; (2) determine the magnitude of incidental mortality in other gillnet fisheries (i.e. sharks and rays, mackerels, corvinas, etc.) to provide accurate estimates of the total annual rate of incidental mortality; (3) investigate possible modified or alternative fishing methods (e.g. net modifications and/or deployment) that could reduce incidental mortality; and (4) obtain accurate estimates of population size and possible seasonal movements. In addition, effort should be made to obtain more information on incidental mortality of

common and bottlenose dolphins and gray whales and the possible effects of this mortality on their regional populations.

Honduras[1]

PORTS

The major ports are Puerto Cortés, Tela, La Ceiba, Roatan, Guanaja, Trujillo and Puerto Lempira on the Atlantic coast and San Lorenzo and Amapala on the Pacific coast.

AREA OF OPERATION

Operations on the Atlantic coast are within 4.5km of the shore.

GEAR (GILLNETS)

Information on the number of boats using gillnets was not provided. The monofilament nylon nets have a mesh size of 75mm. Panel lengths range from 50–400m and there are 1–4 panels/fisherman.

OPERATIONS

A typical trip lasts from 1–3 days and each fisherman makes 150–180 trips/yr. Bottom and surface fishing occurs in waters ranging from 2–25m in depth. The fish are processed fresh.

INTERACTIONS WITH CETACEANS

Small cetaceans have been incidentally killed. Suspected species are *Stenella attenuata graffmani* (Pacific), the Costa Rican spinner dolphin (*S. longirostris*, Pacific), bottlenose dolphins (Pacific, Atlantic), tucuxi (*Sotalia fluviatilis*, Atlantic – see Carr and Bonde, 1993) and common dolphins (Pacific, Atlantic). Dolphins generally become entangled at night, at entrances to rivers or coastal lagoons (and are thus most likely bottlenose dolphins). There are no cetacean catch data, with incidental mortality being reported as occurring 'rarely'. No information was provided on any utilisation of the by-catch and no efforts to reduce the by-catch were reported.

In addition, 166 boats were reported to participate in a lobster fishery deploying traps, but interactions with cetaceans are probably minimal.

Nicaragua[2]

Artisanal fisheries use gillnets set from small boats (4m long) and catch snappers, sciaenids and other small fishes along the coasts (within 10km offshore). There are no data on incidental mortality, but bottlenose, tucuxi (Atlantic), pantropical spotted (Pacific only) and common dolphins are potentially at risk. Apparently, a lobster fishery also exists, possibly using traps.

Costa Rica[3]

Approximately 66 fishing communities exist along the Pacific coast, the most important (by number of boats) are Punta Arenas, Isla Chira, Playa del Coco, Quepos, Costa del Pájaro, Portete, Cuajiniquil, Isla Venado, Samara, Golfito, Chomes, Puerto Thiel and Manzanillo. Along the Atlantic coast the principal ports are Puerto Limón, Barra del Colorado and Puerto Viejo.

TARGET SPECIES

The following species are caught: corvinas (Sciaenidae, *Cynoscion*); seabasses (Serranidae, *Epinephelus*); snappers (Lutjanidae, *Lutjanus*); sierra mackerels (Scombridae, *Scomberomorus*); jacks (Carangidae, *Caranx*); snooks (Centropomidae, *Centropomus*); dolphinfish or dorado (Coryphaenidae, *Coryphaena hippurus*); and sharks of the families Sphyrnidae (hammerheads, *Sphyrna*) and Carcharhinidae (requiem sharks, *Rhizoprionodon longurio, Carcharhinus porosus, C. leucas* and *Galeocerdo cuvier*).

AREA OF OPERATION

Fishing takes place along the entire Pacific coast within *ca* 54km offshore (80% within 22km), in the Gulf of Nicoya and near the far-offshore Isla del Coco and the Costa Rican Dome. Fishing is also mainly coastal in the Atlantic.

VESSELS AND CREW

Boats are made of wood and fibreglass. Two types of vessels operate in the Pacific: *pangas* (4–8m long, 60% of all boats) and *lanchas* (7–12m). In the Atlantic *pangas* (4–8m) comprised 95% of all boats. Over 5,300 boats operated in 1990: Punta Arenas (1,100); Isla Chira (602); Playa del Coco (200); Quepos (260); Costa del Pájaro (230); Portete (160); Cuajiniquil (175); Isla Venado (140); Samara (62); Golfito (59); Chomes (80); Puerto Thiel (60); Manzanillo (25); plus 853 distributed in smaller communities. Country totals were also provided for the following years: 1981 (502 boats); 1982 (615); 1983 (761); 1984 (800); 1985 (1,038); 1986 (1,163); 1987 (2,707) and 1989 (3,000). The fish are handled fresh and iced. Crews range in size from 1–3.

GEAR (GILLNETS)

The gillnets used have a mesh size of 85–150mm (the minimum allowed by law is 85mm). Panels are 500-600m long and 7–10m deep. Both set and drift nets are used.

OPERATIONS

Trips usually last about 1 day (60% of all boats) or 4–5 days. Bottom, midwater and surface fishing takes place in waters ranging from 5–100m.

ECONOMICS

The catch is mostly for domestic use. However, some snappers, sea basses, dolphinfish and shark fins are exported (both fresh and frozen).

DEVELOPMENT OF FISHERY AND CURRENT TRENDS

Both fishing effort and catches have been increasing since 1979, especially since 1981. Between 1981 and 1987, the number of artisanal fishing boats increased four times, with nearly 80% of fishing concentrated within 22km of the coast.

INTERACTIONS WITH CETACEANS

Although no information on incidental catches was provided, bottlenose, pantropical spotted, Costa Rican spinner and common dolphins are potentially at risk along the Pacific coast, while bottlenose, tucuxi and common dolphins may be at risk along the Atlantic coast.

[1] Information from M. Castellón (*in litt.*, 27 August 1990), Departamento de Pesca, Secretariat of Natural Resources of Honduras, Tegucigalpa.

[2] The only relevant information was provided by R. Sánchez (*in litt.*, 8 February 1990), Centro de Investigaciones Pesqueras, Nicaraguan Ministry of Fisheries, Managua.

[3] Information provided by E. Madrigal (*in litt.*, 10 July 1990), Departamento de Pesca y Caza, Costa Rican Ministry of Agriculture, San José.

Considering the relatively high fishing effort, these fisheries should be monitored to determine any interactions with cetaceans.

Panama[4]

There are two main gillnet fisheries in Panama, both off the Pacific coast. The available information is summarised below.

Shark fishery of the Pacific Coast

PORTS

The main ports are Pedregal, Provincia de Chiriquí; Vacamonte, Provincia de Panama and Ciudad de Panama.

TARGET SPECIES

The target species include requiem sharks (Carcharhinidae), smoothhounds (Triakidae) and hammerheads (Sphyrnidae).

AREA OF OPERATION

Fishing operations are coastal and around islands.

VESSELS

Boats are made of wood, steel or fibreglass and are from 15–23m long. The number of boats operating out of each port varies, but no more than ten operate at a given time. The fish are iced.

GEAR (GILLNETS)

Mesh sizes range from 150–200mm. Panels are 126–180m long and 7.5–11.0m deep. Each boat carries 2–4 panels.

OPERATONS

Trips last from 5–15 days and each boat usually makes 15–25 trips annually. About 2,000 panels are fished each year in total. Both set and drift nets are used, with most fishing at the bottom in depths of 18–54m. The soak time is from 6–10 hours.

ECONOMICS AND HISTORY

The product is sold fresh (meat) or salt-dried (fins, skin). Total landings are estimated to be 68,000–90,000 kg/yr. Although the fishery was very important some years ago, it has been decreasing due to the lack of good markets.

INTERACTIONS WITH CETACEANS

At least bottlenose and common dolphins and *Stenella* spp. have been occasionally killed to use their meat for bait for the shark fishery (Vidal, 1992).

Artisanal fishery for fin-fishes ('peces de escama') off the Pacific Coast

PORTS

Fishing occurs from many localities along the coast in coastal waters.

TARGET SPECIES

The main target species are sciaenids, mackerels (Scombridae) and snooks (Centropomidae, *Centropomus*).

VESSELS

The fishery involves some 3,000–4,000 wooden boats, 8–10.5m long. The fish are handled fresh or iced.

[4] Information was provided by D.H. Arosemena (*in litt.*, 24 August 1990), Dirección General de Recursos Marinos, Ministry of Commerce and Industries of Panama.

GEAR (GILLNETS)

The nets used have mesh sizes of 90–140mm. Panels are 180m long and 9–14m deep. Each vessel carries from 1–4 panels.

OPERATIONS

Trips last from 1–5 days and boats usually make 50–100 trips/yr totalling about 225,000 panels. Surface and bottom fishing takes place in waters of 1.8–36m depth using set nets. The soak time is 4–6 hours.

ECONOMICS AND HISTORY

This was a very important fishery in past years, but presently is decreasing.

INTERACTIONS WITH CETACEANS

Only one definite record has been reported; that of an 'adult male' bottlenose dolphin caught *ca* 60km east of Panama City. Pantropical spotted dolphins (Pacific), common dolphins (Pacific and Caribbean) and tucuxi, (Caribbean) are potentially at risk. There are no laws or regulations applying to cetaceans, but there are a number of coastal conservation areas that may provide protection for some of their habitats.

Colombia

The few documented incidental kills of cetaceans in gillnets are from Vidal (1990). Information on the gillnet fisheries is based on Hernández (1986) and Arias and Anzola (1989).

Artisanal fishery of the Atlantic coast of Colombia

PORTS

The main ports are Dibulla, Riohacha, Manaure, Cabo de la Vela, Bahía Portete, Pueblo Viejo, Tasajera, Gaira, Santa Marta, Taganga, Parque Tayrona, Cartagena, Galerazamba, Barú, Tolú, Islas del Rosario, Archipelago of San Bernardo, El Rincón, Caimanera, Puerto Viejo, Coveñas, Berrugas, Aspescordel, Coopetolú, Turbo, El Roto, Punta Urabá, Ciénega, Unguia, Bajo Atrato, and San Andrés and Providencia Islands.

TARGET SPECIES

The major target species are mackerel (Scombridae, *Scomberomorus*), snooks (Centropomidae, *Centropomus*), snappers (Lutjanidae, *Lutjanus*), jacks (Carangidae, *Caranx*) and various species of sharks.

AREA OF OPERATIONS

Fishing occurs between the Gulf of Urabá and Guajira peninsula (the border with Venezuela).

VESSELS AND CREW

Boats are made of wood, fibreglass and aluminum and are of two types: *cayucos* (4–6m long) and *canoas* (8-10m). The number of boats is only available for the Santa Marta region where 440 operate. The fish are handled fresh and iced. Crew size ranges from 2–4.

GEAR (GILLNETS)

Data are available only for the Santa Marta region where the stretched mesh size ranges from 85–400mm. Most nets are made of monofilament nylon but there are some multifilament nets. Panels are 18–600m long and 3.2–21.5m deep. There is usually only one panel per boat.

OPERATIONS
Again, data are only available for the Santa Marta region where set nets are usually used. Vessels operate for about 247 days per year. The soak time ranges from 2–16 hrs.

ECONOMICS
The fish, either processed fresh, frozen or canned are for the domestic market.

INTERACTIONS WITH CETACEANS
Reported catches (Vidal, 1990) are of one individual each of the pygmy sperm whale, *Kogia breviceps* (November 1988, Gulf of Morrosquillo), tucuxi (September 1986, Bahía de Cispatá, mouth of Sinú River), Risso's dolphin, *Grampus griseus* (Islas del Rosario), bottlenose dolphin (1989, Tierra Bomba, *ca* Cartagena), Atlantic spotted dolphin, *Stenella frontalis* (April 1989, Bahía de Barbacoas, *ca* Barú). Pantropical spotted, striped, *S. coeruleoalba*, and common dolphins and short-finned pilot whales, *Globicephala macrorhynchus*, are potentially at risk (Vidal, 1990).

DISCUSSION
In view of the large mesh-sizes of the nets, sizes which regularly catch cetaceans in other regions (e.g. Read *et al.*, 1988; Vidal, In press; this paper), this fishery should be monitored to document the number and species of dolphins incidentally killed.

Artisanal fishery of the Pacific coast of Colombia
PORTS
The main ports are Bahía Solano, Ensenada de Utría, Golfo de Upica, Boca Charambirá, Punta Soldado, Puerto Buenaventura, Pueblo Nuevo, Punta Merizalde, Saija, Chacón, Corozal, Playa de Coco, Trapiche, Noanamito, Chontal, Milagros, Chajal and Salahonda.

TARGET SPECIES
The major species caught are mullets (Mugilidae, *Mugil*), croakers and corvinas (Sciaenidae), snappers (Lutjanidae, *Lutjanus*) and various species of sharks.

AREA OF OPERATION
Fishing occurs between the borders with Ecuador and Panama.

VESSELS AND CREW
Wooden and fibreglass boats, 6–8m and 10–12m long, are used. The fish are handled fresh and iced.

INTERACTIONS WITH CETACEANS
Humpback whales, bottlenose, common and two types of spotted dolphins (*S.a. attenuata* and *S.a. graffmani*) are potentially at risk (Vidal, 1990). One of us (KVW) interviewed members of the fishing community at Buenaventura in March 1990. Although nearly all were circumspect on the matter, one person stated that harpooning of dolphins for bait is a common practice in the area.

Artisanal fishery of the Orinoco River Basin
PORTS
The main ports are Puerto López, Puerto Gaitán and Puerto Carreño (Meta River), San José del Guaviare, Puerto Inírida and Barrancominas (Guaviare and Inírida rivers) and Arauca River.

TARGET SPECIES
Fishing is mainly for pimelodid catfishes (*Sorubim*) and characids (*Colossoma*).

AREA OF OPERATION
Fishing takes place in the Arauca, Meta, Guaviare, Vichada and Tomo rivers.

VESSELS
Wooden vessels, 4–10m long, are used. The fish are handled fresh and iced.

INTERACTIONS WITH CETACEANS
Boto, *Inia geoffrensis*, and tucuxi are at risk (Vidal, 1990; Borobia *et al.*, 1991).

Artisanal fishery of the Colombian Amazon
PORTS
The main ports are Leticia, Puerto Nariño, La Pedrera, Araracuara and Alto Caquetá, Orteguaza and Putumayo rivers.

TARGET SPECIES
The target species are pimelodid catfishes and characids.

AREA OF OPERATION
Fishing occurs in the Amazon, Putumayo, Caquetá, Orteguaza and Vaupés rivers.

VESSELS
Wooden boats, 3–8m long, are used. The fish are handled fresh and then dried or iced.

INTERACTIONS WITH CETACEANS
At least two boto were caught near Puerto Nariño in *ca* 1986 (Vidal, 1990). Beltrán and Trujillo (1992) reported that during 1991–2, 17 dolphins (botos and tucuxis) were found dead in an area of *ca* 80km^2 in the Colombian Amazon: 55.6% in gillnets, 22.2% hunted and 11.1% struck by boats.

Venezuela
According to Northridge (1984), most of the reported 167,000 tonnes of landed catches of fishes by Venezuela in 1981 came from artisanal fisheries along the coast, and included mullets (Mugilidae), croakers and corvinas (Sciaenidae), groupers (Serranidae), grunts (Haemulidae) and sharks. Caldwell and Caldwell (1971) reported that beach-seine nets used along the Venezuelan coast and on offshore islands incidentally kill some cetaceans, mainly bottlenose dolphins and tucuxi around some river mouths. Botos are occasionally incidentally killed in fishing gear, and those dolphins taken are sometimes eaten (O'Shea *et al.*, 1986).

Agudo (1990) reported that in the area between 9°55'-11°25'N and 61°50'-64°30'W, local fishermen use 80-130mm mesh gillnets 50–200m long and 5–12m deep. In February 1987, 1,537 nets were reported fishing in this area. Although no systematic efforts have been made to determine the species of cetaceans involved, or the rate of incidental mortality and its impact on the cetacean populations, preliminary reports indicate that since early 1988, cetacean deaths in gillnets have been 'frequent'. Animals caught have been used for bait and for human consumption. Agudo (1990) reported the sale of six dolphins (*Stenella frontalis*, *S. longirostris* and *S. clymene*) to be used as bait in the bottom-longline shark fishery. He

also reported that other cetaceans incidentally killed were common and bottlenose dolphins, tucuxi and *Balaenoptera* sp. Venezuelan longliners operating out of French Guiana occasionally harpoon dolphins for bait (Van Waerebeek, 1990). Pantropical spotted dolphins, false killer, short-finned pilot and humpback whales are potentially at risk.

Surinam

Information is based on two publications describing Surinam's fisheries (Charlier, 1988; 1989). The only data on cetacean-fisheries interactions come from osteological materials from incidentally killed tucuxi housed in two museums in the Netherlands, the Rijksmuseum van Natuurlijke Historie, Leiden (C. Smeenk, *in litt.*, 20 July 1990) and the Zoologisch Museum, Amsterdam (P.J.H. van Bree, pers. comm., 13 June 1990). Offshore fishing activity in Surinam is dominated by a Venezuelan red snapper (*Lutjanus purpureus*) line fishery and an international trawl fishery for shrimp and fin-fish. Between 18,000 and 20,000 tonnes of penaeid shrimps are caught annually by a flotilla of 120 to 140 trawlers mainly from South Korea and Japan. The coastal artisanal fishery is described below.

Artisanal coastal and estuarine fin-fish fishery

PORTS

The main ports are Paramaribo, Braamspunt and Pomona. Boats are also based in or near villages (85% along the lower part of the Surinam River).

TARGET SPECIES

Fishing is mainly for inshore demersal species. Large demersal species include only a few corvinas (Sciaenidae: *Cynoscion acoupa*; *C. steindachneri*) and sea catfishes (Ariidae: *Arius parkeri*; *A. proops*). Small demersal species include other corvinas and croakers (Sciaenidae: *Macrodon ancylodon*; *Cynoscion virescens; Nebris microps*), other sea catfishes (Ariidae: *Arius grandicassis; A. quadriscutis; A. passany; Bagre* spp., etc.), snappers (Lutjanidae: *Lutjanus synagris*), grunts (Haemulidae), snooks (Centropomidae) and a few other fish families.

AREA OF OPERATION

Fishing occurs in shallow coastal waters (<15m deep) including estuaries of the Corantijn, Nickerie, Coppename, Surinam and Marowijne rivers.

VESSELS AND CREW

The smallest boat used is the *korjaal* (flat-bottom canoe) used in lagoons. Larger boats of similar type are used in rivers and estuaries. In coastal marine waters two types of 'Guyana' boats predominate: decked and open gillnetters. Decked 'Guyana' boats seen in Cayenne, Guyana, were typically *ca* 15m long (KVW, pers. obs.). The available information on numbers of boats for Surinam are: decked gillnetters (30 in 1989), open gillnetters (81 in 1987), estuary gillnet fishery (87 in 1987), riverine drift and set gillnets (74 in 1987). Fish are handled fresh and iced. Crew size varies with the type of vessel: decked gillnetter, 4–5 men; open gillnetter, 3–4; estuarine, 1–4; and riverine, 3–4. Total numbers of fishermen were: 284 on open gillnetters; unknown on decked gillnetters (in 1987, reported to have increased now); 218 in the estuarine gillnet fishery; and 205 in the riverine set and drift gillnet fishery. In the coastal fisheries, 5–50% of the crew are local (foreigners are not specified but are supposedly mainly from Venezuela and Guyana) while in the estuarine and riverine fisheries 50% of the crew are locals.

GEAR (GILLNETS)

Both set and drift nets are used with a range of mesh sizes. Panels are up to 4km long and 10m deep.

OPERATIONS

Gillnets take *ca* 50% of total landings (40% for driftnets only). All present fishing methods are directed towards demersal species and the pelagic element is almost completely unexploited.

ECONOMICS AND TRENDS

Present overall production (all fisheries except shrimp) is estimated at 11,000 tonnes (about three times that recorded in the official statistics). Domestic consumption is estimated at 6,800 tonnes with the remainder of the fish being exported. Fishery resources of the Surinam Exclusive Economic Zone apparently include several underexploited fin-fish stocks and Charlier (1989) suggested that improved versions of the present coastal gillnetters should be developed.

INTERACTIONS WITH CETACEANS

Tucuxi are known to be incidentally killed: three animals were presumably caught in gillnets at the mouth of the Surinam River and two animals at the mouth of the Coppename River (May 1964-November 1972), the skeletal materials are kept in Amsterdam. Three tucuxi at Pomona and one at Braamspunt were caught in 'shrimp traps' at the mouth of the Surinam River (April-June 1963) and the skeletal materials are in Leiden. Seven other animals were also received in Leiden (February-May 1971) from the Fishery Department of Surinam that were probably caught in fishing activities at the mouth of the Surinam River (at Braamspunt or Pomona). Bottlenose dolphins and humpback whales are potentially at risk. Fishermen who seemed reluctant to provide details admitted that dolphins were caught 'occasionally' but dolphin meat is not consumed and carcasses are discarded at sea (C. Lietaer, ABOS, Paramaribo, *in litt.*, 9 October 1990).

French Guiana

Data are based on observations of fishing gear and vessels and on personal interviews with both local and foreign fishermen conducted by one of us during a visit from 25 April-1 May 1989 (Van Waerebeek, 1990).

PORTS

Only Cayenne (04°56'N, 52°20'W) and Saint-Laurent-du-Maroni, Marowijne River (05°30'N, 54°02'W) were surveyed.

TARGET SPECIES

The target species of the fishery are grey mullet (Mugilidae), several sciaenids and carangids, tarpon (*Megalops*) and sharks.

AREA OF OPERATION

Fishing occurs near Cayenne and on the Marowijne River. Reportedly, foreign fishermen based at Cayenne also operate in Surinam and Brazilian waters. Local artisanal fishermen mainly fish close to shore.

VESSELS AND CREW
Wooden boats, typically 15–20m long, are used. About 20–25 Brazilian vessels and approximately a dozen Venezuelan boats operate out of Cayenne. Crewmen are all locals at Saint-Laurent-du-Maroni. The fish are handled fresh and iced.

GEAR (GILLNETS)
Most nets are made of multifilament nylon with a mesh size of 200mm, but at least some small-mesh monofilament nets are used, presumably in the inshore fishery. One net observed being repaired had a panel size of 2,000m long and 7m deep.

OPERATIONS
Trips may last up to a week. The Brazilian vessels operate throughout most of the year.

ECONOMICS
The fish (fresh and iced) is for the domestic market.

INTERACTIONS WITH CETACEANS
At least two species of small cetaceans are commonly mentioned by fishermen as incidentally killed. The smaller one is almost certainly the tucuxi and the 'much' larger one may be either the bottlenose or common dolphin. Dolphins are generally considered of no value and are usually discarded at sea. Some Brazilian fishermen said they had tried dolphin meat but did not particularly like it. However, dolphins are occasionally harpooned for fish bait. One fisherman estimated that for every trip lasting a week, about 4–5 dolphins become entangled, but actual effort data (i.e. number of trips) are not available. Van Waerebeek (1990) deduced from fishermen's assertions that the Brazilian gillnet fishery off French Guiana may account for considerable dolphin mortality, possibly as many as a few thousand animals per year. As an overseas department, French Guiana is governed by the same laws as France, and an order (20 June 1970) by the Director of French Maritime Fisheries prohibits the destruction, pursuit, or capture by any means, whether intentional or unintentional, of all species of dolphins (Marashi, 1986).

DICUSSION
Although information is preliminary, it appears that relatively high numbers of dolphins may have been killed. This suspected mortality may be significant for relatively small and possibly localised populations of such species as the tucuxi and the bottlenose dolphin. It is important that the fisheries are monitored to accurately estimate the extent of this incidental mortality. Also, as recommended by Van Waerebeek (1990), special attention should be given to existing and proposed marine and estuarine conservation areas, such as the Sinnamary and Iracoubo estuary, Kaw Marshes, Pointe Béhague and lower Oyapock River. Observers should be placed on the Brazilian vessels to document and evaluate the extent of incidental kills and the species of dolphins involved.

Trinidad and Tobago[5]

PORTS
Trinidad is the main fishing port, but the area of operation was not reported.

TARGET SPECIES
The main species taken are the serra Spanish mackerel (*Scomberomorus brasiliensis*) and the king mackerel (*S. cavalla*).

VESSELS
At least 107, 10m-long boats operate out of Trinidad.

GEAR (GILLNETS)
Most nets are of multifilament nylon (set at night) although there are a few monofilament nylon nets (set during the day). Mesh size is 100–110mm and panels are 100–150m long and 10m deep. Each boat carries 1–2 panels.

OPERATIONS
Trips usually last overnight. The nets are mostly of the drift type and are deployed at dusk and retrieved around midnight after a 6 hour soak time. Fishing usually occurs in shallow (<50m) waters and takes place at the surface. Sometimes monofilament large-mesh nets (for sharks) are bottom set. A total of 5,325 trips was made in 1989.

TOTAL LANDINGS
In 1989, 1,662 tonnes of serra Spanish mackerel and 174 tonnes of king mackerel were landed (figures include some hook-and-line catches).

INTERACTIONS WITH CETACEANS
The only recorded entanglement was of a killer whale (Ottley *et al.*, 1988). The fisherman reported that the animal became entangled in his drift gillnet as it was being hauled, in the Gulf of Paria between Kronstadt and Gaspar Grande islands, in 6–7m of water.The trapped animal died after struggling for over an hour. The whale was one of about 15 individuals. Bottlenose dolphins and humpback whales are potentially at risk.

DISCUSSION
Although only one documented incidental take exists, the relatively high fishing effort makes it important that more information is gathered. B. Chakalall (FAO) reported some use of driftnets around both islands by day fishermen who leave the nets to drift for 3–5 and sometimes up to 8–10 hours (H. Gieben, 16 November 1986, *in litt.*, to S. Leatherwood).

However, of more concern is the fact that Taiwanese drift-netting activities have been observed for the first time in the western Atlantic-Caribbean region. S. Johnson (Secretary of the Trinidad and Tobago Game Fishing Association) reported[6] the presence of 15 Taiwanese vessels at dock in Port of Spain. According to the report, American experts who inspected photographs of the vessels provided by Johnson identified drift nets aboard. Moreover, M.G. Sturm (*in litt.*, 17 July 1990) of the Trinidad and Tobago Institute of Marine Affairs, reported that several Taiwanese fishermen have been landing catches at Trinidad's main markets. If allegations of high-seas gillnetting operations in the area are confirmed, the impact on cetacean populations should be evaluated as soon as possible.

[5] Fishery information was provided by M.G. Sturm (*in litt.*, 8 August 1990), Trinidad and Tobago Institute of Marine Affairs.

[6] *The Arizona Daily Star*, Tucson, AZ, USA, 16 August 1990.

Barbados[7]

The limited information available concerns gillnets and fish traps used by Barbadian fishermen. Gillnets are used to catch flying fishes. The surface set nets have a mesh size of 41–45mm. Panels are 10–30m long and 3m deep. Fish traps ('Antillean traps') are used to catch 'reef fishes'. Mesh size varies from 25–38mm and traps are 2–3m long and 1–2m deep and set at depths of 5–100m. At least three species of cetaceans are potentially at risk: bottlenose dolphin, short-finned pilot whale and unidentified species of spotted dolphins.

Martinique

No reply to our request for data was received. The only information is that multifilament gillnets, apparently of small-mesh, have been seen (September 1990) in small, open wooden boats used for near-shore fishing in the vicinity of Fort de France. The vessels were equipped with high-powered outboard motors and were mostly launched from the beach (B. Van Waerebeek, pers. comm.). Also see Guadeloupe.

Organisation of Eastern Caribbean States (OECS)[8]

Information on three types of fishery (pot, gillnet and beach seine)[9] was provided by the OECS, although the areas of operation were not provided by country. Information for some individual countries was also provided and is included at the end of this section.

Pot fishery (ports not given)

TARGET SPECIES

The main target species are snappers (Lutjanidae), sea basses and groupers (Serranidae), surgeonfishes (Acanthuridae), jacks (Carangidae), squirrel- and soldier-fishes (Holocentridae), goatfishes (Mullidae), parrotfishes (Scaridae), grunts (Haemulidae=Pomadasyidae) and lobsters.

AREA OF OPERATIONS

The fishery occurs inshore on shallow shelf waters, banks and reef ecosystems.

VESSELS AND CREW

Vessels (2.5–8.8m long) made of wood and fibreglass are used. The catch capacity ranges from 364–682kg. Fish are handled fresh. Crew size is usually 2–3 men.

GEAR (POTS)

Pots are made of wire or bamboo and have mesh size of 32–51mm. The gear is hauled manually.

OPERATIONS

Mainly bottom fishing is carried out with a soak time of 2–3 days and a retrieval time of 4–6 hours. Catches usually range from 0–236kg per pot.

ECONOMICS

Fishermen can earn US$1.80–2.85/kg for reef fishes and US$4.00–8.50/kg for lobsters. The catch is processed frozen.

INTERACTIONS WITH CETACEANS

No cetacean entanglements were reported.

Gillnet fishery for flying fishes and demersal fishes, and turtles (ports not given)

TARGET SPECIES

The main target species are flying fishes (Exocoetidae), demersal fishes e.g. snappers (Lutjanidae), sea basses and groupers (Serranidae), and sea turtles.

AREA OF OPERATIONS

Fishing occurs in both territorial and contiguous zones.

VESSELS AND CREW

Open wooden and fibreglass vessels (2.5–9.2m) are used. Sloops (4.3–19.8m) are also used in Grenada and Dominica. Crew size ranges from 2–4.

GEAR (GILLNETS)

Mesh sizes (stretched) vary by species: flying fishes, 18mm; demersal fishes, 72mm; sea turtles, 128–144mm. Nets are made of nylon and panels are 100–165m long and *ca* 5m deep. The gear is hauled manually.

OPERATIONS

Fishermen operate daily in waters of 36–54m deep. Nets are set in the evening and the soak time is about 12 hours. Catches are usually 0–36kg per panel.

ECONOMICS AND HISTORY

Fishermen can earn US$2.00–2.85/kg. Gillnets have been traditionally used for pelagic fishes (e.g. flying fishes). In Grenada and Dominica some fishermen are now using bottom-set gillnets for demersal fishes.

INTERACTIONS WITH CETACEANS

No incidental catches were reported. Bottlenose and common dolphins and humpback whales are potentially at risk.

Beach seine fishery (ports not given)

TARGET SPECIES

The main species caught are clupeids, carangids and belonids.

AREA OF OPERATIONS

The fishery occurs in coastal waters.

VESSELS AND CREW

Open wooden and fibreglass vessels (2.5–9.2m long), known in Grenada as 'double enders', are used. Crew size can reach 8–10.

GEAR (BEACH-SEINES)

Nets of mesh size 25–38mm made of twine (thicker) or nylon are used. Panel length and depth were reported as 500–600 x 200–300 meshes, respectively. Nets are hauled manually.

[7] Information provided by the Fisheries Officer, Fisheries Division, Ministry of Agriculture, Food and Fisheries, St. Michael, *in litt.*, 24 July 1990.

[8] Most of the information for the members and associated states of the OECS, which includes Antigua and Barbuda, British Virgin Islands, Dominica, Grenada, Montserrat, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, was provided by D.C. Joseph (*in litt.*, 17 September 1990), Fisheries Unit, OECS, Kingstown, St. Vincent and the Grenadines.

[9] Scoop/dip nets are also used to catch flying fishes and other fishes which are attracted to a temporary fish aggregating device made of floating dried banana leaves.

OPERATIONS
About 144–192 trips per year are made. Up to 1,360kg of fish are caught per panel.

ECONOMICS
Fishermen are paid US$1.00–2.50/kg.

INTERACTIONS WITH CETACEANS
No cetacean entanglements were reported. Unless they are very large beach seines, they should have little effect on dolphins, but ambiguous data makes it difficult to judge.

St. Vincent and the Grenadines
No gillnet or trap interactions with cetaceans have been recorded. Traditional cetacean fisheries for 'blackfish' (*Globicephala*) and humpback whales are described by several authors (e.g. Caldwell and Caldwell, 1975; Price, 1985).

St. Lucia
No incidental catches of cetaceans are reported. Reeves (1988) summarised information on direct catches of cetaceans, mainly the short-finned pilot whale.

Dominica
Northridge (1990) reports that the Barbados driftnet type has been introduced to Dominica. The current status of the hand-harpoon fishery for the short-finned pilot whale (IWC, 1982) is unknown. This species is potentially at risk from gillnets.

Antigua and Barbuda
Some information was provided for Antigua alone: a total of less than 50 gillnets (both set and drift) are used to catch sea turtles. Mesh size is limited to 38mm, and nets measure under *ca* 900m in length and 100m or less in depth (E. Boyer, Fisheries Division, Ministry of Agriculture, Fisheries, Lands and Housing, St. Johns, Antigua, *in litt.*, 13 July 1990, to J. Lien, Whale Research Group, Memorial University of Newfoundland, Canada; received by the authors 24 October 1990).

Virgin Islands (British)
Fisheries officers maintain that there are no fishery incidents involving cetaceans. However, it has been rumoured that 'ghost' gillnets have washed up on the shores of Anegada, British Virgin Islands' northernmost island, probably from illegal fishing by foreign vessels (H. Gieben, West Indies Laboratory, St. Croix, US Virgin Islands, *in litt.*, 16 November 1986, to S. Leatherwood, San Diego, California, USA; received by the authors August 1990). Bottlenose dolphins, *Stenella* spp., short-finned pilot whales and humpback whales are potentially at risk.

Virgin Islands (USA)[10]
Only scant information is available. Fishing gear employed by commercial fishermen includes monofilament gillnets and surround nets for the harvest of reef fishes, such as jacks (Carangidae) and parrotfishes (Scaridae). There are no records of cetacean by-catches in the fishery. US laws protecting marine mammals are applicable in the US Virgin Islands.

[10] Information was provided by Wm. Tobias (*in litt.*, 4 October 1990), Department of Planning and Natural Resources, Division of Fish and Wildlife, Government of the Virgin Islands of the United States, St. Croix.

Guadeloupe
The only information available is that members of the French delegation at a 1986 Workshop on Coastal Protected Areas, hosted by the Eastern Caribbean Natural Areas Management Programme, mentioned the use of gillnets in Guadeloupe to H. Gieben (*in litt.*, 16 November 1986, to S. Leatherwood; received by the authors August 1990). Japanese and Koreans reportedly deploy 'tri-nets', which are three nets with different size meshes hung together. Because the foreign fishermen are secretive about their activities, little other information is available. The short-finned pilot whale is potentially at risk.

Puerto Rico (USA)
We received no reply to our request for data. The only information available is that gillnets (both set and drift types) are used and that a minimum 38mm mesh-size is allowed (J.E. Rivera, *in litt.*, to J. Lien; received by the authors 24 August 1990). H. Gieben (*in litt.*, 16 November 1986, to S. Leatherwood) cites Dr. Joe Kimmel of the Fisheries Research Laboratory of the University of Puerto Rico as stating 'that he was not aware of any gillnet fishing going on nor had heard of porpoises or whales being taken.' USA laws protecting marine mammals are applicable in Puerto Rico. Bottlenose, common and spinner dolphins, *Stenella* spp., short-finned pilot whales and humpback whales are potentially at risk.

Dominican Republic[11]

Artisanal fishery of Samaná Bay

PORTS
The main ports are Sánchez and Puerto Viejo. Fishing takes place in Samaná Bay.

TARGET SPECIES
The main target species are snooks (Centropomidae) and mullets (Mugilidae).

VESSELS AND CREW
Wooden *cayucos* and *botes* crewed by 1 or 2 men are used in the fishery.

GEAR (GILLNETS)
Multifilament nylon gillnets with mesh sizes from 40–100mm are used. Panels are 30–255m long and 4–5.7m deep. Each vessel usually carries 4–5 panels.

OPERATIONS
Nets are set at the surface at night, then retrieved in the morning after a soak time of about 12 hours.

INTERACTIONS WITH CETACEANS
A 3m humpback whale calf was caught (date not given) in a gillnet in Samaná Bay, 1.5km from Pueblo Viejo, on the east side of Sánchez and San Lorenzo Bay (at 19°14'N, 60°36'W). The calf was cut into pieces and eaten by the fishermen, who also sold some of the meat. The use of nets is illegal from November to May in the humpback Silver Bank Sanctuary and nearby areas, but this has been difficult to enforce. CRSBJBP is preparing regulations aimed at better protecting the whales entering Samaná Bay. This bay, which is another important humpback whale area, has been proposed for inclusion in the Silver Bank Sanctuary.

[11] Information was provided by I. Bonnelly de Calventi (*in litt.*, 7 September 1990), Comisión Rectora del Santuario de Ballenas Jorobadas del Banco de la Plata (CRSBJBP), Santo Domingo.

Turks and Caicos Islands[12]
There are no gillnet fisheries reported for the country. Two lobster trap boats work the deeper edges of the Caicos Bank, but interactions with cetaceans are not known or suspected. Humpback whales are seen regularly about 45km south of these islands.

Jamaica
According to H. Gieben (*in litt.* 16 November 1986, to S. Leatherwood; received by the authors August 1990) gillnets primarily are used close to shore, and no conflicts with cetaceans have been reported. Common and striped dolphins are potentially at risk.

Cuba
We received no reply to our request for data. The only information comes from H. Gieben (*in litt.*, 16 November 1989, to S. Leatherwood; received by the authors August 1990) who believes that gillnetting is becoming quite popular in Cuba.

Cayman Islands[13]
The Cayman Islands possess a narrow insular shelf which supports limited fisheries operated by local fishermen. There are no pelagic gillnet or trap fisheries around the islands. Inshore net fishing is restricted to a few (7–10) licensed seine-net fishermen who set their nets mainly for sea turtles. Trap fishing by locals is also confined to inshore waters. The traps used are the small, traditional, wire-mesh and frame 'fishpots' widely used in the Caribbean. There have been no reports of any cetaceans entrapped.

Bahamas
The most recent report on the commercial fisheries (Bahamas Department of Fisheries, 1990) states that gillnets are not used (in fact, they are prohibited) and fish pots are not used extensively. The most common method for capturing sea basses (*Epinephelus*), groupers (*Mycteroperca*) and other commercially important 'big fish' (principally snappers, *Lutjanus*) is by trapping them in 'arrowhead-shaped' or 'rectangular' wire traps. Such devices are unlikely to trap cetaceans. The capture or molesting of marine mammals is illegal in the Bahamas. At least three species of cetaceans are known to be found close to shore: bottlenose and Atlantic spotted dolphins and humpback whales.

DISCUSSION AND RECOMMENDATIONS IN ORDER OF PRIORITY

From the limited information available, seldomly reaching beyond the anecdote, it is evident that considerably more data are needed to assess the effects of gillnet fisheries on cetaceans in this large area. Every effort should be made to: (1) further document existing gillnet fisheries and those that may develop, by soliciting co-operation from local fishery officers and biologists, and through dedicated surveys by independent observers in those areas thought to be most seriously affected; (2) identify and stimulate interested local residents (e.g. biology students) and organisations to become actively involved in the monitoring of gillnet fisheries; (3) investigate alternative fishing methods that could reduce or eliminate incidental mortality; (4) develop studies to assess the abundance of cetaceans incidentally killed in order to understand the impact of increased mortality due to fisheries (especially for the vaquita); and (5) design and implement regional educational programmes to increase the awareness of local fishermen and the general public to the problems faced by cetacean populations interacting with gillnet fisheries.

Urgent attention should be given to the endangered vaquita in the upper Gulf of California, Mexico (see Mexico for recommendations). Special attention should also be given to the tucuxi, *Sotalia fluviatilis*, along coastal waters of Honduras, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, Guyana, Surinam and French Guiana. This may be the most commonly killed small cetacean in the Caribbean. Monitoring of incidental mortality is also important for: the coastal pantropical spotted dolphin, *Stenella attenuata graffmani* (Pacific coast of Mexico, Central America and Colombia); spinner dolphins (*Stenella longirostris centroamericana* off the Pacific coast of Mexico and Central America, *S. l. orientalis* off the Pacific coast of Mexico, Central America and Colombia); the offshore pantropical spotted dolphin, *Stenella attenuata attenuata* (off the Pacific coast of Mexico, Central America and Colombia); and common and bottlenose dolphins for all countries.

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[12] Information was provided by C. Ninnes (*in litt.*, 17 July 1990), Turks and Caicos Islands Ministry of Natural Resources.
[13] Information was provided by P. Bush (*in litt.*, 10 October 1990), Natural Resources Laboratory, Cayman Islands Government.

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SC/46/SM24

A Note on Artisanal Fisheries Interactions with Small Cetaceans in Mexico

Alfredo Zavala-González[1], Jorge Urbán-Ramírez[2] and Carlos Esquivel-Macías[3]

ABSTRACT

Between 1982 and 1993, 55 coastal locations throughout Mexico were visited to investigate mortality of small cetaceans. A total of 139 records concerning the use of small cetaceans by fishermen were obtained. The species recorded were, in decreasing order of frequency: *Delphinus* sp., *Stenella attenuata*, *Tursiops truncatus*, *Phocoena sinus*, *Globicephala macrorhynchus* and *Stenella frontalis*. Areas with the highest relative abundance of cetaceans coincided with major fishing areas, making fishery/cetacean interactions likely.

KEYWORDS: INCIDENTAL CAPTURE; NORTH ATLANTIC; NORTH PACIFIC; FISHERIES; COMMON DOLPHIN; SPOTTED DOLPHIN; BOTTLENOSE DOLPHIN; VAQUITA; PILOT WHALE-SHORT FINNED; WHITE-SIDED DOLPHIN.

INTRODUCTION

México has more than 10,000km of coastline, including the Gulf of California and portions of the Gulf of Mexico, the Caribbean Sea and the Pacific Ocean, resulting in great marine biodiversity. A total of 39 cetacean species have been recorded in Mexican waters (45% of known species), including coastal and oceanic species, migratory and resident species, and species from both tropical and temperate waters (Urbán-R, 1994). All marine mammals are protected by Mexican law (Secretaría de Pesca, 1992).

This note considers interactions between small cetaceans and fisheries in Mexican waters. The data presented were obtained mainly from the remains of small cetaceans found during visits to 55 coastal locations between 1982 and 1993 by researchers from the Laboratorio de Mamíferos Marinos of the Facultad de Ciencias, Universidad Nacional Autónoma de México and the Programa de Investigación de Mamíferos Marinos of the Universidad Autónoma de Baja California Sur.

The remains of small cetaceans were considered to be the result of interactions with artisanal fishermen if they were found: (a) in fishing camps or within a 100m radius (if piled up in organic dumps with fish remains); or (b) further than 100m away from fishing camps but with evident human-induced wounds.

RESULTS AND DISCUSSION

Throughout Mexico we obtained 139 records of small cetaceans whose mortality was attributable to interactions with humans. Seven species were recorded (Fig. 1): the common dolphin, *Delphinus* sp. (51.8%), the coastal form of the Pacific spotted dolphin, *Stenella attenuata* (23%), the bottlenose dolphin, *Tursiops truncatus* (18%), the vaquita, *Phocoena sinus* (4.3%), the short-finned pilot whale, *Globicephala macrorynchus* (1.4%), the Pacific white-sided dolphin, *Lagenorhynchus obliquidens* (0.7%), and the Atlantic spotted dolphin, *Stenella frontalis* (0.7%).

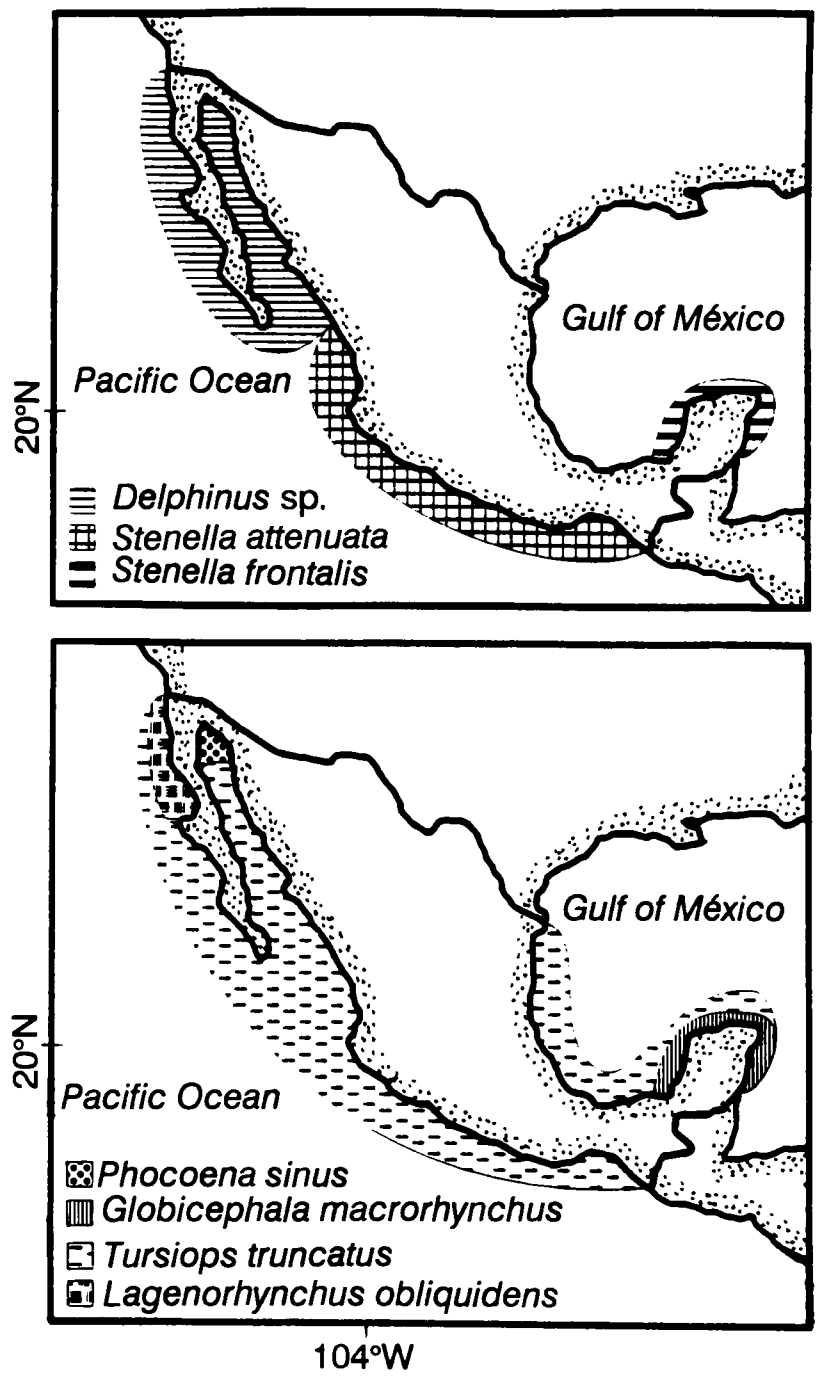

Fig. 1. Areas where the interactions with the different species occur or potentially happen.

The records of common dolphins were not differentiated between the two species proposed by Heyning and Perrin (1994) for the Eastern North Pacific; nevertheless their distribution suggests that the majority would correspond to the long-beaked common dolphin (*Delphinus capensis*).

[1] *Centro de Investigación Cientifica y Educación Superior de Ensenada, Ap. Postal 2732. Ensenada Baja California, Mexico*
[2] *Departamento de Biología Marina, Univ. Aut. de Baja California Sur, La Paz, B.C.S., Mexico*
[3] *Departamento de Biología, Facultad de Ciencias, UNAM, Mexico, D.F.*

Table 1

Killing procedure and use of the dead small cetaceans by artisanal fishermen.

Species	Killing method	Use
Lagenorhynchus obliquidens	Nets(?)	Sometimes for bait (?)
Tursiops truncatus	Gillnets (incidental). Harpoon	Sometimes for bait
Delphinus sp.	Harpoon (54%), Firearms (7%)	Sometimes as shark bait. They are relatively easy to catch.
Stenella attenuata	Highest frequency in Punta Mita, Nay. Harpoon (73%)	Occasional use as shark bait.
Stenella frontalis	Gillnet	Shark bait
Globicephala macrocephalus	Harpoon	Shark bait
Phocoena sinus	Gillnets (incidental). Less frequent in shrimp trawlers	Human food(?). Sometimes as shark bait

Table 2

Locations with records of deliberate or incidental small cetaceans deaths caused by artisanal fishermen.

Region	Location (see Fig. 2)	Species[1] Lo	Tt	Dsp	Sa	Sf	Gm	Ps	Total	Effort[2] (days)	Animal/ Effort
West coast of Baja California Peninsula	1. Estero de Punta Banda	1							1	15	0.07
Gulf of California	2. Golfo de Santa Clara	1						3	3	8	0.38
	3. San Felipe		2					3	5	7	0.71
	4. Isla Granito		1	2					3	98	0.03
	5. Los Cantiles		1						1	270	0.004
	6. Isla Estanque			3					3	6	0.5
	7. Isla Partida		1	8					9	10	0.9
	8. Isla Rasa			3					3	31	0.1
	9. Isla Salsipuedes		1	2					3	10	0.3
	10. Isla Las Animas		1	2					3	10	0.3
	11. Isla San Lorenzo		2	5					7	11	0.64
	12. Isla San Esteban			3					3	34	0.09
	13. Bahia de Agua Dulce			2					2	10	0.2
	14. Eusenada de Perros			25					25	16	1.56
	15. Guaymas			1					1	8	0.13
	16. Isla San Marcos		3	13					16	8	2.0
	17. Isla Monserrat			1					1	4	0.25
	18. Isla Santa Catalina		1						1	4	0.25
	19. Isla San José		1	1					2	4	0.5
	20. Isla Cerralvo			1					1	4	0.25
	21. Laguna Caimanero				1				1	2	0.5
	22. LagunaTeacapan				1				1	2	0.5
	23. Isla Isabel		3		1				4	35	0.11
	24. Punta Mita		2		20				22	730	0.03
	25. Cruz de Huanacaxtle		1		3				4	30	0.13
	26. Cabo Corrientes				1				1	10	0.1
South Pacific	27. Playa de Campos				2				2	51	0.04
	28. Deca de Apiza				1				1	15	0.07
	29. Playa San Jerónimo				1				1	1	1.0
	30. Laguna de Chacahua				1				1	7	0.14
Gulf of Mexico	31. Laguna de Términos		3						3	170	0.02
	32. Dzilam de Bravo					1	2		3	3	1.0
Caribbean Sea	33. Bahia de Ascención		2						2	50	0.04
Total		1	25	72	32	1	2	6	138	1,532	

[1] Lo = *Lagenorhynchus obliquidens*; Tt = *Tursiops truncatus*; Dsp = *Delphinus* sp; Sa = *Stenella attenuata*; Sf = *Stenella frontalis*; Gm = *Globicephala macrorhynchus*; Ps = *Phocoena sinus*.
[2] Effort in days searching fish camps.

All the records of Pacific spotted dolphins where we collected the skulls, corresponded to the coastal form (Urbán-R *et al.*, 1986).

Deliberate or incidental deaths were caused by artisanal fishermen in four main ways: (a) with firearms (several kinds); (b) with harpoons; (c) in gillnets and (d) with clubs. In some cases the killing procedure or weapons could not be identified.

The harpoon was the most common weapon used by artisanal fishermen (60%); a considerably lower

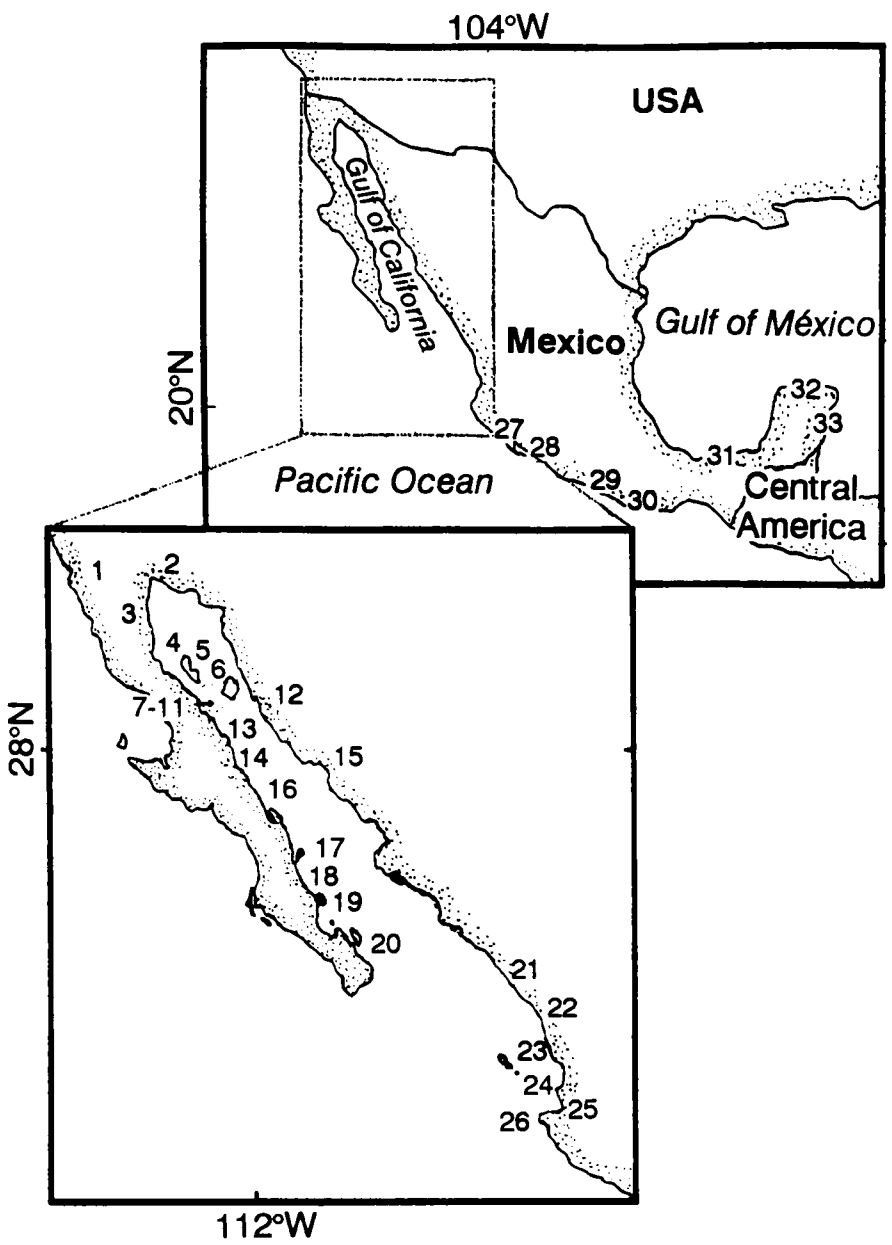

Fig. 2. Localities with records of small cetacean mortality attributable to interactions with humans (see Table 2).

percentage of animals were killed with firearms or gillnets (4.4% for each). Gillnet deaths were accidental. For 31% of the remains found we were not able to determine the weapon used or the method by which the animal was killed. Only 4.4% of the carcasses were flensed. It appears that 65% of the animals found were used by fishermen as shark bait (Table 1).

Most marine mammal/fisheries interactions in Mexico occur in the Gulf of California, and particularly the northern half which includes the Big Islands area. This is perhaps not surprising as the Gulf has both the highest relative abundance of cetaceans in Mexico and, especially in the north, the highest concentration of fishing activities (Table 2; Fig. 2).

Published information about the interactions of artisanal fisheries and cetaceans in Mexico is scarce and primarily concerns the vaquita, an endangered and endemic porpoise of the northern Gulf of California (Silber, 1990; Klinowska, 1991; Rojas Bracho and Urbán-Ramírez, 1993; Vidal, 1993; 1994; D'Agrosa *et al.*, 1994). Information on other species is limited to Vidal *et al.* (1994) which discusses interactions of bottlenosed and common dolphins in the northern Gulf of California, and Urbán *et al.* (1986) which examines the use of coastal Pacific spotted dolphins for shark bait on coasts of Sinaloa and Nayarit. Except in the case of the vaquita, there is no information about the status of the different populations affected.

We consider it especially important to: (a) evaluate the impact of these interactions for common dolphins in the Gulf of California, the coastal form of the Pacific spotted dolphin in the south Pacific coast of Mexico and the different populations of bottlenose dolphins in all Mexican coastal waters; and (b) monitor the artisanal shark fishery on both coasts of Mexico, especially in the Gulf of California and the Caribbean region.

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Western South Atlantic

SC/46/SM10

Review of Small Cetaceans and Fishery Interactions in Coastal Waters of Brazil

Salvatore Siciliano

Fundação Brasileira para a Conservação da Natureza-Rua Miranda Valverde, 103 – Botafogo Rio de Janeiro, RJ 22281–000 Brazil

ABSTRACT

This paper reviews the incidental mortality of small cetaceans in fishing operations along the coast of Brazil. In addition to reviewing the available literature, it includes information from visits to selected fishing ports and from ongoing programmes (up to February 1994). Although a number of cetacean species (including occasional great whales) are incidentally caught, the most common are the tucuxi and the franciscana. In some areas incidentally caught animals are used as fish bait or for human consumption. Further effort is needed to monitor poorly covered areas, especially in the north and northeast regions where direct takes may occur; law enforcement and educational programmes are required. Only the establishment of a long-term plan for monitoring incidental catches and a programme to assess population size and stock identity will allow the rational conservation of small cetaceans in Brazilian waters.

KEYWORDS: SOUTH ATLANTIC; INCIDENTAL CAPTURE; FISHERIES; STRANDINGS; TUCUXI; PILOT WHALE – SHORT-FINNED; PILOT WHALE – LONG-FINNED; BOTTLENOSE DOLPHIN; FRANCISCANA; HUMPBACK WHALE; SPERM WHALE; ROUGH-TOOTHED DOLPHIN; SPOTTED DOLPHIN; COMMON DOLPHIN; SPINNER DOLPHIN; BEAKED WHALE; RISSO'S DOLPHIN.

INTRODUCTION

Although knowledge of cetaceans along the Brazilian coast has increased in recent years (e.g. Borobia and Barros, 1989; Barros, 1991; Borobia *et al.*, 1991) much remains to be learned about their biology and conservation. Of major concern throughout the world is the mortality of cetaceans caused by entanglement in nets during various fishery activities. In Brazil, the problem has been documented for some sites in the states of Rio Grande do Sul, Santa Catarina, São Paulo and Rio de Janeiro (Lodi and Capistrano, 1990; Monteiro Filho, 1990; Borobia, 1991; Simões-Lopes and Ximenez, 1993; Barros and Teixeira, 1994; Pinedo, 1994). Cetaceans are legally protected in Brazilian waters.

METHODS

In addition to reviewing the available literature, this paper includes information on fishery activities and cetaceans obtained during visits to a number of localities along the Brazilian coast (Fig. 1). Data on cetacean mortality was gathered through the collection of specimens from accidental captures. Skeletal and other material was given to the mammal collection of the Museu de Zoologia da Universidade de São Paulo (MZUSP), São Paulo, Brazil. Informal discussions with fishermen provided information on fisheries, fishing methods and cetacean bycatches as did the collection of fish retrieved from gillnets and more formal interviews with fishermen at selected ports. A list of target fish species is provided in Table 1. Most information is available for Rio de Janeiro, Espírito Santo, Paraná and Rio Grande do Sul. The coastal areas in northern Brazil have been less studied and consequently less is known of fishery activities or the presence and interactions with cetaceans. More extensive research facilities must be set up there in order to monitor mortality rates of cetaceans. A recent joint-project funded by UNEP/IUCN should improve our knowledge of small cetaceans and fisheries in northeastern Brazil.

SELECTED PORTS: CASE STUDIES

Pará

Algodoal and Marudá

The fishing villages of Algodoal (00°30'S, 47°28'W) and Marudá were visited on 28–31 January 1990. In Algodoal, 46 boats were counted using both gillnets and longlines. Fishery operations are conducted from wooden sail boats. Information on dolphin bycatch was obtained through informal contact with fishermen. Partial skulls of the tucuxi[1] (*Sotalia fluviatilis*) were found and collected in both villages (MZUSP 27383, MZUSP 28413). Specimen MZUSP 27383 had the rostrum cut off indicating possible interaction with fisheries. Tucuxi (*S. fluviatilis*) were frequently observed in small groups in the area during the visited period.

Salinópolis

Salinópolis (00°37'S, 47°21'W) has been poorly surveyed and information is scant. Borobia *et al.* (1991) reported on a tucuxi that was harpooned and used as bait for the local shark fishery.

Marajó bay area and Vigia

An incidental capture of a tucuxi occurred at the bay of Marajó (01°00'S, 48°30'W) on 9 December 1982 (Borobia *et al.*, 1991). The specimen is held at the Museu Paraense Emílio Goeldi (MPEG 10945). The fishing village of Vigia has been monitored by a UNEP/IUCN funded project since September 1993. Intentional captures of tucuxis are reported to occur in the area (R.T. de Almeida, pers. comm.). Dolphins are captured with nets, killed with a

[1] Although the officially recognised common name for *Sotalia fluviatilis* is the tucuxi, fishermen along the Brazilian coast often refer to *Sotalia* as 'boto', which is usually reserved for *Inia geoffrensis*. For consistency I use tucuxi=*Sotalia* in this paper.

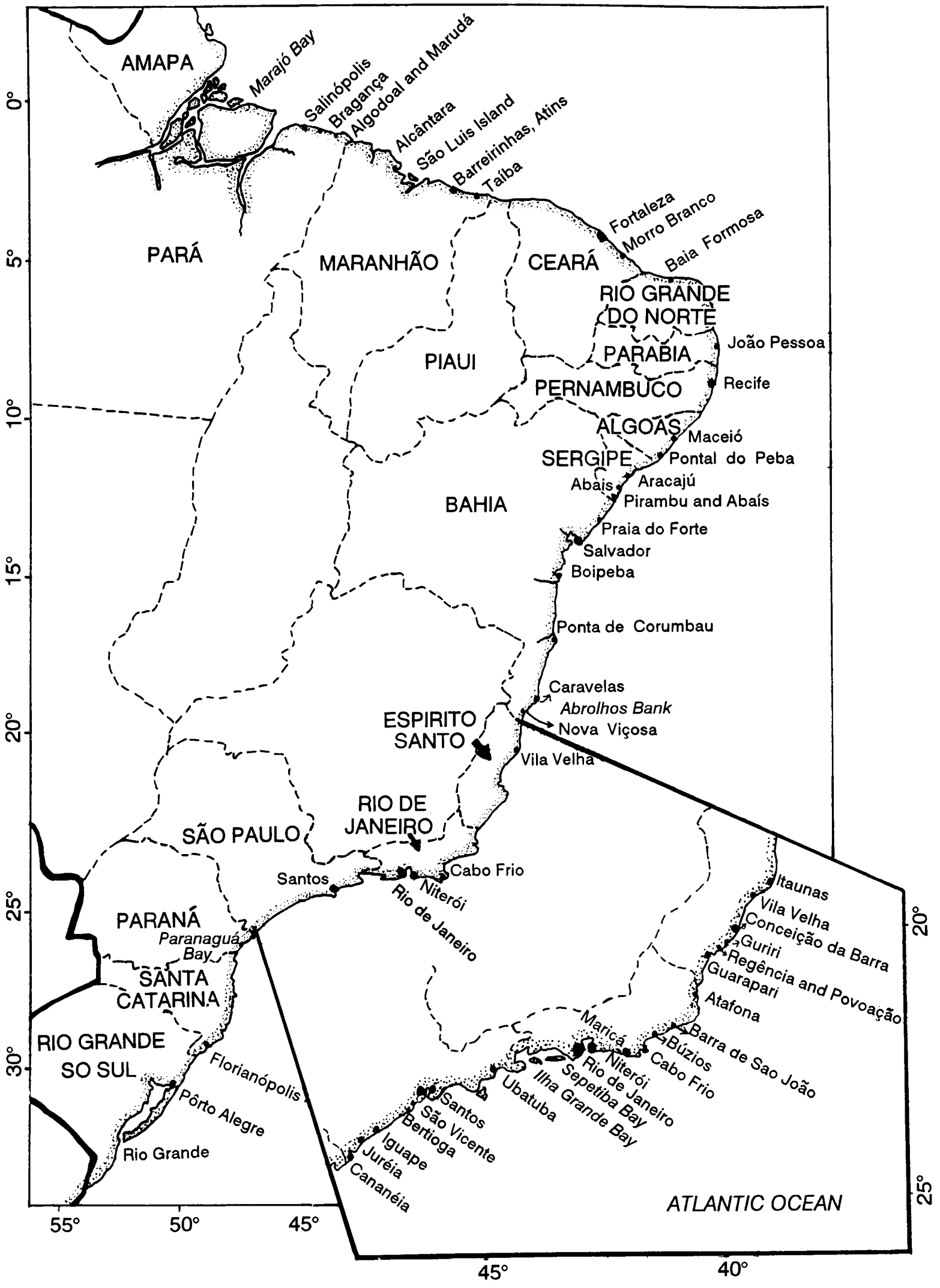

Fig. 1. Map showing localities visited along the Brazilian coast.

knife on the boat and the meat and blubber are saved. The genitals and eyes of males and females are sold as love charms in the markets of Belém Pará's capital. The mandibles are used in local handicraft and the teeth for making necklaces. Although the meat is usually consumed locally it is not considered 'tasty'. The blubber is thought to be the best bait for shark fishing and is stored by salting, and sold for about $1.50 per kilo[2].

General

Dolphin harpooning as well as intentional capture in nets seems to occur frequently along the Pará coast. This is also reported to be common practice in the locality of Bragança. An active market for bait exists in several

[2] Prices are given in US dollars throughout this paper.

Table 1

Local, scientific and English names of fish species from Brazilian waters known to be caught in gillnets by region (following Fabre and Batista, 1992; Barros, 1990; Borobia, 1991; Zanellato, 1994)

Local name	Scientific name	English name	Local name	Scientific name	English name
North/Northeast			Salteira	*Caranx latus, C.hippos* and *Oligoplistes saliens*	Jacks
Serra	*Scomberomorus brasiliensis* *S. maculatus*	Spanish Mackerel	Arraia	?	Ray
Corvina-gó	*Macrodon ancylodon*	Weakfish	**Southeast**		
Pescada	*Cynoscion acoupa*		Bagre-bandeira	*Bagre bagre*	Cocosea catfish
Bonito	*Sarda sarda*		Vento-leste	*Caranx crysos*	Blue runner
Peixe-pedra	*Genyatremus luteus*		Pescadinha	*Isopisthus parvipinnis*	Shortfin corvina
Uritinga	*Arius proops*	Catfish	Pescada	*Macrodon ancylodon*	King weakfish
Gurijuba	*Arius parkeri*	Catfish	Corvina	*Micropogonias furnieri*	Croaker
Cavala	*Scomberomorus cavalla*	King Mackerel	Sarda/Sororoca	*Scomberomorus* spp., *Scomberomorus brasiliensis*	Mackerel
Cação	Carcharhiniformes	Shark	Gordinho	*Peprilus paru*	Butterfish
Guarajuba			Linguado	*Paralichthys*	Flounder
Ariacó	*Lutjanus synagris*	Lane snapper	Tainha	*Mugil spp.*	Mullet
Pargo	*Lutjanus purpureus*	Snapper	Cação	Carcharhiniformes	Shark
Cioba	*Lutjanus* spp.	Snapper	**South**		
Bagre	*Bagre bagre, B. marinus*	Catfish	Robalao	*Centropomus undecimalis*	Common snook
Guaiúba	*Ocyurus chrysurus*		Linguado	*Paralichthys* spp.	Flounder
Camorim/camurim	*Centropomus* spp.	Snook	Tainha	*Mugil liza*	Mullet
Corvina-uçu	*Cynoscion microlepidotus*		Cavala/Sororoca	*Scomberomorus maculatus*	
Carapeba	*Diapterus olisthostomus* and *Eugerres brasilianus*	Mojarra	Salteira	*Oligoplistes saurus*	
Piaba-do-mar	*Pempheris schomburgki*		Corvina	*Micropogonias furnieri*	Croaker
Tainha	*Mugil liza, M. curema* *M. gaimardianus, M. incilis*	Mullet	Bagre branco	*Netuma barba*	
Camurupim/pirapema	*Tarpon atlanticus*	Tarpon	Cação/cambeva	Carcharhiniformes	Shark
Mariquita	*Holocentrus ascensionis*		Cação-martelo	*Sphyrna* spp.	Hammer shark
Corvina/Cururuca	*Micropogonias furnieri*	Croaker	Betara preta	*Menticirrhus americanus*	
Arabaiana			Pescada	*Cynoscion* sp.	
Curimã			Brota	*Urophycis* sp.	Gadid

fishing villages. A survey is needed in these areas to evaluate the extent of the direct take of dolphins for local shark fisheries. Law enforcement and educational campaigns are urgently needed in the area.

Maranhão

Alcântara

The locality of Alcântara was visited on 20–23 April and 1–3 May 1991. At least twenty boats using gillnets operate in the area. A 1.7m tucuxi was collected at Cajual Island and the skeleton was deposited at MZUSP (27999). It was reported by fishermen to have been incidentally caught in nets. The specimen was found in an advanced stage of decomposition and its sex and the cause of its death are unknown. Tucuxis were observed in small groups near Alcântara harbour.

São Luís Island

A short survey was conducted in the fishing villages of Raposa, Vieira (São José do Ribamar) and Quebra-Pote, on São Luís Island (02°31'S, 44°18'W) in February 1989. The village of Raposa is considered the largest producer and most important fishing community of Maranhão state (Stride, 1988) with 194 boats representing the potential fishing effort (Fabre and da Batista, 1992). A number of different kinds of boats are used in the fisheries, mainly dug-out canoes and small wooden sail boats. Operations are usually restricted to coastal waters (within 5 n.miles). Skeletal remains of at least four tucuxis were collected at Raposa on 1 February 1989 and were deposited at the Universidade Federal do Maranhão, Laboratório de Hidrobiologia (UFMA, LABOHIDRO). On 2 February 1989, a complete skeleton of a tucuxi caught in nets at the village of Vieira was collected (MZUSP 26867). Raposa has been monitored by a UNEP/IUCN funded project since September 1993. Direct takes of tucuxi have been observed and appear to have been increasing over the last two years. Fishermen use nets to capture dolphins which are then killed with a knife, and the meat and blubber are kept. The carcass is discarded at sea in order to avoid evidence of killing. Collection of skeletal remains and evidence of direct take is hard to obtain, but the researchers did collect two tucuxi skulls in January 1994 (R.T. de Almeida, pers. comm.). Dolphin blubber is used as bait for the local shark fishery and the meat is consumed locally as an alternative food source, but is not popular. The blubber is frozen and sold for about $1.50 per kilo. The collection of genitals, eyes and mandibles is not practiced on the coast of Maranhão.

Atins, Barreirinhas

Atins is a small fishing village located at the mouth of the Preguiças river, Barreirinhas county. A tucuxi skull (MZUSP 28001) was collected in June 1988 (M.A. Mendonça, pers. comm.). It was reported that dolphins were intentionally captured in the area for human consumption as salted meat (F.C.R. dos Santos, pers. comm.).

Ceará

Taíba

The small fishing village of Taíba is being monitored by a UNEP/IUCN funded project. The fishery uses small (4–8m) sail-rigged open boats called *jangadas* that use gillnets; *jangadas* are found in large numbers along the Ceará coast. Fishermen report that incidental catches of dolphins are frequent in the area (where the tucuxi seems to be

relatively common). A juvenile tucuxi that was caught in nets was collected in October 1993 (Grupo de Mamíferos Aquáticos do Nordeste, unpub. data).

Fortaleza
A survey conducted in April 1991 revealed that six tucuxis were captured in gillnets in the area of Fortaleza (03°43'S, 38°30'W) between November 1987 and January 1991. Skeletal remains and photographs of entangled dolphins were recovered. Specimens collected were deposited at the Universidade Federal do Ceará, Laboratório de Biologia Marinha (UFCE, LABOMAR, in exhibition) and at MZUSP (28000). At least 60 *jangadas* were seen in Mucuripe, the largest port of Ceará's capital, Fortaleza. In one case dolphin meat was being sold for human consumption.

Morro Branco
The fishing village of Morro Branco was visited on 11–12 April 1991. At least 40 *jangadas* were found in the main village of Morro Branco. Gillnets or longlines are used, depending on the target species. The head of the local fishing village informed us that the total number of *jangadas* may reach 64, if the lesser fishing villages of Flexeiras, Diogo, Uruaú, Barra do Sucatinga, Praia do Ariós, Prainha do Canto Verde and Parajuru are included. No specimens were found during the short visit, but fishermen reported the incidental catches of some small cetaceans, mainly 'botos' (cf. tucuxi). Dolphins caught in nets are used for human consumption but no direct takes occur. Fishermen complained about the fact that dolphins cause damage to the net when they get entangled. Each *jangada* brings about 30–50 kg of fish, mainly *serra*, per trip. During casual interviews, fishermen informed us that dolphins come to the nets attracted by the fish caught and then get entangled. Nets are usually set at night and retrieved at early morning.

Rio Grande do Norte

Baía Formosa
Baía Formosa (06°22'S, 35°00'W) is a small fishing village located some 90km south of Natal, Rio Grande do Norte's capital. One tucuxi was caught '*ca.* 6km E Baía Formosa' on 8 December 1986 (A. Langguth, *in litt.*) and the skeleton was deposited in the mammal collection of Universidade Federal da Paraíba (UFPB 547). It was 1.675m and is listed in Borobia *et al.* (1991).

Paraíba

João Pessoa and Mamanguape
Paraíba's capital João Pessoa (07°07'S, 34°52'W) and the small fishing village of Mamanguape (06°50'S, 35°07'W) have been visited and surveyed at different times since the early 1980s. Gillnets are not often used and the fisheries are based on collecting small invertebrates (shrimp, mollusks, conchs). Tucuxi specimens have been collected (Borobia *et al.*, 1991) but there is no information on fishery interactions.

Pernambuco

Recife
Three adult tucuxis were caught in gillnets at Boa Viagem (08°03'S, 34°54'W) on 17 November 1989 (de Almeida *et al.*, 1990; Borobia *et al.*, 1991). Specimens are stored in the collection at the Museu de História Natural, Universidade Federal Rural de Pernambuco (UFRPE). Borobia *et al.* (1991) report on the collection of a specimen at Candeias on 23 September 1990 that had evidence of gillnet entanglement.

Longline fishery in northeast region
Longlines are used to catch tuna, marine catfish, half beaks, ballyhoo, tarpon and other species in coastal areas of northwest Brazil (IWC, 1994). Small cetaceans interact with long-line fisheries. It is reported by fishermen that dolphins (apparently only oceanic species) are attracted to fish caught in the longline, either to steal the bait and/or fish caught on the hooks. There is a case of a short-finned pilot whale (*Globicephala macrorhynchus*) and a bottlenose dolphin (*Tursiops truncatus*) incidentally caught in this fishing gear (R.T. de Almeida, pers. comm.).

Alagoas

Maceió
Fisheries in Maceió (09°40'S, 35°43'W) use *jangadas* and the total catches of artisanal fishermen can reach about 3,000 kg/year (Secretaria de Planejamento do Estado de Alagoas, 1990). A short survey conducted in January 1991 showed the wide use of gillnets and the potential involvement of small cetaceans in fishery operations (Borobia, 1991). Barros and Teixeira (1994) report on the incidental catch of two female tucuxis, 182 and 161cm in length, retrieved from the same gillnet on 23 September 1988 at Praia da Pajuçara, Maceió. Specimens were deposited at the Museu de História Natural, Universidade Federal de Alagoas (no number available). The nets involved were 200m in length, 2m in height and had a mesh size of 35mm. It is interesting to mention that no external evidence of entanglement, such as marks or cuts, were found on the dolphins, although the nets in which they were caught were heavily damaged (Barros and Teixeira, 1994).

Pontal do Peba
Pontal do Peba is a relatively large fishing village dominated by shrimp trawlers but gillnets are also used. Borobia (1991) reported incidental catches of small cetaceans in the area: on 10 February 1991, a 1.67m female tucuxi with net marks on its body was found dead ashore. A second tucuxi was also caught in nets during the same season.

Sergipe

Pirambu and Abaís
One tucuxi (a 1.05m calf, MZUSP 23814) was collected at Pirambu (10°44'S, 36°51'W) on 12 October 1986 (Borobia *et al.*, 1991) having been taken in gillnets about 3 n.miles off the coast together with a reported larger dolphin (probably its mother). Borobia (1991) reported a male tucuxi caught in nets in Pirambu and recovered on 8 January 1991 (MZUSP 27830) and the skull and partial skeleton of a tucuxi reportedly caught in nets in 1990 (MZUSP 28184) at Praia do Abaís in January 1991. All fishing villages visited in January 1991 make use of gillnets and reported the incidental catch of dolphins, mainly 'botos' (cf. tucuxi).

Aracajú
'Occasional' incidental mortality of small cetaceans at Atalaia Nova and Rio Sergipe was reported by the Grupo de Mamíferos Aquáticos do Nordeste (1992). As fishermen are aware of the law protecting dolphins and whales, dolphins are often discarded to avoid problems

with the environmental agency although they are sometimes consumed locally. Fishermen may butcher dolphins retrieved from nets, wrap them in plastic bags and drown the bags in the river in order to erase evidence of bycatch (R.T. de Almeida, pers. comm.). Groups of up to 100 tucuxi are reported to be observed in the area (Grupo de Mamíferos Aquáticos G.M.A.-N.E., 1992).

Bahia

Praia do Forte

Praia do Forte (12°31'S, 38°17'W) is a famous resort located some 80km north of Salvador Bahia's capital. One 1.78m male tucuxi was caught in a gillnet set about 1 n.mile off the beach of Praia do Forte by summer tourists on the night of 27/28 December 1986. The skull was collected (MZUSP 23802). Two marine turtles (unknown species) were also retrieved from the nets.

Salvador and Itaparica (including Todos os Santos bay area)

The Todos os Santos bay (12°55'S, 38°35'W) is the largest bay along the Brazilian coast with an estimated area of 1,110km^2. Tucuxis are relatively abundant in the area, as are fishing villages and gillnet operations (Reis and Queiroz, 1992). One male tucuxi (estimated length 1.60m) found stranded at Mar Grande, Itaparica on December 1988 had probably been caught in gillnets (known locally as *tainheira*); photographs showed that the peduncle was cut off indicating entanglement. Reis and Queiroz (1992) reported on four tucuxi incidentally caught in nets in the area.

Boipeba

Gillnets are commonly used in the fishing village of Boipeba (13°40'S, 38°55'W). The locality was regularly visited by Everaldo Lima de Queiroz of the Universidade Federal da Bahia, who provided information on small cetacean bycatches in the area. A 1.90m lactating tucuxi was caught in gillnets off the coast of Boipeba on 5 December 1987. The specimen was used as bait for the longline shark fishery (Borobia *et al.*, 1991).

Ponta de Corumbau

The small fishing village of Ponta de Corumbau (17°20'S, 39°13'W) was visited in September 1989. Small wooden boats and dug-out canoes operate in the area. Shrimp-trawlers from other localities were reported to operate in this region causing damage to local artisanal fisheries. The post-cranial skeleton of a juvenile tucuxi was found on 29 September 1989 and was collected (MZUSP 26873) and fishermen stated that it was caught in gillnets (Borobia *et al.*, 1991).

Caravelas

The fishing village of Caravelas (17°20'S, 39°15'W), as well as its main port, Ponta de Areia and Barra de Caravelas were visited in January 1987, and subsequently surveyed from September 1988 to October 1992. Although fishing activity is dominated by small shrimp trawlers, a small number of boats use gillnets and/or longlines. Boats from nearby cities also operate in the area. Skeletal remains of three tucuxis were collected at Barra de Caravelas: one skull on 12 January 1987 (MZUSP 23801); 25 vertebrae on 13 January 1987 (MZUSP 23800) and a partial skull on 6 November 1988 (MZUSP 25430). At least two of the animals had been caught in nets. On 7 March 1990, two tucuxis were captured in the same gillnet about 20 n.miles east of Caravelas. The net was 900m long and had a mesh size of 7cm. The skulls were collected (MZUSP 28182, MZUSP 28183).

Abrolhos Bank

Abrolhos Bank (17°20'-18°10'S, 38°35'-39°20'W) is an enlargement of the southern end of the eastern Brazilian continental shelf and encompasses a large coral reef ecosystem. Fishing boats from Espírito Santo and southern Bahia operate in the area using longlines and gillnets. A few cases of entanglements are reported by fishermen. One tucuxi skeleton (MSUSP 26866) was found on the island of Santa Barbara on 18 October 1988 (Borobia *et al.*, 1991). In June 1993, a pregnant female tucuxi was captured in nets (C.E. Leite Ferreira, pers. comm.). Details of the capture are not available and only a photograph of the full term foetus was examined for positive identification.

Nova Viçosa

Small motor powered wooden boats (*traineiras*) operate in coastal waters from Nova Viçosa and on the Abrolhos Bank. Boats from several localities of Bahia and Espírito Santo also fish in the area. One adult tucuxi was found stranded on the beach of Praia do Pontal, at Nova Viçosa (17°53'S, 39°22'W) on 4 September 1989 and the complete skeleton collected (MZUSP 26868); fishermen reported that it was caught in gillnets (Borobia *et al.*, 1991). Small pieces of blubber were taken from the dolphin to be used as bait in shark fishery, a common practice in this area.

Espírito Santo

Itaúnas

Local artisanal fisheries use a small number of dugout canoes, 6m in length, that usually operate within 1 n.mile of the shore. On 12 February 1991, a 117cm female franciscana calf was caught in a gillnet at the village of Itaúnas (18°25'S, 30°42'W). The net was some 250m long with a 70mm mesh. It was set 500m from shore at 0500h and retrieved at 1300h of the same day. Small sciaenids (cf. *Isopisthus parvipinnis*, 'pescadinha') were retrieved from the net. It had milk in its stomach and its length suggests that it would have been unweaned (Pinedo *et al.*, 1989). The complete skeleton is kept at MZUSP (27995). Two dolphins (unknown species) reported to be caught in nets were found dead ashore in the summer of 1994 (A. Higa, pers. comm.). Larger mesh sizes between 12–20cm are used to catch sharks. The above specimen indicates a northward extension of the known range of the franciscana by some 160km. This suggests that the species reaches well into tropical waters where the lowest annual mean surface temperature is 23°C. The Brazilian Current along the northern coast of Espírito Santo state is influenced by the discharge of the rivers Mucuri, Itaúnas, São Mateus and Doce. This discharge causes a lowering of both temperature and salinity of the current (Palacio, 1982). Groups of up to 20 tucuxi were reported to be found in the area.

Conceição da Barra

The city of Conceição da Barra is a traditional fishing port in northern Espírito Santo. Several boats operate in the area using gillnets, trawl nets and longlines. Trawlers are accused of causing damage to nets set by artisanal fishermen. In one case the fisherman reported the loss of 600m of net. Ramos *et al.* (1994) report on the incidental

capture of three tucuxi in March 1989 by boats operating in the area. Dolphins were stored in the freezer to be used as bait in the shark fishery.

Guriri

The locality of Guriri (18°42'S, 39°51'W) has a small fishing community spread along 40km of beach. Dugout canoes, 6m long, are found in small numbers along the beach and operate gillnets as long as 1,200m. The area has been monitored by personnel of a marine turtle project (Projeto TAMAR) since the summer of 1988. The beach is regularly surveyed for marine turtle nests and carcasses. Dolphins found stranded are collected and/or reported. A pregnant 1.41m female franciscana was found washed ashore at Guriri (18°42'S, 39°51'W) on 28 February 1991. Several marks indicating net entanglement and shark wounds were observed. The complete skeleton of the female and the foetus are kept at MZUSP (28410, 28411-foetus in formol). The carcass of a second franciscana was found washed ashore about 7km north of Guriri on 17 January 1992. The body length and sex could not be determined. The condylobasal length of the skull is 392(±1)mm and the tip of the rostrum is broken. The skull is kept at the Projeto TAMAR, Base de Guriri, ES. Although fishermen report that franciscanas are common in the area, the specimens reported here are the first collected. Artisanal operations in this area are known to have resulted in the accidental capture of at least 12 tucuxi (lengths 0.86m-1.90m) between December 1988 and August 1993, i.e. dolphins that have been found washed ashore with clear marks of net entanglement and/or tail, flippers and dorsal fins cut off. The specimens are kept at MZUSP 27520 (December 1988), MZUSP 26870 (January 1989), MZUSP 27521 (February 1989), MZUSP 27522 (February 1990), MZUSP 27523 (April 1990), MZUSP 27997 (November 1990), MZUSP 27996 (March 1991), MZUSP 27998 (March 1991), Base Projeto TAMAR, Guriri (January 1992), MZUSP 28405 (March 1992), MZUSP N/A (March 1993) and MZUSP N/A (August 1993).

Regência and Povoação

The small towns of Regência (19°38'S, 39°49'W) and Povoação are located at the mouth of the Doce river. About 12 small boats operate in the area and nets are usually set 1 n.mile offshore although they have also been seen set at the mouth of the river, the typical habitat of the tucuxi. The area has been relatively well studied. Geise and Borobia (1987) reported the collection of skeletal remains of two tucuxi and one franciscana known to have been caught in nets. Ramos *et al.* (1994) reported on the incidental catch of five franciscanas in March 1989 and of six tucuxi, between January and May 1989. These specimens were deposited at MZUSP. Four tucuxi specimens were collected by the author and are also kept at MZUSP 23809 (January 1987), MZUSP 26865 (May 1989), MZUSP 28181 (September 1990) and MZUSP 26871 (December 1988). The last is a skull collected at Pontal do Ipiranga, some 60km north of Regência and reported to have come from an animal entangled in nets set by Regência-based boats (C. Bellini, pers. comm.). A partially broken skull of a franciscana was collected in January 1987 (MZUSP 23793) and two other skulls in September 1989 (MZUSP 25428, MZUSP 25429). During a visit to Regência in January 1987, a fisherman was observed using the blubber of a franciscana, incidentally caught in nets, as bait in an artisanal lobster trap at the mouth of the Doce river. Dolphins captured in nets can also be used for human consumption. A total of 12 tucuxi and 10 franciscanas are known to have been caught in Regência.

Vila Velha

A 206cm female tucuxi, accidentally caught in a driftnet in waters 5–10m deep, 50–100m from shore, was found at Praia de Itapoã (20°21'S, 40°17'W), Vila Velha, on 5 June 1983 (Barros, 1991). On 28 October 1987, a 4.9m female humpback whale (*Megaptera novaeangliae*) was accidentally caught in a net about 700m from shore at Ponta da Fruta (20°30'S, 40°20'W), Vila Velha (Siciliano and Lodi, 1989; Barros, 1991).

Guarapari

Guarapari is about 50km south of Vitória. Gillnets are widely used in the area and are especially common in Meaípe. Barros (1991) reported on the collection of a mutilated carcass of a bottlenose dolphin in Guarapari on 23 April 1984 that appeared to have been caught in fishing nets. A sperm whale (*Physeter macrocephalus*) was caught in a fishing net set 200m from shore, at Meaípe (20°39'S, 40°27'W) on 6 August 1981 (Barros, 1991).

Anchieta

At least seven small (8–10m) motor-powered wooden boats operate gillnets in Anchieta and along the southern coast of Espírito Santo state. Gillnets are used seasonally and trawl nets and longlines are also used depending on the target species. No evidence of small cetacean mortality was found during a short visit in April 1992.

Rio de Janeiro

Atafona

The fishing operations from the village of Atafona (21°37'S, 41°01'W) are among the best known in terms of small cetacean fishery interactions in Brazil. Occasional visits were made there between 1983 and 1986 to study cetaceans and since June 1987 incidental mortality has been monitored continuously. Specimens of the tucuxi and the franciscana recovered up to 1990 are listed in Lodi *et al.* (1987), Lodi and Capistrano (1990) and Borobia *et al.* (1991). Ramos *et al.* (1994) reported the known mortality of 336 dolphins between June 1986 and January 1994, of which 197 were collected. These included: 96 tucuxi; 88 franciscanas; 6 rough-toothed dolphins (*Steno bredanensis*); 4 bottlenose dolphins; 2 Atlantic spotted dolphins (*Stenella frontalis*); and 1 common dolphin (*D. delphis*). About 60 boats using gillnets operate in the area between Atafona and Macaé (22°23'S, 41°47'W). The tucuxi and the franciscana account for over 90% of the total number of captures and are affected by coastal fishery operations. The boats that operate in deeper waters take bottlenose, rough-toothed, common and Atlantic spotted dolphins. Surface and mid-water/bottom gillnets are used in coastal operations and most animals are caught in surface gillnets. The cetacean bycatch appears to be lower in mid-water/bottom nets. The depth at which the nets are set depends on the target species. Dolphin meat is not consumed but the blubber is used for shark bait.

Barra de São João

The small fishing village at Barra de São João (22°35'S, 42°00'W), 180km north of Rio de Janeiro, was occasionally visited by researchers during the 1980s. Approximately 20 small wooden boats operate in the area using gillnets and

shrimp trawl nets. On 20 October 1982, a 1.57m tucuxi was collected (skeleton lost) that had been taken in a gillnet (Borobia and Barros, 1989; Borobia *et al.*, 1991).

Cabo Frio

Although the town of Cabo Frio has a relatively large fishing industry there is almost no information on cetacean bycatches. On 21 January 1993, three spinner dolphins (*Stenella longirostris*) were caught in nets set for sharks (M.C. de Oliveira Santos, unpubl. data) during a fishing trip from Ubatuba, northern São Paulo, to Cabo Frio. The net was about 3,900m in length and 12m in height with a mesh size of 10–13cm. The dolphins were discarded at sea (the fishermen are aware of the prohibition on taking dolphins) and only photographs are available. Other bycatches taken during this trip included unknown species of sea turtles and manta rays, all discarded at sea.

Búzios

A small number of boats operate in the Búzios area using gillnets and longlines. Castello and Pinedo (1986) reported on a tucuxi stranded on the beach of Geribá, Búzios (22°44′S, 41°52′W) on 8 January 1977 with clear marks of entanglement in a gillnet. In April 1984 on Manguinhos Beach, Búzios, a tucuxi skull, probably from an incidentally caught animal was collected (Borobia *et al.*, 1991) and deposited at the Universidade Federal do Rio de Janeiro, Departamento de Anatomia Comparada (UFRJ, AC-03). A juvenile humpback whale (estimated length 9m) became entangled in gillnets off Manguinhos Beach on 25 July 1990. The whale was released alive from the nets with no large wounds.

Maricá

A small number of boats operate with gillnets around Maricá (22°55′S, 42°49′W). The record of a false killer whale (*Pseudorca crassidens*) cited with no details in Siciliano *et al.* (1987) and Geise and Borobia (1988) is of a specimen captured in a gillnet set off Barra de Maricá on 23 May 1981. The net was set at 1n.mile from the beach, close to Maricá Island and was retrieved the following morning. The specimen was not collected and only photographs are available. It measured about 3.5m and was of unknown sex. It is presumed that the meat was consumed locally. A juvenile tucuxi was collected in an advanced stage of decomposition on 21 September 1985 at Barra de Maricá (MZUSP 23810) but no signs of entanglement in nets were observed (Borobia *et al.*, 1991).

Rio de Janeiro and Niterói (including Guanabara Bay)

There is considerable fishing effort inside Guanabara Bay using various gear types, including fixed traps (*curral*), trawls, purse seines, beach seines and gillnets, as well as recreational fishing. Only gillnets are known to cause cetacean mortality in the bay. Studies on cetaceans have been conducted in the area since 1983. Stranded tucuxis are regularly collected and at least 18 were collected or reported to have been stranded on the beaches of Rio de Janeiro (22°56′S, 43°15′W) and Niterói (22°56′S, 43°04′W) including the Guanabara bay area between February 1983 and December 1993 (Penna *et al.*, 1990; Borobia *et al.*, 1991; R. Novelli, pers. comm.; L. Capistrano, pers. comm.; S. Siciliano, unpubl. data). Evidence of incidental capture in nets was found in at least two dolphins. One had had the tail cut off but was too decomposed to determine if net marks were present. The other, a 1.83m adult male collected on 20 October 1990, had distinctive net marks (Penna *et al.*, 1990). Two other tucuxis were caught in nets in January 1992 according to a local newspaper and were probably consumed locally as food. Other small cetaceans that are known to have recently stranded in the area include: 1 rough-toothed dolphin; 1 Atlantic spotted dolphin; 3 common dolphins; 3 bottlenose dolphins and 1 beaked whale (*Mesoplodon cf. layardii*) (Siciliano *et al.*, 1987; S. Siciliano, unpubl. data) but there is no positive evidence that they were entangled in nets i.e. any scars or other marks present may have been natural, occurred during stranding or been a result of entanglement in nets. The rough-toothed dolphin was found with a large cut in the belly and with no internal organs, a common practice for fishermen who remove the guts to avoid the smell and any contamination of the fish stored on the boat.

Sepetiba Bay

Until recently Sepetiba Bay (22°58′S, 44°02′W) was poorly surveyed for cetaceans. Fishery operations are conducted from small wooden boats and dug-out canoes. Bottom gillnets are usually set for croakers (*Micropogonias furnieri*) and flounders at the mouth of the bay but can also be found in many other areas inside the bay. Nets can reach 1,200m in length and use two mesh sizes. Tucuxi coming in and out of the bay may become vulnerable to the nets. Borobia *et al.* (1991) had reported on a tucuxi stranded off Ibicuí (22°58′S, 44°02′W), Mangaratiba county, on 1 February 1986. Although only colour photographs are available from this record, the animal had some scars indicative of entanglement in nets (S. Siciliano, pers. obsv.). During a recently started on-going study of tucuxi movements and behaviour in the bay, two carcasses were collected in the area. One was found in September 1993 and the other on 10 December 1993. According to local people they were caught in nets. Two other unidentified dolphins, referred to as 'botos' (cf. tucuxi) were observed floating dead on 15 December 1993 and 7 February 1994, but were not collected. Considering the short surveying period, these data suggest a relatively high incidental mortality.

Ilha Grande Bay

Siciliano (1986) reported on a 6.42m juvenile humpback whale caught in gillnets on the eastern side of the Ilha Grande bay (23°10′S, 44°20′W). The stranded whale was found dead on 2 December 1985 at Praia do Cardo, Sepetiba with a small piece of net (mesh size 3cm) attached to its right flipper and head. Several species of small cetaceans are seen in the waters of Ilha Grande, the Grande Bay and relatively high fishery activity suggests that interactions are likely. Atlantic spotted dolphins have been observed to approach fishing boats in the bay.

São Paulo

Ubatuba

Although gillnets are commonly used in the area, usually for capturing sharks, there is little information on cetaceans as the area has been little studied. Four franciscanas have been found stranded since September 1987, probably as a result of incidental catches (Santos and Siciliano, 1994). Siciliano (1986) reported a humpback whale calf incidentally caught in nets in October 1983.

Santos, São Vicente and Praia Grande

De Carvalho (1961) reported the capture of two franciscanas, a 105cm male and a 134cm female, and one tucuxi off José Menino Beach, Santos (23°57′S, 46°20′W),

in February 1961. De Carvalho (1963) reported that another tucuxi, a 1.51m male, was collected in October 1961 (MZUSP 9611). These areas have been poorly investigated since then and information is scant. Reported strandings of franciscanas in recent years may be related to entanglements in nets (Santos and Siciliano, 1994). A large gillnet was found drifting approximately 12 n.miles off Ponta do Itaipu, Praia Grande on May 1993 (A.F. de Amorim, pers. comm. in a letter, 30 March 1994) with at least three dolphins entangled in it. One was recently identified from photographs to be a franciscana. Fish and marine turtles in the net were in an advanced stage of decomposition, suggesting that it had been drifting for a long period. It is the first time that a drifting gillnet, probably lost by fishermen, has been reported to catch small cetaceans off Brazil.

Bertioga

Fishery activities in Bertioga are artisanal, involving small wooden boats. Three franciscanas were caught in a beach seine net at Bertioga on 25 January 1993. Fishermen were accused by tourists of intentionally killing one of the dolphins, which was reported to be retrieved from nets still alive. This incident was extensively covered in the local press.

Juréia

A small number of boats operate artisanal fisheries in Juréia. The only information on cetaceans was collected on a short visit to the village in January 1987. A 108cm female franciscana was captured in a mid-water gillnet set 1n.mile off the beach on 22 January. A few croakers (*Micropogonias furnieri*) and marine catfish (Ariidae) were also retrieved from nets. Fishermen in the area reported the incidental capture of six 'botos' ('larger than a franciscana', cf. tucuxi) that were released alive from nets.

Iguape and Cananéia

Iguape and Cananéia (25°01'S, 47°55'W) are in southern São Paulo state and have a relatively large fishing fleet. A total of 25–30 boats operate in the area with gillnets for capturing sharks. De Carvalho (1963) reported the collection of 13 tucuxi specimens in nets in Cananéia during the early 1960s and these skeletons are in the mammal collection of MZUSP and listed in Borobia *et al.* (1991). The tucuxi is particularly common in the region (S. Siciliano, pers. obs.) and interaction with local fisheries is likely. Schmiegelow (1990) conducted a two-year survey of stranded cetaceans along the beaches of Iguape and Cananéia and 100 odontocetes were measured and collected, including a pygmy sperm whale (*Kogia breviceps*), a short-finned pilot whale (*G. macrorhynchus*), a bottlenose dolphin, a rough-toothed dolphin, 3 Atlantic spotted dolphins, 13 common dolphins, 21 franciscanas and 58 tucuxi. The carcass of a minke whale (*Balaenoptera acutorostrata*) was also found. He noted that the skulls of three common dolphins, the short-finned pilot whale and three tucuxis had knife marks probably made by fishermen trying to release the animals from nets. Most of the specimens were highly decomposed making cause of death difficult to ascertain. Although the author does not classify the specimens as bycatches, it seems that the number of dolphins collected during the survey period is unusually high to consider natural mortality to be the sole explanation. Monteiro Filho (1990) reports on the incidental catch of a young female tucuxi in a fixed trap (locally known as *cerco*) inside the estuarine complex of Cananéia.

Paraná

Paranaguá Bay

The large Paranaguá estuary (25°31'S, 48°30'W) was not surveyed for cetaceans until 1983, although Bittencourt (1984) reported on a netted tucuxi found floating on 30 July 1982. Studies on cetaceans conducted since 1987 revealed preliminary numbers of small cetaceans incidentally caught in fishery operations (Zanelatto, 1992). Between February 1993 and February 1994, 96 small cetaceans were incidentally caught in nets including 79 (82.3%) tucuxis and 17 franciscanas (17.7%) (Zanelatto, 1994). Drift gillnets and bottom gillnets account for 90% of the total number of captures; purse seine and beach seine nets can also capture dolphins. It was reported that 24 dolphins were known to be consumed locally.

Santa Catarina

Simões-Lopes and Ximenez (1993) reviewed the available information on small cetaceans and fishery interactions for the Santa Catarina coast based on specimens incidentally caught in nets and/or found dead ashore. Table 2 summarises the number of small cetaceans known to have interacted with fisheries in the collection of Laboratório de Mamíferos Aquáticos, Universidade Federal de Santa Catarina (LAMAQ, UFSC) and the number of specimens. Other species occur in the collection of UFSC, but with no information on interactions with fisheries, including the killer whale; the long-finned pilot whale (*Globicephala*

Table 2

Number of known specimens of seven small cetacean species caught in nets and long-line fisheries for each coastal state of Brazil.

	S. fluviatilis	*P. blainvillei*	*T. truncatus*	*S. bredanensis*	*S. frontalis*	*S. longirostris*	*D. delphis*
Pará	3	-	0	0	0	0	0
Maranhão	9	-	0	0	0	0	0
Ceará	5	-	0	0	0	0	0
Rio Grande do Norte	1	-	0	0	0	0	0
Pernambuco	4	-	1	0	0	0	0
Alagoas	4	-	0	0	0	0	0
Sergipe	4	-	0	0	0	0	0
Bahia	14	-	0	0	0	0	0
Espírito	21	11	1?	0	0	0	0
Rio de Janeiro	104	88	4	6	2	3	1
São Paulo	71	28	1	1	3	0	13
Paraná	79	17	1 +	?	?	0	?
Santa Catarina	3	7	3	2	3	0	3
Rio Grande do Sul	-	874	31	2	0	0	1

melas); the southern bottlenose whale (*Hyperoodon planifrons*); Blainville's(?) beaked whale (*Mesoplodon cf. densirostris*) and the sperm whale (*Physeter macrocephalus*). The only record of the Risso's dolphin (*Grampus griseus*) for the Santa Catarina coast is of a 1.64m young male (MZUSP 19480), 1.64m in length, that was accidentally captured during commercial tuna longline fishing in September 1983 (Geise and Borobia, 1987). Mr. Alberto F. de Amorim, from the Instituto de Pesca, Santos, who collected the dolphin, reported (pers. comm.) that it was a neonate Risso's dolphin caught in a long-line commercial fishery operating in deep waters of Santa Catarina ('between 28°S and 26°S') and brought to Santos on 12 September 1983 (in Geise and Borobia, 1987 the record is given to the year of 1984 but should be 1983), where the boat was based. The stomach contained squid beaks and other unidentified material. Considering the large coast of Santa Catarina and the magnitude of its fisheries, the information provided by Simões-Lopes and Ximenez (1993) probably underestimates the true number of specimens caught in the area.

Rio Grande do Sul

The mortality of small cetaceans in gillnets along the Rio Grande do Sul coastline is being monitored by a UNEP/IUCN funded project. Preliminary data collected indicate that the franciscana is the species most commonly taken in gillnets in the northern coast of Rio Grande do Sul (Danilewicz *et al.*, 1993) and fishermen report that other species are taken. There are indications that the bottlenose dolphin is involved and it appears that incidental capture may represent a major threat to coastal species such as the franciscana and the bottlenose dolphin. The 95 cetacean specimens recorded in the northern coast of Rio Grande do Sul between October 1991 and December 1993, include 77 franciscanas, 10 bottlenose dolphins, 2 false killer whales, 2 rough-toothed dolphins, 2 striped dolphins, 1 common dolphin and 1 killer whale.

Data collected along the southern coast of this state indicate that the franciscana is commonly taken in nets (Zerbini *et al.*, 1993). An estimated 150–300 boats operate in this area, depending on the season. About 25 boats are being sampled and, of these, 15 are cooperating with the research. Seventy-two franciscanas have been recorded since the beginning of the port monitoring, with most franciscanas being recorded in the 'Farol da Solidão' area, in depths of 16m to 24m (E. Secchi, pers. comm.). A killer whale was found dead ashore with marks suggesting interaction with fisheries. Incidental catches of a dwarf minke whale and a long-finned pilot whale (*Globicephala melas*) were recorded by the oceanic fishing fleet in deeper waters.

CONCLUSION

A large number of small cetaceans are incidentally caught in gillnets every year along the Brazilian coast. The tucuxi and the franciscana are the species most commonly taken during artisanal fishery operations. The cetacean bycatch seems to be higher during the austral spring and summer, with adult tucuxis and juvenile and sub-adult franciscanas predominating. The sex ratios for both species are about 1:1. Other species that are caught include the bottlenose, rough-toothed, Atlantic spotted, striped, spinner and common dolphins, and the long-finned pilot, false killer, killer and minke whales. Even rudimentary fishing gear can potentially cause mortality of small cetaceans, particularly along the northeast coast of Brazil. Reported mortality appears to be greatest where a combination of factors occur: regular fishing effort; relatively high cetacean abundance; and, of course, the presence of an observer. Some areas are poorly surveyed and this results in the absence of information on cetacean bycatch. Although gillnets are the major source of mortality, deaths can occur through entanglement in longlines. The direct take of dolphins in the north and northeast region needs to be evaluated and monitored and both law enforcement and educational campaigns are urgently needed.

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Review of Small Cetacean Fishery Interactions in Southern Brazil with Special Reference to the Franciscana, *Pontoporia blainvillei*

Maria Cristina Pinedo

Departmento de Oceanografia, Fundação Univeridade do Rio Grande
C.P. 474, CEP 96201-900 Rio Grande, RS, Brazil

ABSTRACT

The distribution, stock identity, growth, reproduction and feeding of nine small cetacean species interacting with fisheries in southern Brazil (23°16'S-33°45'S) is reviewed, based on published and unpublished data. The stock identity of most species is unknown. The most important cause of death is the incidental capture of animals in gillnets, particularly *Pontoporia blainvillei* in the Rio Grande do Sul and Santa Catarina states and *Sotalia fluviatilis* in Paraná state. Interactions with driftnets and longline fisheries is also recorded. The reported mortality and descriptions of these fisheries are presented. Assessing the status and abundance of *Pontoporia* population is a high priority.

KEYWORDS: FISHERIES; INCIDENTAL CAPTURE; SOUTH ATLANTIC; BOTTLENOSE DOLPHIN; FRANCISCANA; FALSE KILLER WHALE; KILLER WHALE; LONG-FINNED PILOT WHALE; COMMON DOLPHIN; ROUGH-TOOTHED DOLPHIN; STRANDINGS; TUCUXI; ATLANTIC SPOTTED-DOLPHIN.

INTRODUCTION

Thirty one species of cetaceans have been recorded in Brazil (Pinedo *et al.*, 1992; Simões-Lopes *et al.*, 1992). Table 1 lists the 17 small cetacean species recorded in the southern states of Rio Grande do Sul, Santa Catarina and Paraná (Bittencourt and Zanelatto, 1992; Pinedo *et al.*, 1992; Sacchi-Santos *et al.*, 1992; Secchi and Siciliano, 1992; Simões-Lopes *et al.*, 1992; Zanelatto and Domit, 1992). Interactions with fisheries have been reported for nine of these species as shown in Table 1. Since 1976, the coast of Rio Grande do Sul has been surveyed for stranded marine mammals (Pinedo, 1986; 1994) from Barra do Estreito (31°57'S) to Farol de Sarita (32°38'S) and occasionally up to Tôrres (29°20'S) and Chuí (33°45'S) (Fig. 1). In the northern Rio Grande do Sul (29°19'S-31°15'S) beach surveys have been conducted since 1991 (Danilewicz *et al.*, 1993). Most of the offshore Rio Grande do Sul sightings were recorded during 19 oceanographic cruises up to over 1900m depth, aboard R/V *Atlantico Sul* (FURG), from 1980–1987. In Rio Grande do Sul, the franciscana and the bottlenose dolphin are the most frequently stranded species, followed by the false killer, killer and long-finned pilot whales and the common and rough-toothed dolphins; on the continental shelf the common dolphin, long-finned pilot whale and killer whale are the most frequently sighted

Table 1

A list of the small cetaceans recorded in southern Brazil, by states. (From Pinedo *et al.*, 1992 and Simoes-Lopes *et al.*, 1992). RS = Rio Grande do Sul, SC = Santa Catarina and PR = Paraná.

Species	Common Name
Physeteridae	
Kogia breviceps (RS)	Pygmy sperm whale
Kogia simus (RS)	Dwarf sperm whale
Delphinidae	
*Delphinus delphis** (RS,SC)	Common dolphin
Stenella attenuata (RS)	Pantropical dolphin
*Stenella frontalis** (SC)	Atlantic spotted dolphin
Stenella longirostris (PR)	Spinner dolphin
Stenella coeruleoalba (RS)	Striped dolphin
Stenella clymene (SC)	Clymene dolphin
*Steno bredanensis** (RS,SC)	Rough toothed dolphin
*Tursiops truncatus** (RS,SC,PR)	Bottlenose dolphin
*Sotalia fluviatilis** (PR,SC)	Tucuxi
*Pseudorca crassidens** (RS,SC)	False killer whale
*Orcinus orca** (RS,SC)	Killer whale
Grampus griseus (SC)	Risso's dolphin
*Globicephala melas** (RS)	Long-finned pilot whale
Pontoporiidae	
*Pontoporia blainvillei** (RS,SC,PR)	Franciscana
Phocoenidae	
Phocoena spinipinnis (RS)	Burmeister's porpoise

* Information on fishery interactions available.

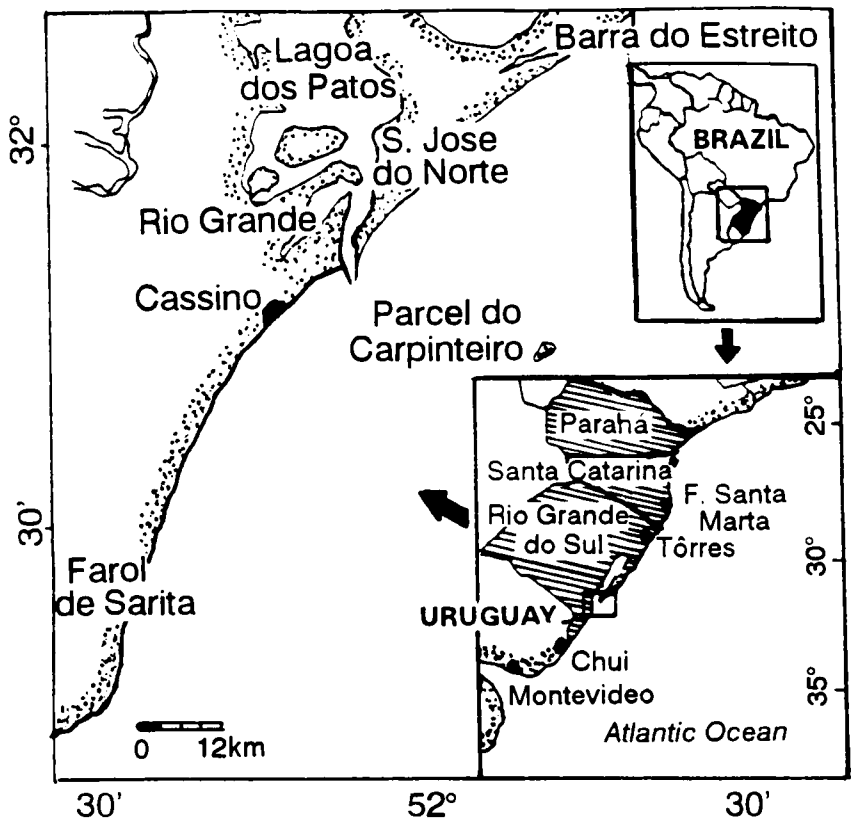

Fig. 1. Southern Brazil and study areas in Rio Grande do Sul.

(Castello and Pinedo, 1986; Pinedo, 1986; Danilewicz *et al.*, 1993; Pinedo, unpublished). In beach surveys begun in 1985 on Santa Catarina Island (27°10′S-27°50′S), most of the specimens were franciscanas (*Pontoporia blainvillei*), bottlenose dolphins (*Tursiops truncatus*) or tucuxis (*Sotalia fluviatilis*) (Paula *et al.*, 1992). In Paraná (25°14′S–25°59′S), where data collection began in 1989, most stranded animals are tucuxis (Zanelatto, 1992).

SPECIES SUMMARIES

***Pontoporia blainvillei* (franciscana)**

The franciscana is an endemic dolphin of central eastern South America, occurring up to approximately 30 miles offshore (Praderi *et al.*, 1989). Its distribution is known to extend from Itaúnas in Espírito Santo State (18°25′S), Brazil (Moreira and Siciliano, 1991) to Rio Negro Province (41°09′S), Argentina (Crespo and Harris, 1992). It was recorded in Espírito Santo (Geise and Borobia, 1987; Moreira and Siciliano, 1991), Rio de Janeiro (Lodi *et al.*, 1987; Lodi and Capistrano, 1990), São Paulo (de Carvalho, 1961; Schmiegelow, 1987; 1990), Paraná (Bittencourt and Zanelatto, 1992), Santa Catarina (Ximenez *et al.*, 1987; Paula *et al.*, 1992) and Rio Grande do Sul (von Ihering, 1892; Gliesh, 1925; Cabrera, 1960; Pinedo, 1982; 1986; Mondin-Machado *et al.*, 1992). There are no records for the Uruguay River, Paraná River (Cabrera and Yepes, 1940; Brownell, 1981) or for the Lagoa dos Patos, in southern Brazil (Pinedo *et al.*, 1989; Pinedo, 1991).

Multivariate analyses of osteological measurements has revealed two geographical forms: a smaller form between 22°S-27°S and a larger form between 32°S-38°S (Pinedo, 1991). These two forms should be considered separately for management and conservation purposes. The species is also found between 27°S and 32° and morphometric data are being collected by the author. The status of the franciscana is still considered as 'insufficiently known' according to the IUCN (1991) Red List, although Perrin *et al.* (1989) had recommended that it should be classified as 'vulnerable'.

Along the Rio Grande do Sul coast (29°20′S-33°45′S) between 1976–1987 and between 1992–1993, at least 1,085 and 88 specimens, respectively, were found dead (Pinedo, 1986; Praderi *et al.*, 1989; Pinedo, unpublished). On Santa Catarina Island (27°10′S-27°50′S) 27 specimens were found dead between 1984–1992 (Ximenez, pers. comm.; Ximenez and Canella, 1992) and in Paraná (25°14′S-25°59′S) 3 dead specimens were recorded between 1989–1992 by Bittencourt and Zanelatto (1992).

The species has been threatened by incidental captures throughout its distribution and obtaining estimates of abundance and determination of stock identity were identified as research priorities by Perrin *et al.* (1989) and Crespo (1992). Crespo also attached importance to obtaining mortality estimates simultaneously with abundance estimates and the necessity of placing observers on fishing vessels. He suggested the area of Valizas-Cabo Polonio, in Uruguay, where there is a high concentration of franciscanas as an area for a pilot study to estimate abundance, along with the use of a number of methods to assess stock identity.

The biology and status of the franciscana was reviewed by Pinedo *et al.* (1989), from specimens taken incidentally in gillnet fishing operations. Males and females can reach 158cm and 177cm, respectively (Brownell, 1989). Age was estimated based on growth layer groups in the teeth (Pinedo, 1991). Females are larger than males and physical maturity is attained between 4 and 8 years, for both sexes (Pinedo, 1991). The oldest female was 21 years old (Pinedo, 1994) and the oldest male was 16 years old (Brownell, 1989).

Sexual maturation occurs between 2 to 4 years for both sexes and a 2-year breeding cycle has been reported (Brownell, 1989). In southern Rio Grande do Sul, calving occurs mainly in November (Pinedo *et al.*, 1989), at the same time that the peak of mortality in gillnets occurs.

Seventeen species of bony fishes were identified from the stomach contents of franciscanas collected from 1976–1981 in southern Rio Grande do Sul. Most fishes eaten were sciaenids of less than 50mm total length and *Cynoscion striatus* was the most abundant prey. The squid *Loligo sanpaulensis* and the shrimps *Pleoticus muelleri, Artemesia longinaris* and *Penaeus paulensis* were also part of the diet. Females eat more squid than males and juveniles eat more shrimps than adults (Pinedo, 1982). The same species of squid and shrimps and an overlap of 12 fish species was observed between the diet of franciscanas from Uruguay and southern Rio Grande do Sul (Brownell, 1975; Pinedo *et al.*, 1989).

***Tursiops truncatus* (bottlenose dolphin)**

The bottlenose dolphin occurs in the coastal southwestern Atlantic from Rio Grande do Norte (*ca.* 5°47′S) in Brazil (Best *et al.*, 1986) to Chubut Province (43°20′S) in Argentina (Mermoz, 1977). In Brazil it is found on the continental shelf and at the entrance of estuaries and rivers (de Carvalho, 1975; Gomes, 1986; Pinedo *et al.*, 1992). It was recorded in Rio Grande do Norte, Paraíba (Best *et al.*, 1986), Bahia (Siciliano *et al.*, 1987a), Espírito Santo (Barros, 1991), Rio de Janeiro (Gomes, 1986; Siciliano *et al.*, 1987a; Geise and Borobia, 1988), São Paulo (de Carvalho, 1975; Schmiegelow, 1990), Paraná (Bittencourt and Zanelatto, 1992), Santa Catarina (de Carvalho, 1975; Ximenez *et al.*, 1987; Ximenez, 1990; Paula *et al.*, 1992) and Rio Grande do Sul (von Ihering, 1892; Gliesh, 1925; Castello and Pinedo, 1977; Pinedo, 1982; 1986; Möller *et al.*, 1992; Mondin-Machado *et al.*, 1992; Santos *et al.*, 1992).

In Rio Grande do Sul, the species is frequently seen along the coast, at the mouth of Tramandaí River and inside Lagoa dos Patos up to the São Gonçalo channel and, off Santa Catarina at the entrance of Lagoa Santo Antônio (Castello and Pinedo, 1977; Pinedo, 1986; Pryor *et al.*, 1990).

Between 1976–1993, 76 specimens were found dead along Rio Grande do Sul (29°19′S-33°45′S) (Pinedo, 1986; Danilewicz *et al.*, 1993; Pinedo, unpublished). In Santa Catarina, at least 17 specimens have been found (Barreto, pers. comm.) and in Paraná 1 stranding was recorded from 1989 to 1992 (Bittencourt and Zanelatto, 1992).

Age estimation based on the growth layer groups (GLGs) of the teeth (Hohn *et al.*, 1989) and the skull development of dolphins from southeast and southern Brazil is in progress (Barreto and Pinedo, in prep.)

There is no information on reproduction in this region, but in the estuary of Lagoa dos Patos juveniles are present year-round (Castello and Pinedo, 1977).

Eleven species of bony fishes, mainly white croaker (*Micropogonias furnieri*), were found in the stomachs of 12 stranded dolphins from Rio Grande do Sul between 1976–1981. Most fish eaten were above 150mm in length. No squid or shrimps were found (Pinedo, 1982).

***Pseudorca crassidens* (false killer whale)**
There are records of this species for Paraíba (Antonelli *et al.*, 1987), Rio de Janeiro (Siciliano *et al.*, 1987b; Geise and Borobia, 1988), Santa Catarina (Simões-Lopes and Ximenez, 1988; Ximenez, 1990; Paula *et al.*, 1992) and Rio Grande do Sul (Castello and Gianuca, 1976; Silva, 1984; Pinedo and Rosas, 1989).

Between 1976–1993, 11 animals were found stranded in Rio Grande do Sul (Pinedo and Rosas, 1989; Pinedo, unpublished; Ott, pers. comm.). White croakers from 460–610mm in length, black drums (*Pogonias cromis*) from 1,070–1,130mm in length and an unidentified serranid were found in the stomachs of two stranded animals (Pinedo and Rosas, 1989).

***Orcinus orca* (killer whale)**
The species occurs along the coasts of the following states: Paraíba (Antonelli *et al.*, 1987), Pernambuco, Alagoas, Bahia (Best *et al.*, 1986), Rio de Janeiro (Castello and Pinedo, 1986; Geise and Borobia, 1988), São Paulo (Daniel *et al.*, 1988), Santa Catarina (Bittencourt, 1983; Castello and Pinedo, 1986) and Rio Grande do Sul (Castello, 1977; Castello and Pinedo, 1986; Ximenez *et al.*, 1987; Secchi and Vasque, 1992).

In Rio Grande do Sul and Santa Catarina, killer whales have been seen in waters between 110–3,500m depth in groups of up to 10 animals (Castello and Pinedo, 1986; Secchi and Vasque, 1992). They were seen during two cruises of the R/V *Atlântico Sul* (Pinedo, unpublished). Six strandings have been recorded in Rio Grande do Sul, 3 prior to 1976 and 3 between 1976–1993, all in the summer or spring (Castello and Pinedo, 1986; Pinedo, unpublished).

Tooth plates of eagle sting rays, *Myliobatis* sp. were found in the stomach of a killer whale stranded in Rio Grande do Sul (Castello, 1977) and predation on swordfish, *Xiphius gladius*, and tuna was recorded by Secchi and Vasque (1992).

***Globicephala melas* (long-finned pilot whale)**
There are records of this species for São Paulo (de Carvalho, 1975) and Rio Grande do Sul (Pinedo *et al.*, 1986; Secchi *et al.*, 1991).

It was seen during six cruises of the R/V *Atlântico Sul* in groups of 6 to approximately 100 animals and at depths from 120 to 1,000m (Castello and Pinedo, 1986; Pinedo, unpublished). Seven strandings were recorded in winter and spring in Rio Grande do Sul, two between 1976–1987 and five between 1992–1993 (Pinedo *et al.*, 1986; Pinedo, unpublished; Secchi *et al.*, 1991). Three stranded specimens in Rio Grande do Sul had squid beaks of Ommastrephidae and Histioteuthidae in the stomachs. Species identification is in progress (Pinedo, 1986; Santos and Pinedo, in prep.).

***Delphinus delphis* (common dolphin)**
This species occurs in northeastern Brazil (Best *et al.*, 1986), Rio de Janeiro (de Carvalho, 1963; Gomes, 1986; Siciliano *et al.*, 1987b; Geise and Borobia, 1988; Lodi and Capistrano, 1990), São Paulo (de Carvalho, 1975; Siciliano *et al.*, 1987b; Schmiegelow, 1990), Santa Catarina (Ximenez *et al.*, 1987; Ximenez, 1990; Paula *et al.*, 1992) and Rio Grande do Sul (Castello and Pinedo, 1986; Secchi and Vasque, 1992).

Common dolphins are frequently seen along the coast of Rio Grande do Sul and Santa Catarina, from at least 50 miles offshore, in depths of 70 to 2,500m and in groups of up to 500 animals (Castello and Pinedo, 1986; Pinedo *et al.*, 1992; Secchi and Vasque, 1992). In Rio Grande do Sul, the species was sighted during 17 of 19 oceanographic cruises aboard R/V *Atlântico Sul* (Pinedo, unpublished). Although frequently sighted in offshore waters of Rio Grande do Sul, only two strandings have been reported (Castello and Pinedo, 1986; Danilewicz *et al.*, 1993).

***Steno bredanensis* (rough-toothed dolphin)**
Records are available for the states of Ceará (Themotheo-Sobrinho, 1992), Pernambuco (Best *et al.*, 1986), Rio de Janeiro (Pinedo and Castello, 1980; Siciliano *et al.*, 1987a; Lodi and Capistrano, 1990), Santa Catarina (Praderi and Ximenez, 1987; Ximenez and Praderi, 1988; Ximenez, 1990; Paula *et al.*, 1992; Ximenez and de Flôres, 1992) and Rio Grande do Sul (Mondin-Machado *et al.*, 1992; Sacchi-Santos *et al.*, 1992).

In Rio Grande do Sul, a sighting of eight animals at 18 n.miles from Tôrres (*ca.* 29°22'S) and 2 stranded specimens (*ca.* 30°09'S) were reported by Sacchi-Santos *et al.* (1992).

***Sotalia fluviatilis* (tucuxi)**
There are two forms of this species as described by Borobia and Sergeant (1989). The marine coastal form is commonly found from Pará (Borobia *et al.*, 1987) to Santa Catarina (Simões-Lopes, 1987), whilst the freshwater form is endemic to the Amazon river basin (Magnusson *et al.*, 1980; da Silva, 1983). The marine form was recorded in Pará, Paraíba, Bahia (Borobia *et al.*, 1987), Maranhão (de Almeida *et al.*, 1992) and Ceará (Themotheo-Sobrinho, 1992), Rio Grande do Norte, Sergipe (Siciliano *et al.*, 1987b; Magalhaes *et al.*, 1993), Pernambuco (de Almeida *et al.*, 1990), Bahia (Reis and Queiroz, 1992), Espírito Santo (Barros, 1984; 1991; Borobia *et al.*, 1987; Geise and Borobia, 1987), Rio de Janeiro (Castello and Pinedo, 1986; Geise and Borobia, 1988; Lodi and Capistrano, 1990), São Paulo (de Carvalho, 1963; Castello and Pinedo, 1986; Monteiro Filho, 1990; Schmiegelow, 1990), Paraná (Bittencourt, 1984; Bittencourt and Zanelatto, 1992) and Santa Catarina (Simões-Lopes, 1987; 1988; Ximenez, 1990).

Off Santa Catarina Island, a resident group of 50–60 animals has been observed in Baía Norte (de Flôres, 1992). In Paraná it was the most common cetacean stranded: from 1989 to 1992 fifty two animals were found dead on the beach, with a peak in mortality between June and July (Zanelatto, 1992).

According to de Flôres (1992) Baía Norte is a feeding and probably a breeding area.

***Stenella frontalis* (Atlantic spotted dolphin)**
There are records of this species for São Paulo (Schmiegelow, 1990; Pinedo *et al.*, 1992), Rio de Janeiro (Lodi and Capistrano, 1990) and Santa Catarina, where four strandings have been reported (Ximenez *et al.*, 1987; Ximenez and Praderi, 1988; Ximenez, 1990; Paula *et al.*, 1992).

SMALL CETACEAN FISHERY INTERACTIONS IN SOUTHERN BRAZIL

Incidental catches and fishery characteristics

Franciscanas
Incidental catches occur along Brazil, Uruguay and Argentina and are the major cause of mortality. The characteristics of these fisheries have been summarised by

Table 2

Gillnet fishery characteristics in Rio Grande do Sul during spring (southern) and year-round (northern) by year (Pinedo, 1982; Pinedo, 1986; Praderi *et al.*, 1989; Reis, 1992; Pinedo, unpublished; Ott *et al.*, 1992). Blank space means information not available.

	Southern				Northern
Description	1976-81	1986	1988	1991	1992
Net					
length(m)	Up to 3,000	3,000-5,000	<8,000	*ca.*8,000	Up to 300
height(m)	2.5-16			4	
mesh(cm)	9.32			14-16	9-38[a]
twine mat.		Nylon			Nylon
twine const.		monofilament			
twine diam(mm)		6			
soak time(hrs)			2.5-4	x=4	
no. soaks/day			x=3	x=4	
Boat size (m)	8	8-15	12-20	12-20	10-18
number		1,560[b]; 60[d]	200[c]; 150[d]	150; 139[d]	35
crew		6	4-12	4-12	4-8
horsepower			90-325	90-325	90-160
Max. dist. (nm)	15	30	16	35	30
Depth(m)	25	20-30	13-26	13-44[e]	10-60[f]
Days/trip		1-7	1-4		1-6
Fishing areas	31°44'-32°38'		31°44'-32°30'	31°15'-33°00'	29°19'-31°15'
Target species		Sciaenids			Sciaenids, Gadids, Mugilids Flounders, Sharks

[a] Four franciscanas caught in mesh sizes 11-14cm. [b] 8m boats including estuary and coast licensed by SUDEPE (Rahn, pers.comm.). [c] Probably too high. [d] Only 15m coastal boats. [e] 25m preferred. [f] Four franciscanas taken between 23-29m.

Table 3

Gillnet fishery characteristics in Santa Catarina from data collected in 1993 (Pinedo, unpublished) and in Paraná (Zanelatto, 1992). South latitudes in parenthesis. Blank space means information not available.

	Santa Catarina				Paraná
Description	Garopaba (28°03')	Imbituba (28°15')	Farol Sta. Marta (28°29')	Passo Tôrres (28°40')	Paranaguá (25°32')
Net length(m)	1,500-2,225	500-1,200	1,500-2,225	4,500-6,000	100-1,000
height(m)	3	2-2.5	3	3.5	3-8
mesh(cm)	10-11	[a]	[b]	14-15	4-20
twine mat.	Nylon	Nylon			Nylon
twine const.	monofil.				
twine diam(mm)					4-6
soak time(hrs)	12		24	4	
no. soaks/day	1				
Boat size(m)	9-12	8-11		8-15	
number	25	8	70	33	
crew					
horsepower					
Max.dist.(nm)	8-9	[c]	[d]	1	
Depth(m)	30			70	
Days/trip					
Fishing areas			P.Campo Bom, P. Flora	I. Lobos	
Fishing period	Jul-Oct	Jul-Dec	Year-round		Jun-Jul
Target species	Sciaenids	Sciaenids	Sciaenids, Sharks	Sciaenids, Sharks	Flounder*, Snook, Drumfish, Sciaenids, Catfish, Mackerel, Sharks

[a] 8-10cm inside/35-50cm outside. [b] 10cm inside/40cm outside. [c] 1h 30' south. [d] 1h 30' offshore. * Correlated with high mortality of small cetaceans.

Pinedo *et al.* (1989), Praderi *et al.* (1989) and Crespo (1992). In Rio Grande do Sul, most catches occur in spring, in bottom gillnets set mainly for sciaenids. The white croaker, *Micropogonias furnieri*, is a major target species of both artisanal and industrial fisheries and is taken by gillnets (in spring) and trawls (year-round). The trawl fishery is directed at both small and large fishes while the coastal gillnet fishery is directed to spawning adults (Haimovici, 1987; Haimovici *et al.*, 1989; Reis, 1992). Artisanal fishing effort has been increasing since 1982 (Pinedo, 1986; Praderi *et al.*, 1989). The total catch of sciaenids, especially the white croaker, has decreased as a result of overexploitation (Haimovici *et al.*, 1989). The mean annual catch of sciaenids between 1984 and 1990 was about 28,000 tonnes, of which 35% was white croaker (IBAMA, 1993). Almost all (95%) artisanal catches were made with gillnets. Mesh sizes, height and lengths vary according to the season and the target species (Reis, 1992). Characteristics of the gillnet fisheries in Rio Grande do Sul and Santa Catarina are presented in Tables 2 and 3.

Between 1976–1987, 919 dead franciscanas were found along 120km of the Rio Grande do Sul coast, from 31°57'S to 32°38'S, with a mean annual catch of 84. Fewer dead animals were recovered yearly between 1982–1987 (n=69.5) than between 1976–1981 (n=83.6). In the two years 1992 and 1993, 64 dead animals were found (Pinedo, unpublished).

Off Santa Catarina Island, incidental catches of franciscanas, bottlenose dolphins and tucuxis account for 69% of the catches of the seven small cetaceans reported caught; mesh sizes range from 4 to 20cm (Ximenez, 1990; Paula *et al.*, 1992; Ximenez and de Flôres, 1992). According to local fishermen, in Farol de Santa Marta (28°29'S), franciscanas are more frequent in winter and approximately 20–30 animals are caught annually. Groups of 3–6 franciscanas were reported by fishermen of Farol de Santa Marta and Garopaba (28°03'S) and groups of 8–10 animals were reported for Passo de Tôrres (29°20'S) (Pinedo, unpublished). In Sombrio (28°40'S) and Passo de Tôrres, franciscanas seem to occur mainly in summer (November to February) and in November 1991, 2–3 animals per week were caught in Sombrio (Pinedo, unpublished). Characteristics of the gillnets used in southern Santa Catarina (28°03'S-28°40'S) and Paraná are presented in Table 3. Zanelatto (1992) reports catches of franciscanas in longlines set for sharks in Paraná, but gives no further information.

Tursiops truncatus

Incidental capture in fishing gear does not appear to be a major cause of mortality of the bottlenose dolphin in Rio Grande do Sul (Pinedo, 1986). Twenty of the 76 strandings

Table 4

Summary of incidental mortality of small cetaceans in southern Brazil (in gillnets unless otherwise indicated). South latitudes in parenthesis. Blank space means information not available. Source: [1] Pinedo, 1986; [2] Pinedo, unpublished; [3] Pinedo *et al.* 1989; [4] Rosas, unpublished; [5] Möller *et al.*, 1992; [6] Santos *et al.*, 1992; [7] Zerbini *et al.*, 1993; [8] Danilewicz *et al.*, 1993; Mondin-Machado *et al.*, 1992; [10] Pinedo *et al.*, 1986; [11] Ximenez, pers. comm; [12] Ximenez and Canella, 1992; [13] Paula *et al.*, 1992; [14] Simoes-Lopes and Ximenez, 1988; [15] Ximenez and de Flôres, 1992; [16] Bittencourt and Zanelatto, 1992; [17] Bittencourt, 1984 and [18] Zanelatto, 1992. [a] Caught between 16-52m depth by two fishing boats. [b] Estimates annual mortality. [c] Longline (for tuna). [d] Longline (driftnet). [e] Driftnet (for sharks).

Location and species	Year(s)	Estimated no. killed
Rio Grande do Sul		
P. blainvillei		
(31°57',32°38')	1976	13 [1]
	1977	23 [1]
	1978	20 [1]
	1979	97 [1]
	1980	129 [1]
	1981	168 [1]
	1982	35 [1]
	1983	76 [1]
	1984	39 [2]
	1985	70 [2]
	1986	135 [3]
	1987	59 [4]
	1992	14 [2]
	1993	50 [2]
(32°00',33°45')	1987-92	54 [5]
(31°51',32°37')	1987-90	58 [6]
(31°18',33°45')	1992	11 [a,7]
(29°19',31°15')	Oct 91-Apr 93	61 [8]
T. truncatus		
(29°19',31°15')	1976-83	5 [1]
	Oct 91-Apr 93	6 [8]
S. bredanensis		
(29°19',31°15')	Oct 91-Apr 93	2 [8,9]
D. delphis		
	Oct 91-Apr 93	1 [8,9]
S. coeruleoalba		
	Oct 91-Apr 93	1 [8,9]
G. melas		
	1986	1 [c,10]
	1992-93	4 [d,2]
	1990	1 [e,7]
Santa Catarina		
P. blainvillei		
(27°37')	1984-90	27 [11]
	Apr 90-Sep 92	0 [12]
(28°40')	Nov 91	8-12 [2]
(28°29')	-	20-30 [b,2]
T. truncatus		
(27°37')	-	- [13]
S. fluviatilis		
(27°37')	-	- [13]
D. delphis		
(27°37')	-	- [13]
P. crassidens		
(27°37')	-	1 [13,14]
S. frontalis		
(27°37')	-	- [13]
S. bredanensis		
(27°36')	1992	1 [15]
Paraná		
P. blainvillei		
(25°14'-25°59')	Jul 89-Apr 92	3 [16]
T. truncatus		
(25°14'-25°59')	Jul 89-Apr 92	1 [16]
S. fluviatilis		
(25°32')	1982	1 [17]
(25°14'-25°59')	1989	6 [16]
	1990	6 [16]
	1991	14 [16]
	Jan 92-Apr 92	7 [16]
	May 92-Sep 92	18 [18]

in Rio Grande do Sul were attributed to fishery interactions. Five were caught in 22cm mesh gillnets set for sharks two miles offshore (Pinedo, 1986; Pinedo, unpublished). A dolphin swimming with gillnet debris around its body was observed by Zerbini *et al.* (1993). From October 1991 to April 1993, six dolphins were caught in gillnets in northern Rio Grande do Sul (Mondin-Machado *et al.*, 1992). Incidental catches were also reported (Table 2) in Santa Catarina (Paula *et al.*, 1992) and Paraná (Bittencourt and Zanelatto, 1992). Mortality in nets may be higher than reported for this species, as most stranded animals were highly decomposed when found and the bodies could not be examined for net marks.

Long-finned pilot whales
The deaths of four animals found stranded in southern Brazil from 1992 to 1993 were probably related to the longline fishery for tuna.

Tucuxis
Mortality in gillnets has been reported for Santa Catarina by Paula *et al.* (1992) and for Paraná by Bittencourt (1984) and Bittencourt and Zanelatto (1992). According to Zanelatto (1992) there is evidence that the fishery for flounders, *Paralichthys* spp. (Table 3), is responsible for high mortality of tucuxi. This fishery uses large mesh sizes (18–20cm).

Other small cetaceans
Interactions between fisheries and small cetaceans have also been recorded for false killer whales, common dolphins, rough-toothed dolphins and spotted dolphins in southern Brazil (Table 4).

Intentional catches
Ximenez (1990) reported a directed catch of franciscana off Santa Catarina Island.

Predation on catches and fishery characteristics
Killer whales
Killer whale attacks on tuna and swordfish, *X. gladius* hooked by longlines have been reported off Rio Grande do Sul and Santa Catarina (27°S-34°S), in waters from 500 to 3,500m deep. Attacks on swordfishes were more common during autumn and spring, when higher catches occur. Killer whales may damage up to 50% of the catch on a single fishing trip (Secchi and Vasque, 1992).

Longline fisheries in Rio Grande do Sul began in 1977, using leased Japanese tuna vessels (and Chinese vessels since 1991). Fishing effort has increased from 3 vessels in 1977 up to 20 in 1993 (Silva, J.N.A., pers. comm.). The longline fishery is described by Silva (1992). Two fishing areas were reported: in autumn and winter south of 25°S (area 1) and in spring and summer north of 25°S (area 2). The catch per unit effort (CPUE) in area 1 is higher, accounting for 82% of the fishing. Fishing in area 2 depends on the result of the catch in area 1. In area 1 the most important species caught by weight, are the yellow fin tuna (*Thunnus albacares*), the bigeye tuna (*Thunnus obesus*), the albacore (*Thunnus alalunga*) and the swordfish (*X. gladius*). The first three species represented 62% and the latter 15% of the total catch by weight (Silva, 1992).

Changes in the composition of the catches
Franciscanas
The ages of 184 franciscanas collected in Rio Grande do Sul from 1976–1986 revealed a higher vulnerability of the species to gillnets in the first three years of life: 50% of the dolphins caught were up to 3 years old, i.e., before or at the age of sexual maturation (Pinedo, 1994). Between 1982–1986 the relative frequency of dead franciscanas older than 3 years increased compared to the 1976–1980 period (Pinedo, 1994).

An increase of fishing effort has occurred since 1982 in Rio Grande (Praderi *et al.*, 1989) but there is no information about possible shifts in fishing grounds. If it is assumed that fishing grounds have remained the same between 1976–1986, the apparent change in age composition may indicate that the franciscana population structure is being affected by this coastal gillnet fishery (Pinedo, 1994).

CONCLUSIONS AND RECOMMENDATIONS

Over the last ten years, the number of observers interested in cetaceans has increased in Santa Catarina, Paraná and Rio Grande do Sul, and this is reflected by a higher number of records. Although mortality for most species of small cetaceans in southern Brazil seems to be lower than other geographical regions, more detailed information, based on systematic monitoring of the fisheries and catches is needed (data collection methods and requirements should be standardised). Coastal fisheries mainly appear to affect the tucuxi in Paraná and the franciscana in Rio Grande do Sul and Santa Catarina. The known mortality of the franciscana is higher in Rio Grande do Sul but incidental takes in Santa Catarina might have been underestimated. More accurate reporting for both species is required, especially for Santa Catarina and Paraná. The mortality of long-finned pilot whales in southern Rio Grande do Sul has increased since 1992, associated with the increase in the longline fishery.

This review suggests a number of research and management priorities.

(1) Estimation of the abundance of the franciscana population is urgently needed.
(2) Gillnet fisheries in northern Rio Grande do Sul, Santa Catarina and Paraná should be monitored in order to assess the level of mortality of the franciscana and other small cetaceans and to enable the impact of such catches to be assessed.
(3) Incidental catches of the franciscana should be monitored in the fishing villages of Santa Catarina state.
(4) Gillnet fisheries should continue to be monitored in southern Brazil and fishery characteristics reported in accordance with the guidelines developed in IWC (1994).
(5) In Paraná from 1989 to 1992 fifty four specimens of small cetaceans were incidentally caught in gillnets and longlines, a third of which were eaten by fishermen (Zanelatto, 1992). The situation must be monitored to ensure that a shift from incidental to directed catches does not occur. The level of franciscana deaths due to longlines needs to be investigated.
(6) Studies on the age, sex composition and reproductive parameters of the franciscana should be initiated in northern Rio Grande do Sul, Santa Catarina and

Paraná and continued in southern Rio Grande do Sul, to allow comparisons with those of Uruguay and Argentina.

(7) Levels of incidental catches of long-finned pilot whales and other small cetaceans in longline fisheries should be assessed in view of the current development of such fisheries.

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Impact of Incidental Fishery Mortality on the Age Structure of *Pontoporia blainvillei* in Southern Brazil and Uruguay

Maria Cristina Pinedo

Depto. Oceanografia, Fundaçao Universidade do Rio Grande, C.P. 474, CEP 96500–900, Rio Grande, RS Brazil

ABSTRACT

Incidental catches of franciscanas occur in Argentina, Uruguay and Brazil. Ages were estimated for 430 incidentally caught dolphins from Uruguay and southern Brazil (Rio Grande area) taken from 1969 to 1982 and from 1976 to 1986, respectively, based on GLGs in teeth. A total of 62% of the combined sample was less than four years old. For Uruguay, no change in relative abundance was observed for dolphins in two age strata (<4yrs and ≥4yrs) before and after 1979, when a decrease of fishing effort occurred. For Rio Grande, relatively fewer animals less than 4yrs of age were observed after 1982, coinciding with an increase in fishing effort. This may reflect a long period of incidental mortality of dolphins and a consequent impact on the species in southern Brazil.

KEYWORDS: SOUTH ATLANTIC; FRANCISCANA; AGEING; INCIDENTAL CAPTURES.

INTRODUCTION

In Argentina and Uruguay *Pontoporia blainvillei* is known as the 'franciscana' whereas in Brazil its called the 'toninha' or 'cachimbo'. The species is incidentally caught in gillnets and trammel nets throughout its distribution in the coastal waters of these three countries (Fig. 1). This paper concentrates on incidental catches taken in Uruguayan and southern Brazilian waters.

A review of the characteristics of these fisheries was given by Praderi *et al.* (1989). In Uruguay, catches occur mainly during the summer whilst in southern Brazil they occur mainly during spring. These seasons coincide with the calving period of the species in both areas (Pinedo *et al.*, 1989). In Uruguayan waters, at least 2,499 dolphins were caught from 1969 to 1982 (Brownell, 1975; Praderi *et al.*, 1989). A change in fishing practice occurred in Uruguay in 1975, when nets began to be set at the extreme inshore range of the earlier fishing grounds, i.e. 15–20 miles from the coast instead of up to 20–30 miles (Van Erp, 1969). A decrease in fishing effort has occurred since 1979 (Praderi *et al.*, 1989). In southern Brazil (the Rio Grande area), at least 867 dolphins were caught from 1976 to 1986 (unpublished data) and an increase in fishing effort has occurred since 1982 (Praderi *et al.*, 1989).

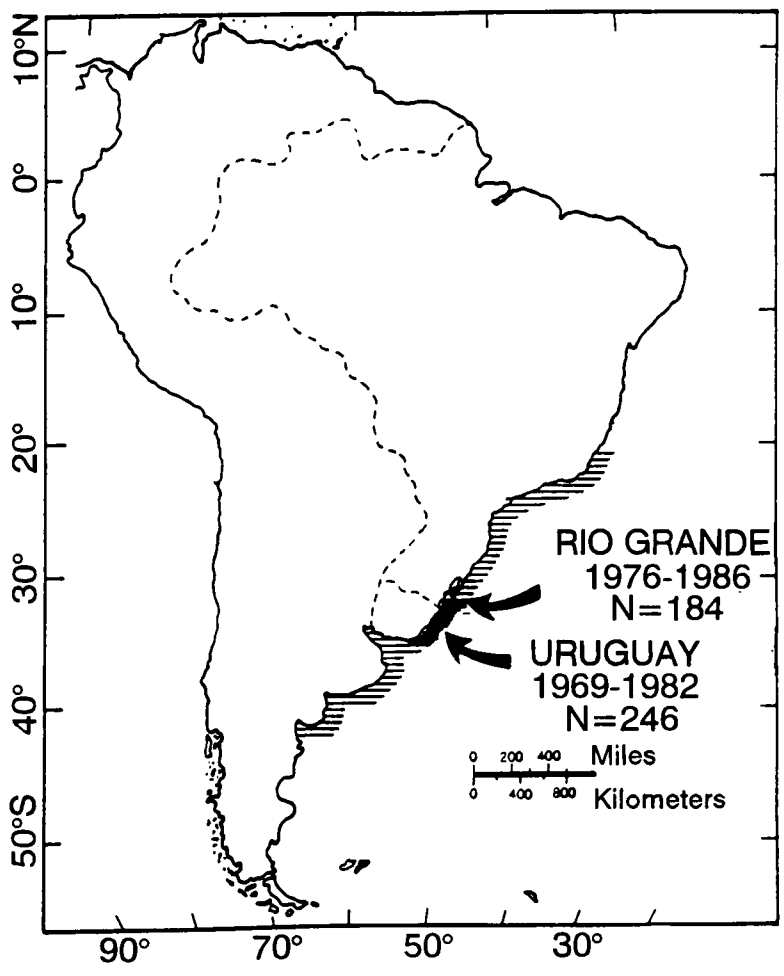

Fig. 1. Distribution of the franciscana in western South Atlantic with locality, time-period and size of samples (modified from Pinedo *et al.*, 1989).

Multivariate analysis of morphometric data has revealed two geographical forms: a smaller form between 22°S and 27°S; and a larger form between 32°S and 38°S (Pinedo, 1991). It is not yet known what form(s) the animals between 27°S and 32°S are. Thus the animals from this study are all from the larger form and probably from the same population (Pinedo, 1991).

The first study to examine age determination of the franciscana was that of Kasuya and Brownell (1979) who looked at teeth from 260 animals incidentally caught off Uruguay. Crespo *et al.* (1986) used the same method (decalcified, stained longitudinal ground sections) to look at further samples from Uruguay.

MATERIALS AND METHODS

Teeth collected from 246 Uruguayan specimens from 1969 to 1982 and from 184 Rio Grande specimens from 1976 to 1986 were examined in this study. Age was estimated based on growth layer groups (GLGs) present in dentine and cementum (IWC, 1980). Teeth were prepared as described by Hohn *et al.* (1989). A model series of ideal 'on-center' cuts was obtained. A comparison of on-center and 'close-to-center' cuts revealed that for most specimens readability was equal or similar for both types of cuts (Pinedo and Hohn, unpublished data). Both types were therefore used to estimate age in this study. Calibration for the first dentinal GLG was based on the mean length obtained by Kasuya and Brownell (1979) for one-year-old specimens and from one specimen aged by them and also available in this study. An annual GLG deposition was confirmed indirectly (Pinedo and Hohn, unpublished data). Although Kasuya and Brownell (1979) used slightly different techniques to those used here, the age frequency distributions for the Uruguayan specimens obtained in this

study were similar to those obtained by them, suggesting that the results are comparable.

Based on an age of attainment of sexual maturity of 2–3 years for both sexes (Kasuya and Brownell, 1979), the sample was divided in two groups: 'immatures', from 0–3.9 years (<4yrs), and 'matures', above 3.9 years (≥4yrs). Specimens were classified to a specific age class based on complete formation of dentinal or cemental GLGs.

A chi-square goodness of fit test at the 1% significance level was applied to compare age distributions before and after changes in fishing effort, between and within areas, and to test homogeneity before pooling annual samples. Analyses were performed for specimens <4yrs and ≥4yrs and for individual age classes. In the latter, the age classes with smaller sample sizes were pooled to avoid introduction of bias due to expected frequencies less than 1.0 (Zar, 1984). The 1986 Rio Grande sample was treated separately, because it was unusual in containing a larger number of older specimens when compared with the samples from previous years. For the two group comparisons, since the degree of freedom was 1 (2 × 2 contingency table), the Yates correction for continuity was used, to better approximate the distribution to the confidence level set (Zar, 1984). Comparisons between areas were performed using the null hypothesis that the distributions of specimens <4yrs and ≥4yrs were the same for Uruguay and Rio Grande. Comparison within areas and homogeneity tests for annual samples were performed using the null hypothesis that the distributions of specimens in the years compared were the same. For each analysis, the alternative hypothesis was that the relative age frequency distributions were different.

RESULTS

Of the total pooled sample, 176 were males, 198 were females and 56 of unidentified sex. The oldest male and female were 15 and 21 years old, respectively. Of 18 pregnant females aged, the youngest and oldest were 2 and 14 years old, respectively. Thirty specimens were of age 12 or older (19 females) while 265 (62%) were less than four years old (Fig. 2). Results obtained from chi-square comparisons for specimens <4yrs and ≥4yrs are shown in Table 1. A comparison of the Uruguay and Rio Grande frequencies (Fig. 2, Table 1) revealed that a higher percentage of dolphins under 4yrs old was observed for the former area (70% vs 50%).

For the Uruguayan sample, no differences were observed in the relative frequency of dolphins <4 years over time (Fig. 3, Tables 1 and 2). By contrast, for the Rio Grande sample, a difference in the relative frequency of dolphins <4 years old was detected between 1982–1985 and 1986 (Fig. 4, Table 1). When individual and grouped age classes were compared, the distributions were not the same for individual age classes less than six years old and for age classes at age six or older between 1976–1980 and 1982–1985 and between the latter period and 1986 (Table 3). Age classes 2 and ≥6 contributed most of the difference, with lower and higher values in 1986 than expected, respectively.

Table 1

Chi-square comparisons between and within areas by age groups.

Area and years/Age groups		< 4 years	> 4 years	N	Chi-square	DF
Uruguay	1969-1982	172	74	246		
					15.90*	1
Rio Grande	1976-1986	93	91	184		
Uruguay	1969-1972	67	35	102		
					0.40	1
	1980-1982	25	9	34		
	1969-1972	67	35	102		
					1.05	1
	1973-1975	79	29	108		
					0.03	1
	1980-1982	25	9	34		
Rio Grande	1976-1980	49	48	97		
					0.53	1
	1986	25	33	58		
	1976-1980	49	48	97		
					4.73	1
	1982-1985	18	5	23		
					6.82*	1
	1986	24	33	58		

* Statistically significant at $\alpha = 0.01$.

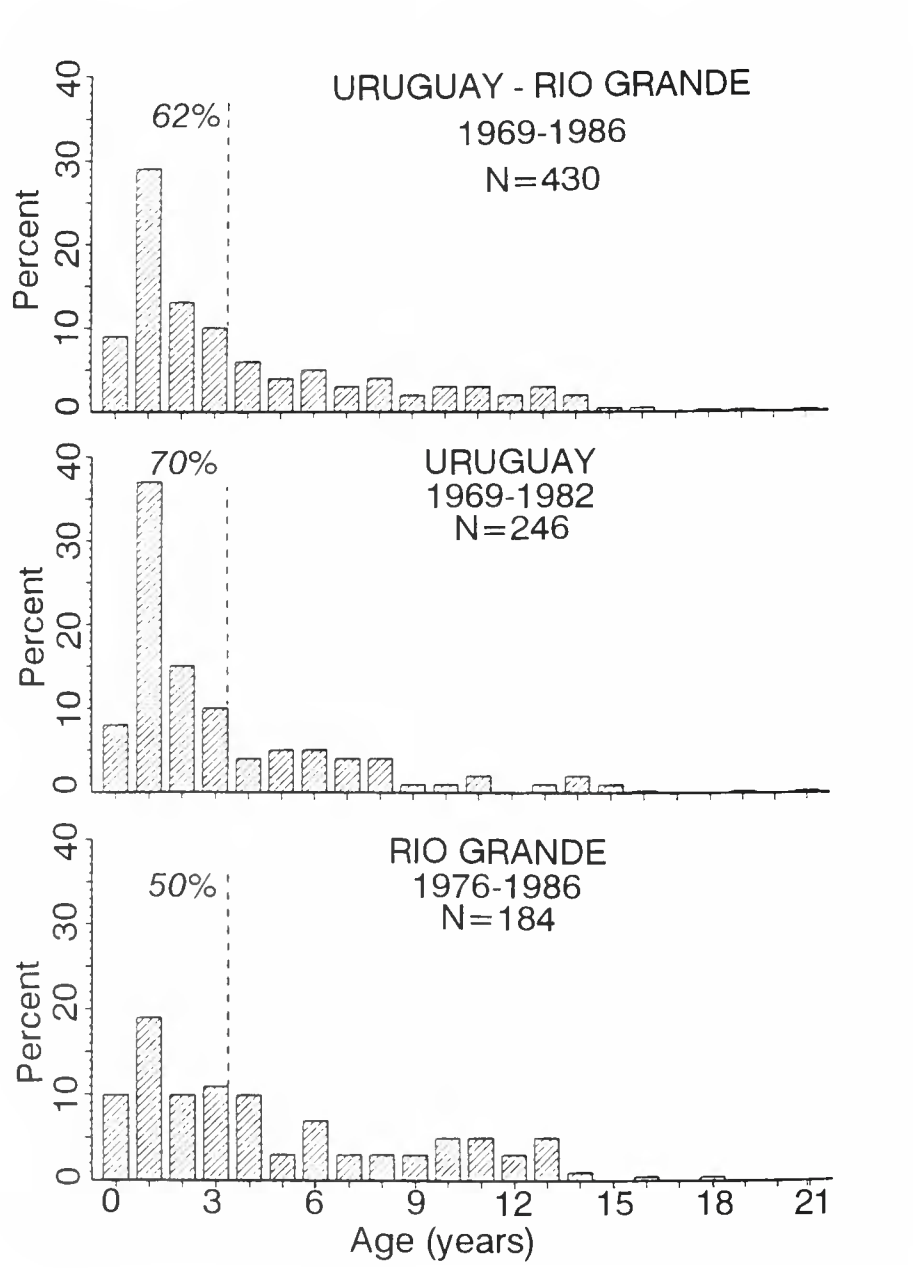

Fig. 2. Age frequency distribution of the total sample, Uruguay and Rio Grande combined, and by area.

DISCUSSION

On the basis of the pooled sample in this paper, females appear to have a greater longevity than males. The age range of pregnant females is in agreement with results from previous studies. Age frequencies obtained in the present study were similar to those obtained by Kasuya and Brownell (1979) and Crespo *et al.* (1986). In all three studies, a higher frequency of specimens <4 years old was observed, with the one-year age class being prevalent.

Table 2

Chi-square comparisons between years for Uruguay by individual and grouped age classes. The expected frequencies predicted by the null hypothesis are given in parenthesis.

	Age (years)												
Years	0	1	2	3	4	5	6	7	8	>9	N	Chi-square	DF
1969-1972	8	30	15	14	5	4	4	6	4	12	102		
	(6)	(37)	(15)	(11)	(4)	(5)	(5)	(5)	(5)	(10)		12.93	9
1980-1982	0	19	5	1	0	3	2	1	2	1	34		
	(2)	(12)	(5)	(4)	(1)	(2)	(2)	(2)	(2)	(3)			
1969-1972	8	30	15	14	5	4	4	6	4	12	102		
	(10)	(34)	(15)	(12)	(4)	(4)	(4)	(4)	(4)	(10)		5.42	9
1973-1975	12	41	16	10	4	5	5	3	4	8	108		
	(10)	(37)	(16)	(12)	(5)	(5)	(5)	(3)	(4)	(10)			
1973-1975	12	41	16	10	4	5	5	3	4	8	108		
	(9)	(46)	(16)	(8)	(3)	(6)	(5)	(3)	(5)	(7)		12.01	9
1980-1982	0	19	5	1	0	3	2	1	2	1	34		
	(3)	(14)	(5)	(3)	(1)	(2)	(2)	(1)	(1)	(2)			

* Statistically significant at $\alpha = 0.01$.

Table 3

Chi-square comparisons between years for Rio Grande by individual and grouped age classes. The expected frequencies predicted by the null hypothesis are given in parenthesis.

	Age (years)									
Years	0	1	2	3	4	5	>6	N	Chi-square	DF
1976-1980	9	23	9	8	13	1	34	97		
	(10)	(20)	(7)	(9)	(11)	(3)	(37)		8.33	6
1986	7	9	2	7	4	4	25	58		
	(6)	(12)	(4)	(6)	(6)	(2)	(22)			
1976-1980	9	23	9	8	13	1	34	97		
	(9)	(20)	(14)	(11)	(11)	(2)	(30)		21.20*	6
1982-1985	2	2	8	6	1	1	3	23		
	(2)	(5)	(3)	(3)	(3)	(0)	(7)			
1982-1985	2	2	8	6	1	1	3	23		
	(3)	(3)	(3)	(4)	(1)	(1)	(8)		18.68*	6
1986	7	9	2	7	4	4	25	58		
	(6)	(8)	(7)	(9)	(4)	(4)	(20)			

* Statistically significant at $\alpha = 0.01$.

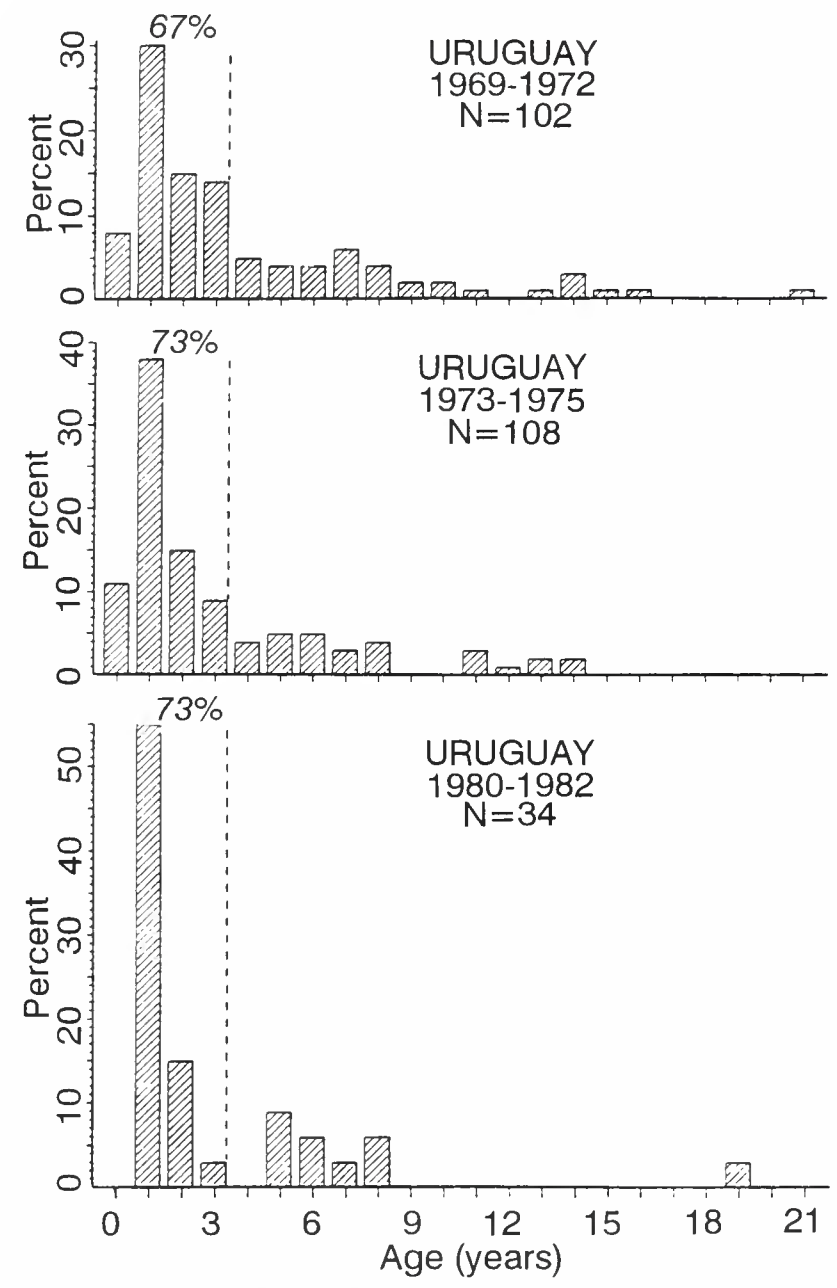

Fig. 3. Age frequency distributions for Uruguay.

Some authors have speculated that juveniles might exhibit behaviour (e.g. curiosity) more likely to result in their entanglement than adults (e.g. IWC, 1994).

The higher proportion of dolphins <4 years old found in the Uruguayan sample might indicate that: (1) juveniles are more vulnerable to larger mesh size used in Uruguay (32–34cm) than those (10–32cm) used in southern Brazil (Praderi *et al.*, 1989); (2) in Uruguay the nets are set in areas mainly used by juveniles; (3) juveniles are more frequent in Uruguay; or (4) a combination of these.

In considering the Uruguayan results, some aspects of the fisheries need to be taken into account. During the first two periods (1969–1972 and 1973–1975) before the decrease of fishing effort, the characteristics of the fisheries from which the samples were obtained were similar: samples came from Punta del Diablo, a fishing village where nets were set up to 20–30 miles from the coast and at depths of 20–30m (Van Erp, 1969; Brownell, 1975). However, during the 1980–1982 sampling period fishermen of this village (from which 35% of the aged dolphins came) had moved to mainly offshore (>20 miles). The remaining 65% of the sample came from another village, Barra Valizas, where nets were set in shallower waters, between

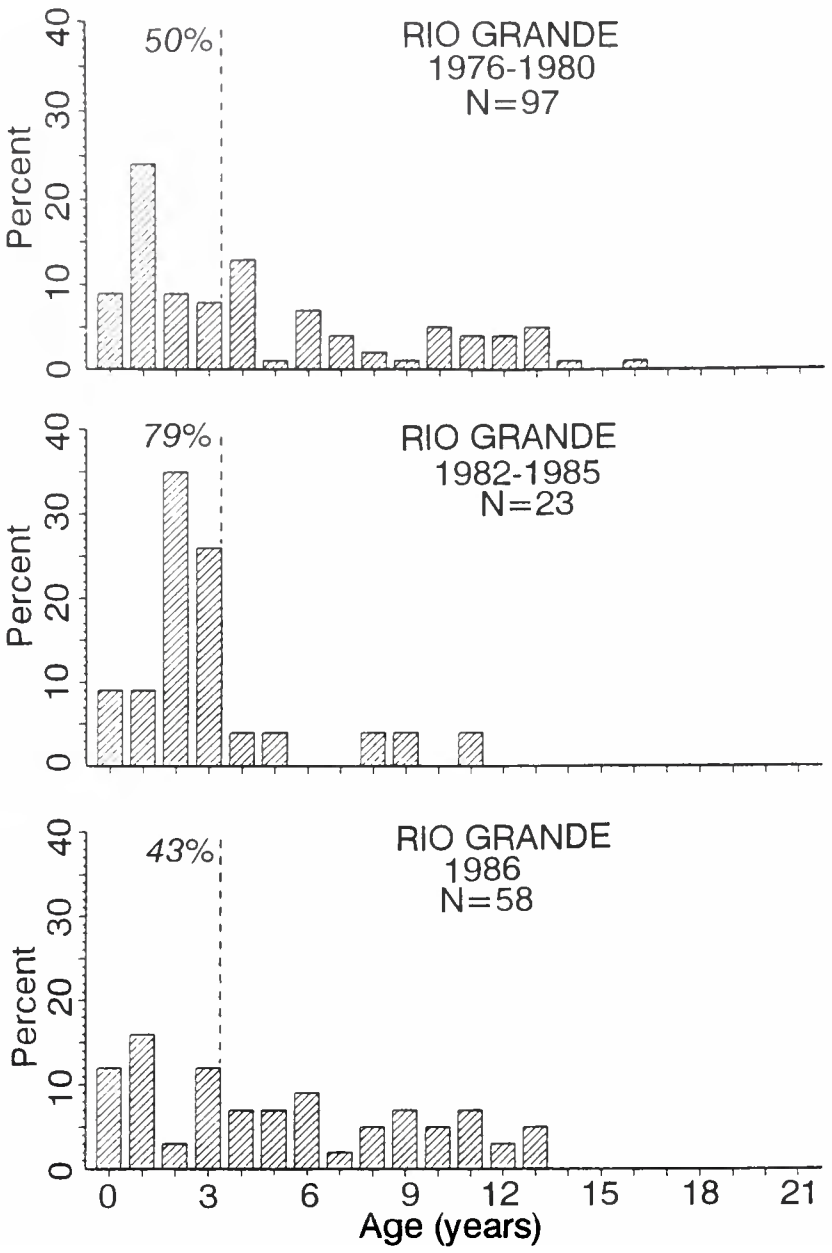

Fig. 4. Age frequency distributions for Rio Grande.

6–15m deep (Praderi *et al.*, 1989). According to Praderi *et al.* (1989), 68–75% of the dolphins died in nets set at 6–20m, while the remaining died in nets set in waters deeper than 20m. Although an annual increase of 25% in the catch of franciscanas was observed for this village between 1979 and 1982 (Praderi, 1984), no difference in the distribution of age frequencies for Uruguayan specimens was observed from 1969 to 1982. This suggests the possibility of a constant age distribution at different distances from the coast and different water depths. If this is true, alternative (2) above seems unlikely.

Unfortunately, there is less information about operations from Rio Grande during this period and in particular about possible shifts in fishing grounds. If it is assumed that they have remained constant and considering that the franciscana is most highly vulnerable to fishing nets in the first three years of life, the higher mortality of 2–3 year old individuals observed during the first three years since the increase of fishing effort, followed in 1986 by a decline in these frequencies and an increase of older specimens, could indicate that the age structure of the local population had been affected by the fishery. Unfortunately there are at present (November 1994) no post 1986 data with which to examine this further.

Since the dolphins from southern Brazil, Uruguay and Argentina appear to be from the same geographic population and since they continue to be killed in fishing nets in these countries (with an apparently greater impact at present in southern Brazil), the species may require further protection. In Argentina and Brazil, where legal protection exists, it should be more strongly enforced and legislation may need to be enacted in Uruguay as well. Further research and management recommendations are discussed in Pinedo (1994).

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Incidental Catch of Marine Tucuxi, *Sotalia fluviatilis*, in Alagoas, Northeastern Brazil

Nélio B. Barros[1]

Division of Marine Biology and Fisheries, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149–1098, USA

and

Rogério L. Teixeira[2]

Laboratório de Ciências do Mar, Convênio Comissão Interministerial para os Recursos do Mar e Universidade Federal de Alagoas, Praça Sinimbu, 206 Maceió, Alagoas, Brazil 57025

ABSTRACT

We report the gillnetting of two marine tucuxi in northeastern Brazil. The stomachs of the dolphins contained fish that are also caught in artisanal fisheries. The entangled animals showed no external net marks. The magnitude of tucuxi mortality in nets is not known; management policies should include an assessment of fishery impact on local dolphin populations.

KEYWORDS: TUCUXI; INCIDENTAL CAPTURE; FEEDING; FISHERIES; COMPETITION; MANAGEMENT; SOUTH ATLANTIC.

INTRODUCTION

Small cetaceans are increasingly threatened worldwide by entanglement in various fishing gear (e.g. Mitchell, 1975; Northridge, 1984; Read and Gaskin, 1988; Brownell *et al.*, 1989). Only recently has gillnetting of the marine tucuxi (*Sotalia fluviatilis*) been reported at the southern portion of their range in southern Brazil (Lodi and Capistrano, 1990; Simões-Lopes and Ximenez, 1990; Barros, 1991). The magnitude of these catches has not been evaluated.



Fig. 1. Map showing place names mentioned in the text.

[1] Present address: Hubbs-Sea World Research Institute, PO Box 691602, Orlando, FL 32869–1602, USA
[2] Present address: Virginia Institute of Marine Science, PO Box 1346, Gloucester Point, VA 23062–1346, USA

Two distinct morphological forms of the tucuxi are recognized: a large, coastal (marine) form and a smaller, riverine form (Borobia and Sergeant, 1989). *Sotalia* is currently listed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora, i.e. is considered endangered and in need of protection.

We report the entanglement of two females of the marine form in Maceió, Alagoas State, northeastern Brazil (Fig. 1). Although sightings of tucuxi have been made in this region and in the adjacent States of Pernambuco and Sergipe (Borobia *et al.*, 1991), our specimens are the first collected from the waters of Alagoas.

The fisheries at Pajuçara Beach are artisanal. The distance from shore at which the nets are set is dependent on the size and type of boats used. Most fishermen in this region can only afford *jangadas* (small wooden rafts with a



Fig. 2. *Jangadas* used in the artisanal fishery at Pontal do Coruripe, Alagoas, northeastern Brazil. Photo by Wyb Hoek.

sail, Fig. 2) and thus nets must be set in waters very close to shore generally not exceeding depths of 20m and outside the breaker zones of the low-energy sandy beaches. Nets vary in length from 100–300m and are set at dawn and retrieved the following morning. According to our observations, the main target fish species are mullets (*Mugil liza*, *M. gaimardianus* and *M. curema*), with mojarras (*Diapterus olisthostomus* and *Eugerres brasilianus*), marine catfish (*Bagre bagre* and *B. marinus*) and jacks (*Caranx latus*, *C. hippos* and *Oligoplistes saliens*) caught in lesser numbers.

The fisheries in the area of Maceió are seasonal. From late spring until the end of the summer (Nov-Mar), the shrimp (mainly *Penaeus schmitti*, *P. subtilis* and *Xiphopenaeus kroyeri*) fishery is closed and most fishermen switch to gillnetting and/or fishing with hook and line. We believe that during this time the potential for incidental catches of the tucuxi increases.

RESULTS

The entangled specimens were retrieved on 23 September 1988 from the same gillnet, at Pajuçara Beach (9°41'S, 35°40'W). The net was 200m in length, 2m in height, had a mesh size of 35mm and was made of nylon approximately 0.6 mm in diameter ('nylon 30'). No external signs of entanglement, such as marks or cuts, were found on the dolphins, although the nets in which they were caught were heavily damaged.

Dolphin total lengths (measured along the curvature of the body) were 182cm (female No. 1) and 161cm (female No. 2). The skulls of both dolphins have been deposited at the zoological collection of the Federal University of Alagoas and a series of skull measurements is presented in Table 1. Examination of tooth sections revealed 14+ dentinal growth layer groups (GLGs) in female No. 1, and 2+ GLGs in female No. 2 (Borobia, pers. comm.). Whereas the former was clearly an adult animal, as indicated by the closed sutures on the skull, the latter was a young animal, with most of its skull bones unfused.

Recognized stomach contents from each specimen are listed on Table 2. Most fish in the two stomachs were only partially digested and identification could be made from external morphological characters. In female No. 1, mullets and mojarras accounted for 95% of the total wet weight of the contents. Cutlass fish (*Trichiurus lepturus*)

Table 1

Skull measurements (1-36 after Perrin (1975), 37-40 after Schnell *et al.*, (1985), and 41-42 after Borobia and Sergeant (1989)) of marine tucuxi from Pajuçara Beach, Maceió, Alagoas, northeastern Brazil.

	Female No. 1		Female No. 2	
Measurement	mm	%CBL	mm	%CBL
1. Condylobasal length (CBL)	375.0	100.0	335.0	100.0
2. Length of rostrum	220.0	58.7	174.8	52.2
3. Width of rostrum at base	82.3	22.0	-	-
4. Width of rostrum 60mm anterior to No. 3	58.1	15.5	-	-
5. Width of rostrum at midlength	47.9	12.8	-	-
6. Width of premaxillaries at midlength	26.5	7.1	-	-
7. Width of rostrum at 3/4 length	32.1	8.6	-	-
8. Tip of rostrum to external nares	267.0	71.2	-	-
9. Tip of rostrum to internal nares	274.0	73.1	-	-
10. Greatest preorbital width	140.4	37.4	-	-
11. Greatest postorbital width	152.8	40.7	-	-
12. Least supraorbital width	139.0	37.1	-	-
13. Greatest external nares width	37.0	9.9	-	-
14. Greatest zygomatic width	164.4	43.8	-	-
15. Greatest premaxillary width	60.4	16.1	-	-
16. Greatest parietal width	123.2	32.9	-	-
17. Vertical external height of braincase	123.0	32.8	-	-
18. Internal length of braincase	10.4	2.8	-	-
19. Greatest length left posttemporal fossa	85.4	22.8	-	-
20. Greatest width left posttemporal fossa	61.4	16.4	-	-
21. Major diameter left temporal fossa	42.2	11.3	-	-
22. Minor diameter left temporal fossa	31.7	8.5	-	-
23. Nasals to occipital crest	24.6	6.6	-	-
24. Length of left orbit	43.8	11.7	-	-
25. Length of left antorbital process	33.2	8.9	-	-
26. Greatest width of internal nares	42.1	11.2	-	-
27. Greatest length of left pterygoid	50.2	13.4	-	-
28. Length of upper left tooth row	188.3	50.2	-	-
29. Number of teeth (upper left)	31	-	30	-
30. Number of teeth (upper right)	31	-	28	-
31. Number of teeth (lower left)	29	-	30	-
32. Number of teeth (lower right)	29	-	28	-
33. Length of lower left tooth row	189.9	50.6	-	-
34. Greatest length of left ramus	321.0	85.6	80.0	83.6
35. Greatest height of left ramus	72.0	19.2	63.0	18.8
36. Length of left mandibular fossa	103.7	27.7	101.9	30.4
37. Maximum separation of pterygoids	9.7	2.6	-	-
38. Length of left tympanic cavity	57.5	15.3	-	-
39. Length of right tympanic cavity	60.7	16.2	-	-
40. Width of pterygobasioccipital sutures	40.9	10.9	-	-
41. Greatest height of foramen magnum	39.7	10.6	-	-
42. Greatest width of foramen magnum	36.7	9.8	-	-

were found in the stomach of both dolphins, and accounted for about 60% of the total wet weight of the contents of female No. 2.

DISCUSSION

The food habits of marine tucuxi are poorly known. In Brazil, prey species such as *T. lepturus* and *Lolliguncula brevis* have been reported in their diet (Borobia and Barros, 1989). Prior to this paper, mojarras (*D. olisthostomus*), drums (*Stellifer* sp.) and mullets (*Mugil* spp.) had not been reported as prey items. Several specimens of marine tucuxi have been observed on different occasions chasing leaping mullets in Atafona, Rio de Janeiro (Lodi, pers. comm.) whereas anchovies (Engraulidae) are thought to be the preferred prey in Florianópolis, Santa Catarina (Simões-Lopes, 1988).

Local fishermen believe that the dolphins are present throughout the year in the Maceió area, but are more numerous during the austral spring and summer, supposedly to take advantage of the seasonal abundance of mullet. The observation by fishermen of an increase in dolphin numbers during periods of mullet abundance might indicate movements of adjacent populations of marine tucuxi into the area of Maceió. A similar seasonal increase in dolphin abundance has been documented for the west coast of Florida, where bottlenose dolphins (*Tursiops truncatus*) may follow migrating mullets from offshore to coastal waters (Weigle, 1990). Mullets are an important seasonal resource in the diet of bottlenose dolphins in southern Brazil (Pinedo, 1982) and also form the basis for a cooperative fishing interaction between fishermen and dolphins in this area (Pryor *et al.*, 1990; Simões-Lopes, 1991).

Table 2

Stomach contents of two marine tucuxi entangled in gillnets at Pajuçara Beach, Maceió, Alagoas, northeastern Brazil.

Stomach contents	Total length of prey (cm)	Wet weight of prey (g)	Number of prey
Female No. 1 (182cm long)			
Trichiuridae			
Trichiurus lepturus	31.2	8.1	1
	31.5	8.4	1
Gerreidae			
Diapterus olisthostomus	16.9	56.9	1
Mugilidae			
Mugil liza	22.1	127.0	1
Mugil sp.	25.9	105.1	1
Mugil sp. remains	-	43.1	-
Total		348.6	5
Female No. 2 (161cm long)			
Trichiuridae			
Trichiurus lepturus	33.2	13.9	1
	37.5	25.8	1
	34.2	15.1	1
	36.2	13.2	1
Sciaenidae			
Stellifer sp.	16.9	9.3	1
Unidentified remains	-	41.5	-
Loliginidae			
Lolliguncula brevis	8.6[3]	5.2	1
Total		114.7	6

[3] Mantle length.

On at least four different occasions, one of us (RLT) observed groups of up to five tucuxi close to shrimp boats operating around the Maceió harbour. We do not know if the dolphins follow shrimp boats to feed on the discarded fish (or fish perturbed by the trawling) nor do we have any information on the spatial/temporal extent of the apparent association with shrimp boats. Interestingly, the cutlass fish, present in the stomach of both dolphins in this study, is among the finfish species discarded by shrimpers, particularly in the smaller size classes. Cutlass fish was the dominant species in the bycatch of trawlers off Rio Grande do Sul state (Haimovici and Perez-Habiaga, 1982). In areas where other coastal species of dolphins (e.g. bottlenose dolphins) associate with shrimp boats, their food habits can be substantially altered (see Barros and Odell, 1990).

The overlap in the species composition of fish caught in artisanal fisheries and those consumed by female No. 1 (mullets and mojarras) suggests some competition between dolphins and fisheries for common resources. Fishermen from this area believe that the dolphins actually take mullets (fish of high local commercial value) directly from the nets, causing damage to fishing gear in the process. Direct competition between other odontocetes and commercial fisheries has been reported for other areas of the world (e.g. Cato and Prochaska, 1976; Schlais, 1984; Freeman, 1986).

Lodi and Capistrano (1990) report the capture of two marine tucuxi in the same net for the coast of Rio de Janeiro and on one occasion a fisherman reportedly caught eight dolphins in a single net (Lodi, pers. comm.). Dawson (1991) reported the entanglement of two or more Hector's dolphins (*Cephalorhynchus hectori*) in waters off New Zealand to be a common occurrence, young (< 3 years of age) dolphins being particularly susceptible to entanglement. Multiple capture of marine tucuxi may be due to cooperative feeding of small groups in this species, for which there is some evidence (Simões-Lopes, 1988; Borobia, pers. comm.).

The absence of scars or marks is not a reliable indicator that dolphins have not been entangled. For instance, over 60% of all small cetaceans caught in nets set between Atafona and Macaé, Rio de Janeiro, would not have been categorised as entanglements based solely on external examination (Lodi and Capistrano, 1990). Similarly, the specimens from this study were retrieved directly from the nets but did not show any external evidence of net capture.

Our findings indicate that incidental catches of marine tucuxi are not restricted to southeastern Brazil. Artisanal fisheries are found along much of the coast of Brazil, and coastal dolphins, such as tucuxi, may be at risk throughout their entire range. The magnitude of this incidental catch is presently unknown and cannot be estimated from our data. Accurate assessments of the impact of this catch require population estimates, which are not yet available for any portion of the dolphins' marine range.

Morphological differences indicating population discreteness within the marine form have not been found, despite an indication of residency in certain areas (Borobia and Sergeant, 1989). However, if the Maceió population of tucuxi is resident, as thought by fishermen, then incidental catches by the local fisheries could be considered a serious threat. Information on fish landings and fishing effort should be collected to evaluate the extent of these fishery interactions in Maceió and surrounding waters.

Small cetaceans have only recently been protected in Brazilian waters, after regulations (Portaria No. N-011, 21 February 1986) were passed by the former Federal

Fisheries Development Agency (Superintendência do Desenvolvimento da Pesca – SUDEPE). However, this protection is not effective because of the long coastline and
limited human resources for enforcement. The mortality of marine tucuxi in such rudimentary fishery operations such as *jangadas*, shows how vulnerable these dolphins might be to larger scale commercial fisheries. We recommend that future studies determine the number of dolphins caught by this fishery and assess its impact on local populations of marine tucuxi.

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Interactions Between Marine Mammals and Fisheries in Some Coastal Fishing Areas of Argentina

Enrique Alberto Crespo

Centro Nacional Patagónico and Universidad Nacional de la Patagonia, Casilla de Correo 67, 9120 Puerto Madryn, Chubut, Argentina

Javier Francisco Corcuera

CONICET and Museo Argentino de Ciencias, Naturales Bernardino Rivadavia, Av. Angel Gallardo 470, 1405 Buenos Aires, Argentina

and Andrea López Cazorla

Universidad Nacional del Sur, Av. Alem 1256, 8000 Bahía Blanca, Argentina

ABSTRACT

Interactions between marine mammals and fisheries were monitored along the southwestern Atlantic coast of Argentina from Bahía Samborombón (Buenos Aires Province) to Tierra del Fuego Island. A variety of fisheries with several types of gear are used and in some fisheries there are incidental catches of small cetaceans. Different cetacean species are taken depending on area, gear and target fish species involved. However, throughout the region, information is scarce and good estimates of mortality and the stock identity and abundance of the affected marine mammal species are required. In Buenos Aires Province, the franciscana, *Pontoporia blainvillei*, is the species most frequently caught in shark and croaker gillnet fisheries. In some places in this province, such as Necochea (the best studied area of Argentina), gillnets also catch Burmeister's porpoises (*Phocoena spinipinnis*) and purse seines catch dusky, common, and bottlenose dolphins (*Lagenorhynchus obscurus*, *Delphinus delphis* and *Tursiops truncatus*). Passive fishing gear is not used in the area between San Matías Gulf and San Jorge Gulf, but bottom and mid-water trawls, mainly for shrimp and hake, catch dusky dolphins and to a lesser extent common dolphins, Commerson's dolphins (*Cephalorhynchus commersonii*) and spectacled porpoises (*Australophocoena dioptrica*). Although the dolphin mortality per fishing vessel and per month seem to be low, the high level of fishing effort may result in a high absolute number of dolphins killed. In southern Patagonia (Santa Cruz Province, south of Puerto Deseado) gillnets are used for *róbalos* (*Eleginops maclovinus*); Peale's dolphin (*Lagenorhynchus australis*), Commerson's dolphins and spectacled porpoise are caught incidentally. At Tierra del Fuego Island, gillnets are used for *róbalo*, hake and silverside on the northeast coast and take Pealé's and Commerson's dolphins and spectacled and Burmeister's porpoises. The use of marine mammals as bait for fishing *centollas* seems to have decreased recently in the Argentinean section of the Beagle Channel, but information on mortality rates is far from complete. In some localities the southern sea lion (*Otaria flavescens*) has been reported to damage catch and nets and is occasionally entangled. When considering management and conservation strategies, the economy and market conditions are important variables in less developed countries and should be studied along with biological parameters.

KEYWORDS: KEYWORDS: SOUTH ATLANTIC; INCIDENTAL CAPTURE; MANAGEMENT; FISHERIES; FRANCISCANA; BURMEISTER'S PORPOISE; DUSKY DOLPHIN; BOTTLENOSE DOLPHIN; COMMON DOLPHIN; COMMERSON'S DOLPHIN; SPECTACLED PORPOISE; PEALE'S DOLPHIN; PINNIPEDS

INTRODUCTION

In recent years, considerable attention has been given to the problem of incidental captures of marine mammals (and other species) in fishing gear (e.g. Brownell *et al.*, 1989). Argentina, with its long coastline (more than 3,000km) and extensive continental shelf, is home to several small-scale coastal and pelagic fisheries utilising a wide variety of vessels and types of gear.

Since 1974, the Uruguayan coast has been the most thoroughly surveyed region of the southwestern Atlantic with respect to marine mammals (Brownell and Praderi, 1974; Praderi, 1976; 1979; 1982; 1983; 1984; 1985; Kasuya and Brownell, 1979; Crespo *et al.*, 1986; Praderi *et al.*, 1989). The species most often incidentally caught by small-scale fisheries in the region was the franciscana, *Pontoporia blainvillei*. Fishery mortality involving this species was also observed along the southern coast of Brazil by Pinedo (1984; 1985; 1986) and Praderi *et al.* (1989). By comparison, Argentinian studies of marine mammals and their interactions with fisheries (e.g. Goodall and Cameron, 1980) began in the mid 1980s. Pérez Macri and Crespo (1989) carried out a preliminary survey of the coast of Argentina between 1984 and 1986, in a study of the incidental mortality of the franciscana and other cetacean species (bottlenose dolphins, *Tursiops truncatus* and dusky dolphins, *Lagenorhynchus obscurus*). They estimated an approximate annual mortality for the franciscana of at least 340–350 animals. Incidental captures of long-finned pilot whales (*Globicephala melas*) have also been reported for the region (Bastida and Bastida, 1986).

Although there remain few detailed studies, comprehensive data recording has recently been initiated in several areas of Argentina, including Necochea-Claromecó (Buenos Aires province, see Fig. 1), where surveys of interactions have been conducted since 1988 (Monzon *et al.*, 1990; Corcuera *et al.*, 1994). Biological studies of incidentally caught animals have also begun. These include studies of reproduction (Corcuera and Monzón, 1990; Monzon and Corcuera, 1990), physical maturity (Corcuera *et al.*, 1990), parasites (Raga *et al.*, 1990) and organochlorine levels (Borrel *et al.*, 1990). Studies in the north of Patagonia began in 1989. In the remaining areas, surveys have been rather sporadic.

METHODS

Fishing activities were monitored in the harbours of four areas of Argentina: Area I – the Province of Buenos Aires (including the ports of San Clemente del Tuyú, Necochea,

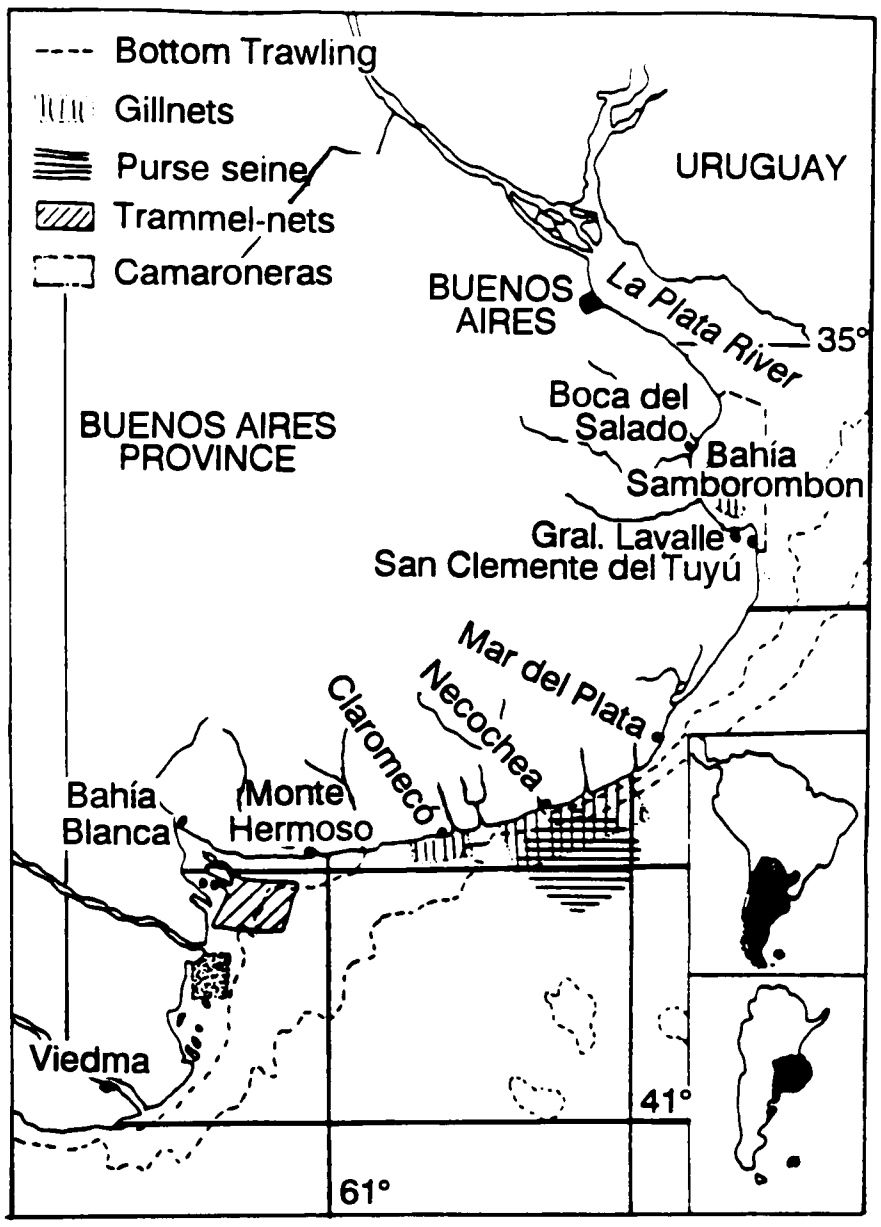

Fig. 1. Fisheries and fishing areas of Buenos Aires Province.

Claromecó and Bahía Blanca); Area II – northern and central Patagonia including the Provinces of Rio Negro (port of San Antonio Oeste) and Chubut (ports of Puerto Madryn, Rawson, Camarones, Caleta Córdova and Comodoro Rivadavia) and Puerto Deseado (Province of Santa Cruz); Area III – the Province of Santa Cruz (south of Puerto Deseado); and Area IV – Tierra del Fuego (the northeast coast of the island and the port of Ushuaia).

Three interview surveys were conducted between June and August 1990. The following harbours were visited: San Clemente del Tuyú, Bahía Blanca, Viedma, San Antonio Oeste, Rawson and Puerto Deseado. The purpose of the surveys was to obtain descriptions of fishing gear used locally and, when possible, estimate fishing effort and cetacean bycatch levels. Data collected included number of boats operating each day, type of fishing, net type, length and mesh size of nets employed, location of fishing ground, and number and species of dolphins caught.

In addition, Puerto Madryn has been monitored since September 1989, Necochea was monitored from 15 September – 17 October 1988 and 29 October – 12 January 1989 and Claromecó was monitored from 2–25 December 1989.

Information was recorded from interviews with fishermen and people associated with government fishery agencies, Coast Guard files, officers and captains of fishing vessels, investigators conducting fishery research projects and direct observation by the authors. We consider that the information obtained was reliable, especially that concerning descriptions of fishing gear and estimates of fishing effort. Contradictions among fishermen were resolved by direct observation (when possible) or by further interviews.

A number of vessels from each port co-operated with our studies and brought incidentally killed dolphins to Necochea-Claromecó and Puerto Madryn where biological samples were collected for several projects. Data are also available for Santa Cruz and Tierra del Fuego (R.N.P. Goodall and A.C.M. Schiavini, abstracts submitted to this symposium).

RESULTS

Area I. Province of Buenos Aires

Samborombón Bay (Fig. 1 and detail in Fig. 2)

The Samborombón Bay area was monitored between 1984 and 1987, and again in 1990. The area includes the ports of San Clemente del Tuyú (36°22′S, 56°43′W), General Lavalle (38°21′S, 56°55′W) and Boca del Salado (35°45′S, 57°22′W). Recent information shows that previous estimates of the number of boats were low, although fishing effort has apparently remained constant over time. Some 16 boats operate with perhaps no more than 7–8 using gillnets and the remainder operating bottom trawls.

Fishing gear used in the area include 10cm stretched mesh gillnets for silverside and mullet, 30cm stretched mesh gillnets for most croaker species and bottom trawls (worked by two boats) for another croaker species, corvina rubia (*M. furnieri*).

Although the areas fished using the different gear types overlap, the precise limits for each gear type have not been

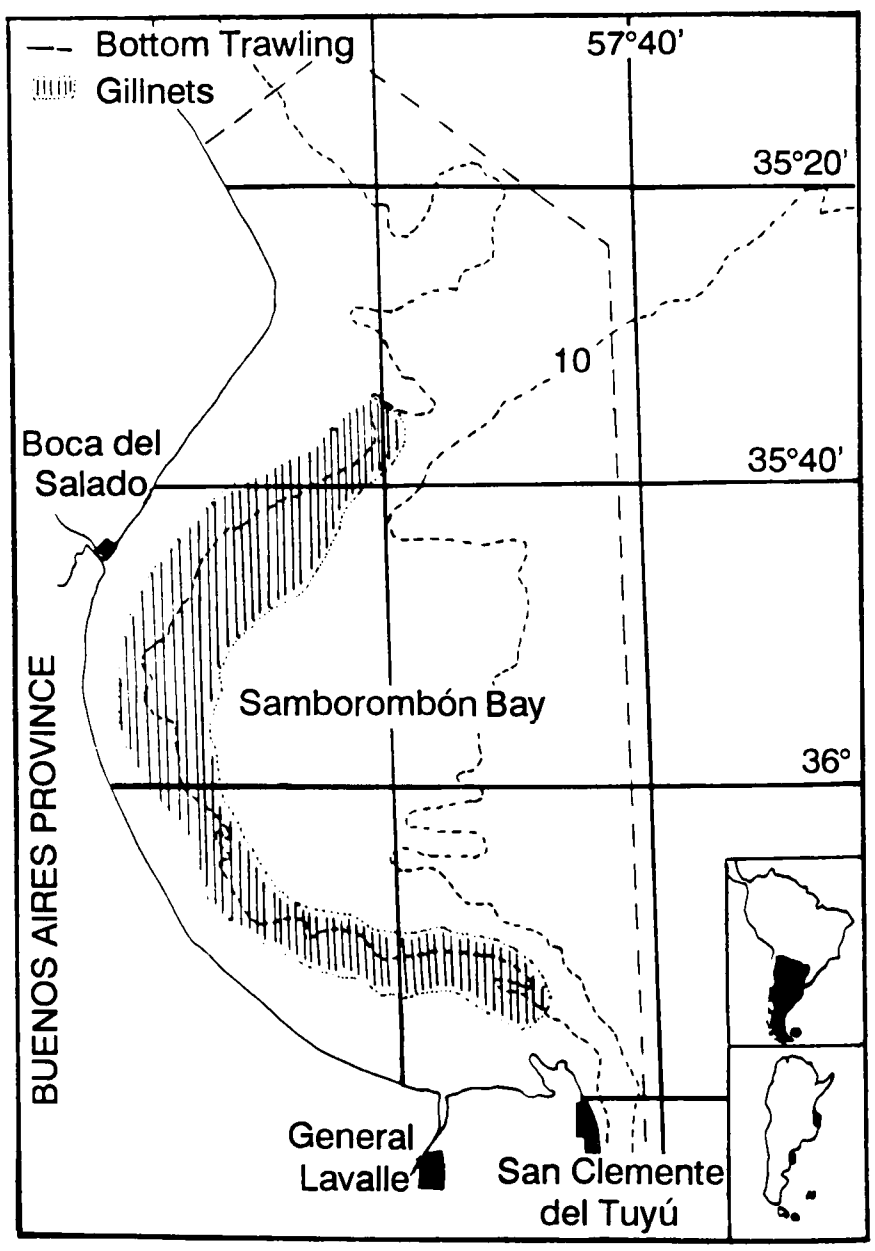

Fig. 2. Detail of the fisheries and fishing areas of Samborombón Bay, Buenos Aires Province.

determined. However, from the depth contours we estimate a fishing ground of around 1,500km^2 for croaker gillnets and about 7,500km^2 for bottom trawling operations.

Specific features of the Samborombón Bay fishery are presented below.

TARGET FISH SPECIES

The most important target species are the croakers: *Micropogonias furnieri* (local name: '*corvina rubia*'), *Pogonias cromis* ('*corvina negra*'), *Cynoscion striatus* ('*pescadilla*'), *Macrodon ancylodon* ('*pescadilla real*'), all of the Sciaenidae. Other species include mullet *Mugil brasiliensis* ('*lisa*') and silverside *Austroatherina* sp. ('*pejerrey*').

VESSELS, AREA OF OPERATION

The area of operation in Samborombón Bay is shown in Fig. 2. Sixteen boats operate in the area with 3–4 men per boat (mostly Argentinean and Italian). The wooden boats are about 8–10m in length, with 6–7 operating from San Clemente del Tuyú, 5 from General Lavalle and 4–5 from Boca del Salado. The fish is handled fresh and iced. Vessels from Uruguay also operate in the area (see below).

GEAR

Two gillnet types are used in the area: a 10cm gillnet for silverside and mullet and a 30cm gillnet for croaker. Both are made of nylon monofilament with a twine size of 2–3mm. The panels are 100m long and 2–3m deep. The boats now carry 2–3 panels of 100m each per boat, which are joined and called an *encollarada* (between 1984 and 1986 the panels were 50m and 4–6 units were carried in the boats and joined). The floats are 12cm in diameter and are spaced 1.2m apart. The gear is hauled on the side of the vessel.

OPERATIONS

Trips usually last 8–12hrs. During the fishing season, boats go to sea every day if the weather is good. The gillnets for croakers are set for at least two months (60 days on average) from October to December, 2–3 n.miles from the coast. The boats fish in water 1–15m in depth depending on the target species; 1m for mullet, 2–3m for silverside and 4–6m for croakers. The nets remain in the water for the entire season and are surveyed periodically by the fishermen.

ECONOMICS AND HISTORY

At present the markets are domestic although plans are being made to begin export of *M. furnieri*. The fish is sold both fresh and frozen and processors are located in the area and at Mar del Plata. There are no data available on the total landings of fish.

DEVELOPMENT OF THE FISHERY AND CURRENT TRENDS

The fishery for *M. furnieri* is economically more important for fishermen than that for *P. cromis* and catches of the former appear to be increasing.

The local fishermen believe that foreign and uncontrolled fishing, in this case from Uruguay and the Mar del Plata harbour fleet has led to the depletion of the croaker species. Although the Shared Fishing Area established by an international treaty between the Governments of Argentina and Uruguay does not include Bahía Samborombón, Uruguayan fishermen do, however, fish there.

EFFORT DATA

The gillnet fishery involves 7–8 boats that set 200m nets for approximately 60 days each season.

INTERACTIONS WITH CETACEANS

Franciscana are typically found dead in gillnets when fishermen retrieve their catch; in only one case was an individual found alive and released. The dolphins are thrown away or brought aboard if requested (carcasses were recovered in 1985 and 1986). In special cases when the animals are fresh they are eaten as *mushame* (see Pérez Macri and Crespo, 1989). Franciscana are caught throughout the season. No new information has been collected to allow us to modify the estimate of mortality given by Pérez Macri and Crespo (1989). Since fishing effort has remained constant, we consider their estimate of at least 50 dolphins per year to be the best for this fishery. Bottom trawling was first observed to cause deaths of franciscana in 1986. As in previous years, the 1990 survey confirmed this to be a rare event. No other significant mortality was recorded with other fishing gear in this area. Although cetaceans are protected by law (see Atkins, 1989) there is no special consideration of incidental mortality under Argentine legislation and to date there have been no efforts to reduce the bycatch. The impact on cetacean population(s) is unknown. Information on stock identity, stock size and better estimates of mortality rates are required.

DISCUSSION (SAMBOROMBÓN BAY)

The surveys carried out between 1984–86 and in 1990, reveal few changes with respect to gillnet fishing effort. Although a few individuals die in bottom trawls, the most dangerous gear for cetaceans (and then only the franciscana) seems to be the 30cm gillnet. The increasing trawl effort for *P. cromis* therefore, will not significantly increase franciscana incidental mortality. However, along with other croaker species, it has been reported as an important prey item of the franciscana (Pinedo, 1982a; b; Praderi, 1982; Pérez Macri, 1986) which may thus be affected indirectly by competition.

In view of this we recommend that a programme be established to (1) monitor operations to improve estimates of franciscana mortality; (2) develop a method to estimate its abundance in the area; and (3) examine stock identity between animals from similar areas (e.g. Bahía Blanca estuary) and open sea areas (Punta del Diablo in Uruguay and Necochea and Claromecó).

Mar del Plata harbour (Fig. 1)

A large (more than 180 vessels; both coastal and offshore) fleet operates from Mar del Plata using a wide variety of vessels and gear (e.g. gillnets, traps, lines, bottom trawls, dredge trawls, purse seine, etc.). Detailed information on the operation of the fishery, levels of fishing effort and marine mammal mortality data is scarce. One franciscana was brought back to port in mid 1990 (Bastida, pers. comm.). An unknown number of dusky dolphins are entangled during purse seining operations (Goodall and Cameron, 1980), probably in the same way as described below for the Necochea area (Corcuera *et al.*, 1994). Given

the lack of information for this fishery we recommend that a detailed study of fishing effort and associated incidental mortality is carried out.

Necochea and Claromecó Harbours (Fig. 1)

This area has been the most intensively surveyed in Argentina thanks to an on-going project on the mortality of the franciscana begun two years ago (Monzon *et al.*, 1990). Most of the information contained in this section is a summary of that presented by Corcuera *et al.* (1994).

Three major types of fishing gear are used in the Necochea area: bottom trawls, purse seines and nylon monofilament bottom set gillnets. *Nasas* (traps; fishing baskets) are sporadically used by a few boats. In Necochea, the boats use different gear according to the target species and seasons but in Claromecó only gillnets are employed. Two types of fishing result in dolphin mortality: purse seining and gillnetting.

Purse seining is carried out by two co-operating vessels, which usually set their nets between 0.5 to 30 n.miles from the coast. The main target species are anchovies (*Engraulis anchoita*) and mackerel (*Scomber japonicus*). The presence of anchovies and mackerel is seasonal (October-November). Either birds or dolphins attract the attention of the fishermen. The fish are herded by the dolphins and the boats encircle the dolphins and set their nets around them. Although the frequency of incidental catches appears to be low at present (68–102 in 1989; 5 in 1990), fishermen report that the number of dolphins (dusky and common) captured was greater in the past. The dolphins die when they become entangled, not in the bottom of the purse seine, but in the sides of the net where the mesh size varies from 30 to 60cm. Live dolphins are usually returned to the sea, but some may be killed by the fishermen if they are heavily coiled in nets (in order to quickly discard the carcass and repair the damaged gear).

Bottom set gillnets for sharks are used both in Necochea (38°37′S,58°50′W) and Claromecó (38°50′S, 60°10′W). More detailed information is given below.

TARGET FISH SPECIES

The most important target species for the gillnet fishery are shown in Table 1.

Table 1

Main target species for the Necochea and Claromecó gillnet fisheries

Zoological name[1]	English name	Local name
Order **Carchariniformes**	Ground sharks	
Family Triakidae	Houndsharks	
Galeorhinus galeus	Tope shark	Trompa de Cristal
Mustelus spp.		Gatuzo
Order **Lamniformes**	Mackerel sharks	
Family Odontospididae	Sand tiger sharks	
Eugomphodus taurus	Sandtiger shark	Bacota
Order **Squatiniformes**	Angelsharks	
Family Squatinidae		
Squatina argentina	Argentine angelshark	Pez angel, Excuadro

[1] Following Compagno (1984)

AREA OF OPERATION

As shown in Fig. 1, the fishing area extends from 0.5 n.miles to 22–25 n.miles from the coast in the case of Necochea and less for Claromecó.

VESSELS AND CREW

There are 40–44 vessels at Necochea, of which 20 operate with gillnets. All three vessels from Claromecó use gillnets. Crew size ranges from 4–9 (mainly Argentinean and Italian). Most (60%) vessels are made of steel with the remainder being wooden. Vessel length ranges from 8 to 44.9m (mean=16.01m; SD=2.73; n=20). Fish capacity ranges between 7 and 64 tonnes (mean=23.6 tonnes; SD=13.3; n=20). The fish is handled fresh and iced.

GEAR

The nets have a mesh size (stretched) of 19–21cm and are made of nylon monofilament with a twine size of 2–3mm. The panels are 55–71m long (mean=66m; SD=11.3m) and 3.8m deep; 500m of net consists of 8–9 joined panels, or one *posta*. Each boat carries seven *postas* in Necochea (range = 4–9) and only two in Claromecó (range = 1–3). A mean of 57.75 panels/vessel are used at Necochea and 16.5 panels/vessel at Claromecó. The buoys are 10 to 14cm in diameter and are spaced 1.2m apart. The gear is located visually at sea by means of flags on the ends of the net. The net is hauled from the port side of the boat.

OPERATIONS

Trips usually last from 6–12hrs and each vessel makes about 70–90 trips per year. The depths in the fishing areas are between 2–30m (Claromecó) and 10–70m (Necochea). The nets are bottom set at a mean depth of 26.4m (SD=12.5m; n=26) from 1000 to 1600hrs and are retrieved from 0700 to 1300hrs. The time taken to retrieve nets depends on the extent of the nets and the number of sharks caught; it increases when dolphins are entangled. The mean time is 20–30 minutes for each 500m of net and typical catches (per panel) are 6–15 angelsharks or 1–20 of the other species.

ECONOMICS

The fishery has both a domestic and foreign market (mainly Europe, especially Italy). The sharks for export (mainly *Galeorhinus*) are cleaned and frozen. Fins are exported independently from the rest of the carcass. Sharks carcasses that are damaged (by *Mustelus* and/or southern sea lions, *Otaria flavescens*) are cleaned, salted and dried, producing a substitute for cod meat called *bacalao* that is sold locally. The fins are processed in the same way as *bacalao*. *Mustelus* spp. are consumed fresh or frozen locally. The price per kilo to fisherman for *Galeorhinus* (10kg size) varies from US$3–4 (for export) to US$1–2.5 when sold as *bacalao* in the local market. The prices for shark fins, *Squatina*, *Mustelus* and other fish species are not available. The total annual value of the catch per vessel is uncertain. The total annual catch may be around 5,000kg of product per vessel per year, but the rate of damaged *Galeorhinus* catch has not yet been calculated. The processing factories are all located at Necochea.

HISTORY AND DEVELOPMENT OF THE FISHERY AND CURRENT TRENDS

The *Galeorhinus* fishery in Buenos Aires Province was already important in the 1950s (López, 1954). At that time exploitation must have been severe as one of the first papers on this species called for conservation measures (Ringuelet, 1958). The main objective of the fishery was shark liver oil, exported to the US and Europe. *Bacalao* meat has been used to replace imported cod for some time, perhaps since the 1940s. In those times, fishing was at lesser depths and shorter distances from the coast.

Since the late 1980s, fishermen have claimed that the shark migration routes have moved farther from the coast each year. Similar behaviour has been reported for Uruguayan sharks, but in neither case has it been confirmed. Although this will raise the operating costs of the fishery, fishing effort has not decreased as it has in Uruguay. This seems to be due to the relative stability of the shark fishery profits, in contrast to the greater financial risks in catching the other local target-species (anchovy, mackerel). Thus, bottom-trawling and gillnet fisheries appear to be less risky than purse seining, and the country's economic instability may enhance the trend of increase in their use. Some vessels that did not operate with gillnets in 1988 or 1989 planned to use them during the 1990 shark season.

TOTAL LANDINGS

There are no reliable data available, but landings may reach up to 3,000–4,000 sharks/day during the peak of the fishing season (November-December). A rough estimate of 50–70,000 sharks per season seems reasonable. Official statistics of gillnet landings do not necessarily reflect all off-loaded sharks.

EFFORT DATA

In 1989, the total length of gillnets set at Necochea was around 76,230m while at Claromecó it was around 3,270m.

INTERACTIONS WITH CETACEANS

The entanglements of cetaceans in fishing gear in this area are discussed in detail by Corcuera *et al.* (1994). Only a brief summary of their work is presented here.

The franciscana and Burmeister's porpoise (*Phocoena spinnipinnis*) comprise most of the incidental cetacean catch in gillnets (77% and 19% respectively) although dusky and common dolphins are occasionally caught. Annual total catches are estimated to be around 50–70 per year. A similar number of dolphins (bottlenose, dusky and common) are caught in purse seine operations. There is little utilisation of the bycatch although in a few cases dried and salted meat is used for human consumption.

PINNIPED BYCATCHES

Southern sea lions do not get entangled but damage the sharks caught by biting the belly, exposing the viscera and eating only the liver. During a 1989 survey fishing trip, almost 60% of the sharks recovered (a vessel catches a mean of 150 sharks/day) from one *posta* were damaged in this way by one male sea lion observed from the vessel. *Mustelus* sp. sharks also prey on shark carcasses entangled in the gillnets, biting any exposed part of the body. The rate of occurrence of both phenomena needs to be evaluated as well as the resulting economic damage.

DISCUSSION (NEOCOCHEA AND CLAROMECÓ)

Partly as a result of discussions during the 1986 Workshop on River Dolphins (Perrin and Brownell, 1989), these two harbours have been carefully monitored. The 1988 and 1989 seasons showed that the conflict between small cetaceans and fisheries is not restricted to the franciscana but also affects the Burmeister's porpoise and the dusky and common dolphin (Monzon *et al.*, 1990; Corcuera *et al.*, 1994). Although fishing effort in Claromecó was smaller and the monitoring period was shorter, the catch of dolphins per day was 2.07 times higher than at Necochea. This may be because Claromeco's gillnets are set in shallower waters closer to the coast. Burmeister's porpoises appear to be caught in deeper waters than franciscanas and further from the coast.

The projected trend for fishing in this area (a gradual increase in the use of gillnets and bottom-trawls) suggests that incidental mortality of franciscana and Burmeister's porpoise may increase in the coming years.

In addition, although fishermen have suggested that the length of the purse seine fishing season for anchovies and mackerel has decreased in recent years due to over-exploitation of the stocks, the impact of purse seining on common and dusky dolphins cannot be ignored and still needs to be evaluated and monitored.

In view of the lack of biological information available, we recommend that projects be established to (1) obtain estimates of abundance for the affected cetacean species in the area; (2) examine questions of stock identity by examining genetic variation and establishing whether there are growth and reproductive pattern differences between the Uruguayan and the Necochean franciscana (Corcuera and Monzón, 1990; Corcuera *et al.*, 1990; Monzon and Corcuera, 1990); and (3) further examine the age distribution and reproductive status of incidentally caught animals and examine any trends over time. Information such as this will enable a rational management policy to be designed.

Monte Hermoso (Fig. 1)

A small-scale fishery operates in the area of Monte Hermoso for the croaker species *M. furnieri*. On the basis of a survey in 1986, Pérez Macri and Crespo (1989) report that this fishery is similar to that at San Clemente del Tuyú. They reported no dolphin mortality at that time. The area was not surveyed during 1990. We recommend that this fishery be surveyed briefly to determine the fishing gear employed and the level of fishing effort.

Bahía Blanca (Fig. 1)

This region has one main fishing harbour, Ingeniero White, near the city of Bahía Blanca and a seasonal (October-December) fishing camp near Riacho Azul, in Bahía Unión. About 15–16 wooden fishing vessels (mean length 13–15m) operate. A maximum of 12 small motor boats (canoes) operate in Bahía Unión, apparently at 5 n.miles from the coast, and depths of 14–15m, taking two shrimp species (*Pleoticus muelleri* and *Artemesia longinaris*). The Bahía Blanca area seems to be an important breeding region for several fish species (López Cazorla, pers. comm.).

In the Bahía Blanca estuary, the fishermen employ three different kinds of passive nets: *tapadura* or *tapacanal* (Fig. 3), *camaronera* (Figs 4 and 5) and trammel nets (Figs 6 and 7). No active fishing gear is used.

The *tapacanal* is used to block the small channels which are common in the area in order to catch croakers, particularly *M. furnieri*. The net is about 150–500m long and 3.5m high and the stretched mesh is 50mm. It is irregularly shaped with the bottom placed between two arms, one about one-third of the length of the net and the other of about two-thirds (Fig. 3). The nets are set with anchors by two small boats. Fishermen splash the water to scare fish and run them into the net. The net is recovered after six hours by the small boats and a mother vessel, beginning from the long arm. Fish remain alive in the bottom of the net and are retrieved live on board.

The *camaronera* takes its name from 'little shrimp' (*camarón* in Spanish) and it is set mainly to catch them (*P. muelleri* and *A. longinaris*) and the croaker *Cynoscion*

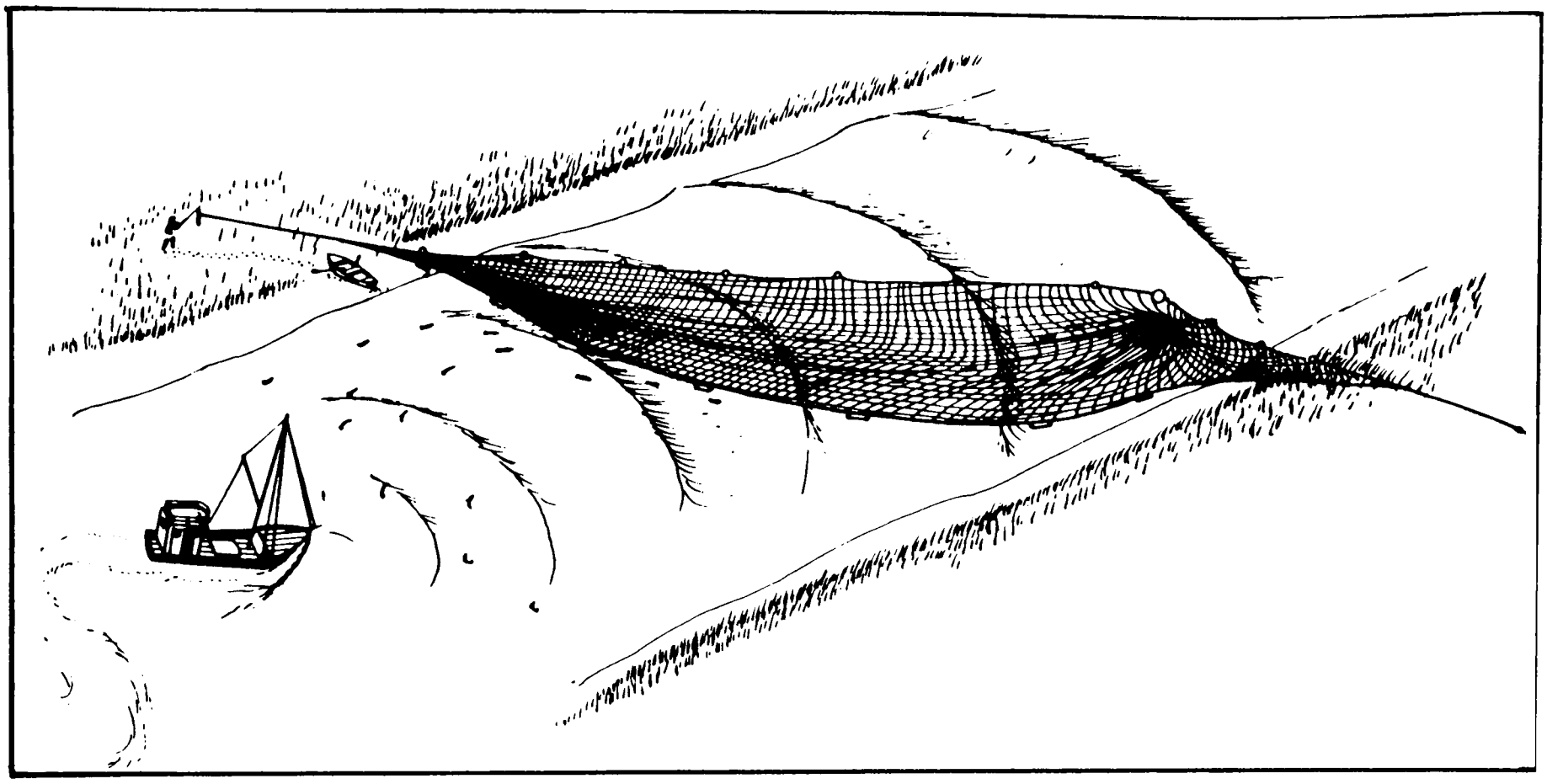

Fig. 3. *Tapadura* or *tapacanal*: net set for croakers in Bahía Blanca. During the decreasing tide water is splashed from the boat to scare the fish into the net before retrieving it.

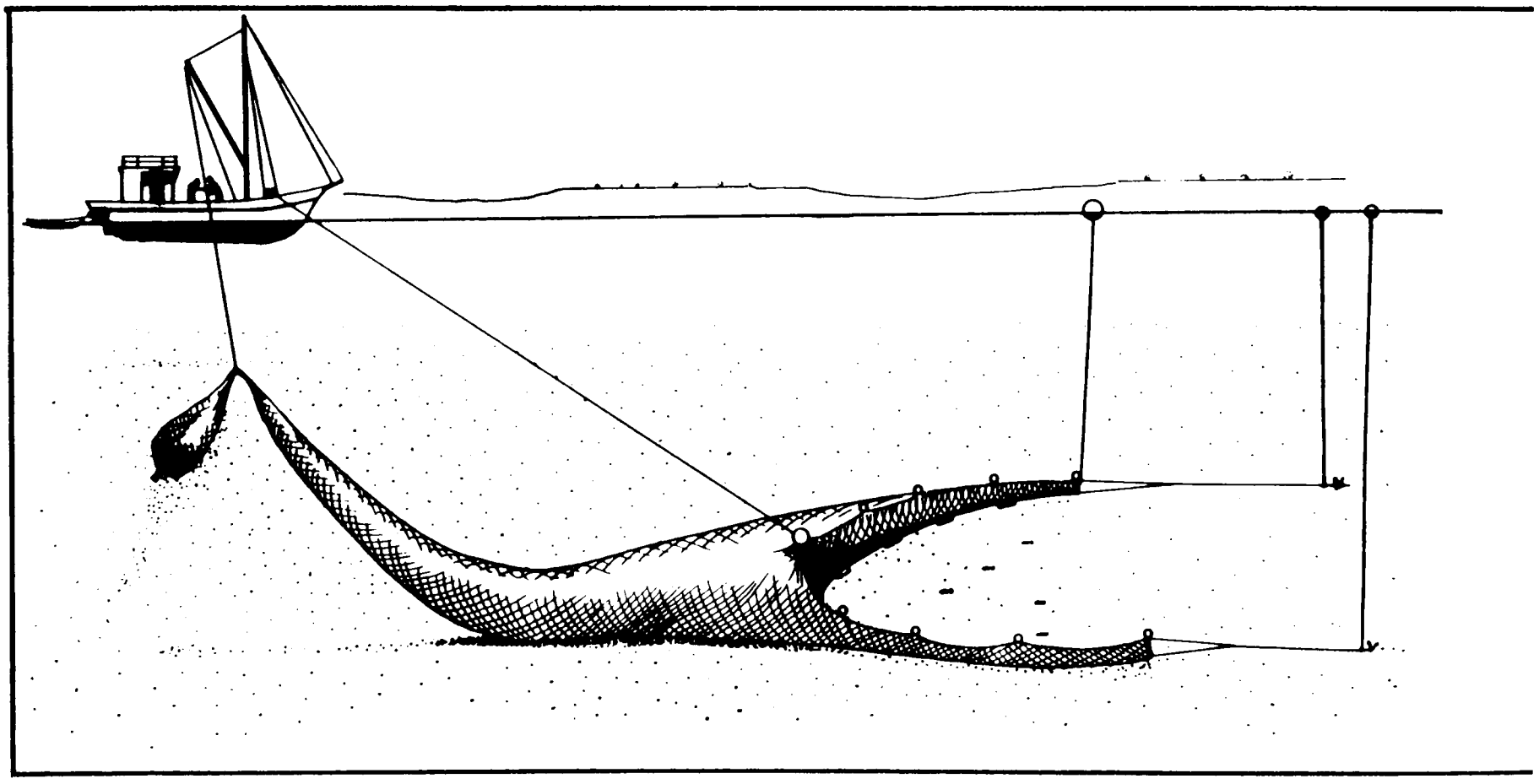

Fig. 4. *Camaronera* (shrimper): net used mainly for shrimps and small croakers. The mouth of the net is open to the water current. The catch is raised up from the bottom of the net 2–3 times during the tide.

striatus. It is funnel-shaped with walls and a pocket (Figs 4 and 5). The stretched mesh is 60mm in the walls, 40mm in the middle of the mouth and in the bottom of the pocket it is 20mm for shrimp and 60mm for the croaker. The net is set with anchors at a stationary tide and is recovered before the next stationary tide when the water current is slight. The fishermen decide to work with increasing or decreasing tides based mainly on the hours of light available.

Outside the channel areas, a few vessels use trammel nets to catch the narrownose smooth-hound shark, *Mustelus schmitti* (Fig. 6), a silverside species *Odontesthes bonaeriensis* (Fig. 7) and the parona (*Parona signata*). The stretched mesh is 10cm, and the nets are 70m long and 5m high. They are set between August and October in the middle areas of the bay at depths of 7–13m for 24hr periods.

Information on marine mammal and fishery interactions in this area is scarce, partly because the bays are large and difficult to navigate. The estuary provides large areas of shallow waters, inhabited by franciscana (Pérez Macri and Crespo, 1989). Although it seems inevitable that incidental mortality of this species occurs both in Bahía Blanca and Bahía Unión, its extent is unknown. One fisherman from Bahía Unión reported that franciscanas are incidentally

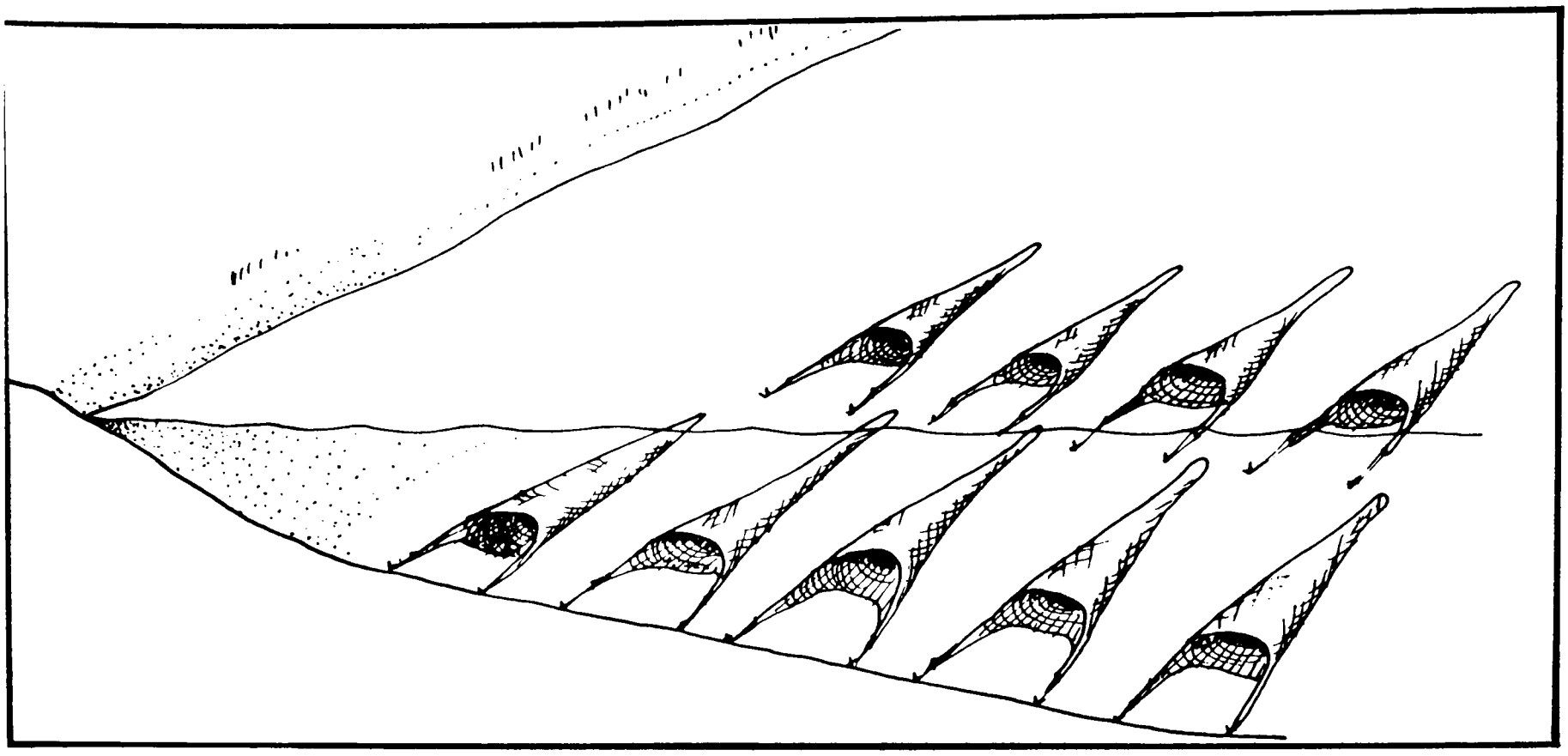

Fig. 5. Distribution of the shrimpers at sea.

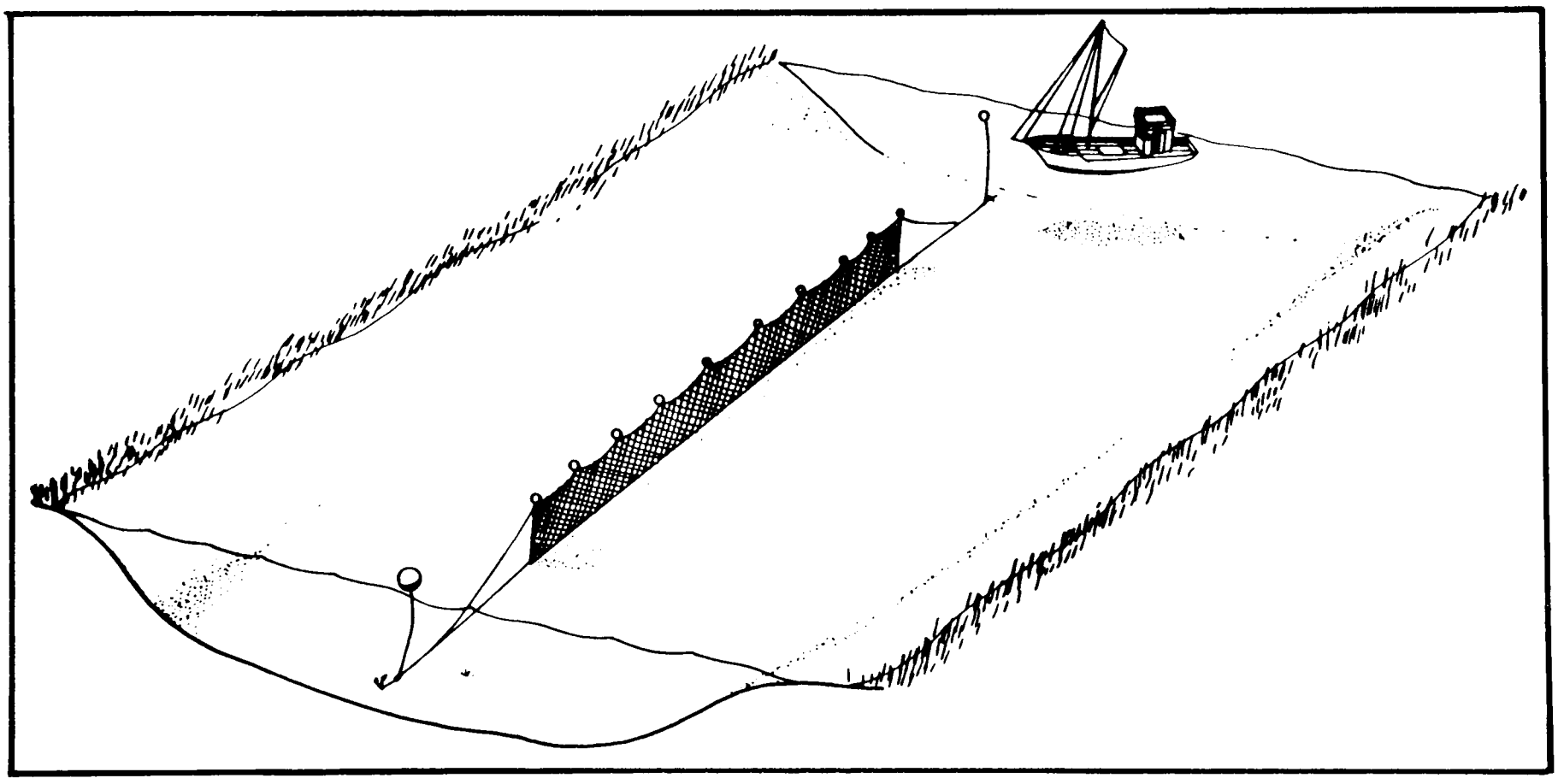

Fig. 6. Single trammel-net used for *gatuzo* (*Mustelus* sp. a requium shark species). The net is set along the channel, at 3–4m depth.

captured, but estimates of mortality cannot be made. It is also possible that dusky dolphins might sometimes be entangled. It is therefore impossible to determine which gear causes most entanglements, or where cetacean bycatches occur. Although local fishing effort might be slowly decreasing in the estuary for economic reasons, there may be an overall increase in effort due to the possible movement of vessels from neighbouring harbours into the area, due to its high productivity. A study of cetacean mortality for some of the Ingeniero White vessels has just begun, but monitoring needs to be carried out systematically for the whole area.

A further factor to take into account is that the coast surrounding Ingeniero White harbour includes one of the most important petroleum and chemical processing centres in the country. In addition, a major private development in this area is about to begin and levels of industrial waste may increase in the near future. Thus in addition to monitoring incidental capture, the monitoring of pollution levels is also necessary wherever there is a potentially high risk, for example in the Bahía Blanca estuary. Pollutants may affect the reproductive success of cetaceans including the franciscana (e.g. Addison, 1989).

Area II. North and Central Patagonia (Fig. 8)

Viedma and San Antonio Oeste

There are no fisheries near Viedma, almost at the mouth of the Río Negro. However, a small-scale fishery operates in the San Matías Gulf from San Antonio Oeste. This

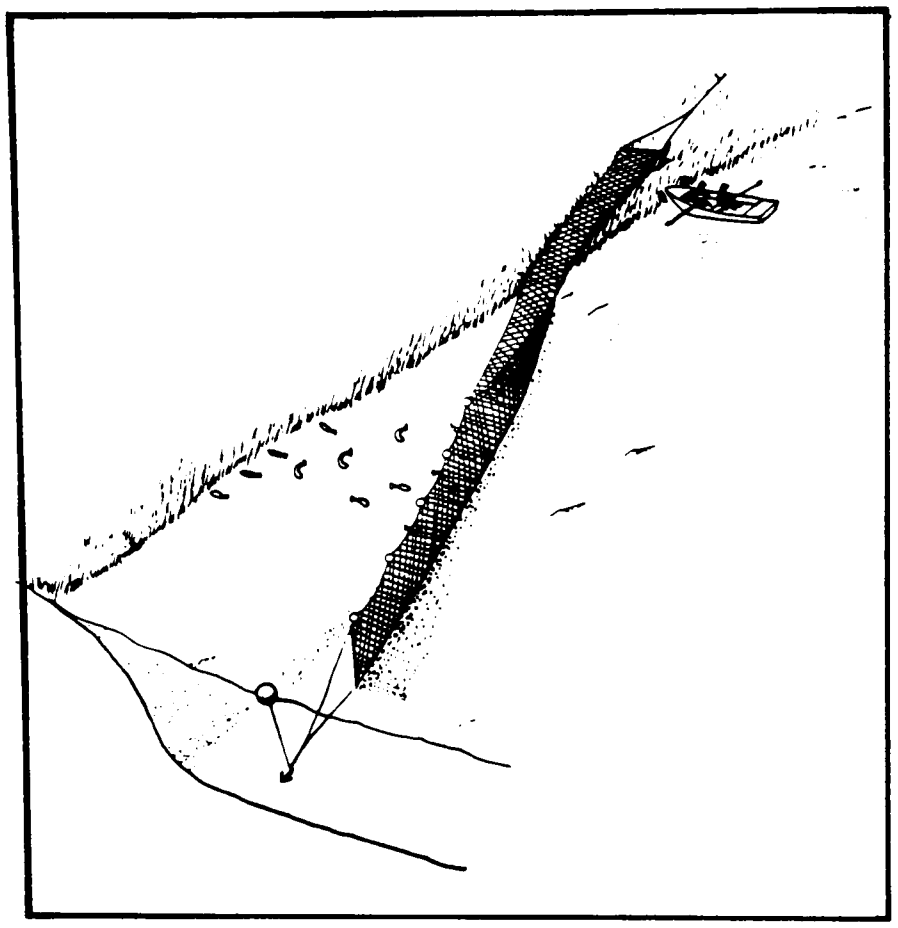

Fig. 7. Single trammel-net used for *pejerrey* (silversides). The net is set diagonally with one extreme on the beach and the other in the water.

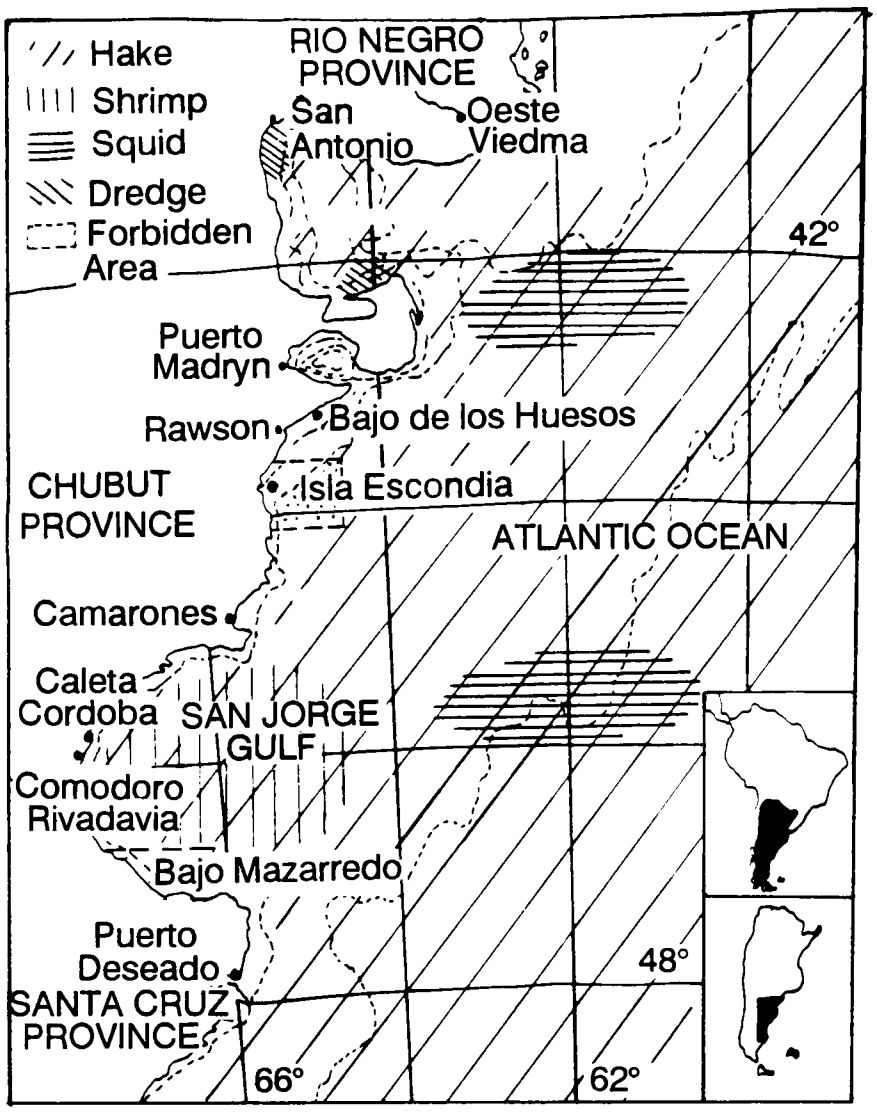

Fig. 8. Fisheries of northern and central Patagonia.

includes two vessels bottom trawling for Argentine hake (*Merluccius hubbsi*) and another three vessles dredge trawling for shellfish such as the mussel species *Mytilus platensis* and *Aulacomya ater* and the scallop *Chlamys tehuelchus*. The most abundant cetaceans in the gulf are the common and dusky dolphins. No mortality of dolphins was recorded in 1986 or 1990. However, a project for mid-water trawling for anchovies is continuing and an experiment in the gulf with this gear led to the death of one dusky dolphin in 1989 (R. González, pers. comm.).

Harbours of Chubut Province (Fig. 8)

Fisheries in the northern waters of Patagonia involve not only vessels from fishing ports from Chubut Province (Puerto Madryn, Puerto Rawson, Camarones, Caleta Córdoba and Comodoro Rivadavia) but also an unknown number of fishing vessels from northern and southern harbours (e.g. Mar del Plata in Buenos Aires Province and Puerto Deseado in Santa Cruz Province). Bottom or mid-water trawling are the most common fishing methods in the area. Gillnets or other passive gear are not used in this area.

Detailed information on the bottom and mid-water trawling fishery in Chubut is given below.

TARGET FISH SPECIES

There are several target fish species in this area (see Table 2) but by far the most important is the red shrimp (*P. muelleri*) because of its extremely high export value. This is illustrated by the fact that fishermen will throw away any other fish if a shrimp school is found. The amount of fish discarded may reach 10 tonnes per ship per day during the shrimp season. The figures are very preliminary.

AREA OF OPERATION

The most important fishing areas (Fig. 8) are near Isla Escondida and in Golfo San Jorge. The major concentration of hake is between 43° and 44°30'S in summer. Spawning (in summer) is at Isla Escondida which is a protected area. The most important areas for shrimp are Bajo de los Huesos and Bajo Mazarredo (a protected area). Areas for squid are between 42–43°S, 61–63°W and 45–46°S, 61–64°W.

Table 2

Main target species for the bottom and mid-water trawling in Chubut Province

Zoological name	English name	Local name
Merluccius hubbsi	Argentine hake	Merluza
Merluccius australis	Southern hake	Merluza
Micromesistius australis	Southern blue whiting	Polaca Argentina
Pleoticus muelleri	Red shrimp	Langostino
Illex argentinus	Argentine shortfin squid	Calamar
Loligo gahi	Patagonian squid	Calamarete
Pinguipes spp.	Southern salmon	Salmon
Genypterus blacodes	Pink cusk-eel	Abadejo
Acanthistius brasilianus	Grouper	Mero
Paralicthys sp.	Sole	Lenguado

VESSELS AND CREW

Fishing vessels range in length from 35–50m at Puerto Madryn, 18–25m at Rawson and 30–45m at Comodoro Rivadavia; the average engine power is about 1400 HP.

Only a few small vessels are made of wood, the larger ones are made of steel. Some of the smaller vessels are side-trawlers and the rest are bottom-trawlers. Detailed information is given in Tables 3 and 4.

GEAR

The mesh size of hake trawls is 6cm at the bottom and 10cm in the wings. For shrimp trawls the mesh size is 4cm at the bottom and 6cm in the wings. The nets are made of

Table 3

Fishing vessels operating out of Chubut harbours

Type of vessels	Length (m)	HP	Fish cap (kg)	Process	No. of trips	Nationality
Close coastal	16-25	up to 500	30,000	Fresh	5-8	Arg.
Distant coastal	25-32	500-800	50,000	Fresh	8-12	Arg.
Offshore ships	32-45	1,000-1,500	95,000	Fresh	10-15	Arg.
Freezing ships	40-55	1,500-2,700	180,000	Frozen	15-25	Arg., Jap.
Factory ships	80-110	3,500-4,000	900,000	Processed	50-80	Arg., Jap.

Table 4

Number of fishing vessels by port

Puerto Madryn	30-35 (distant coastal, offshore and freezer) 2 (factory)
Rawson	20 (close coastal)
Camarones	4-10 (distant coastal and offshore)
Cta. Cordova	4 (close coastal)
Cro. Rivadavia	15-20 (offshore)

multifilament. The wings are 50–60m in length and 30m in depth. Small vessels carry only one net, but vessels over 30m in length carry more. The float size is 20cm and floats are spaced 1.5m apart. The vessels carry echosounders on board and new foreign factory ships carry net echosounders in the mouth of the net.

OPERATIONS

The usual duration of trips varies with the size of the vessels and the success of the catch (nearshore coastal = 1 day; distant coastal = 4 days; offshore = 7–10 days; freezer ships = 25–40 days; factory ships = 50–70 days); the usual numbers of trips per year are 200, 50, 50, 8–10 and 6 per vessel type, respectively. From September to November at Puerto Deseado, the trips are shorter because fish are at their most abundant. The fishing depth for bottom trawling is up to 70–80m; in midwater trawling the depth is variable. The small vessels fish from early in the morning until night. The larger vessels fish continuously. It usually takes three hours to retrieve nets. The size of the catch depends on the equipment used; a full net may contain 3–4 tonnes in the small vessels and 6–7 tonnes in larger vessels.

ECONOMICS

The price per kilo to fisherman (during September 1990 in US$) is given in Table 5, for the various target species. As already noted, *P. muelleri* is the most valuable species.

In the local market the price of fish approaches the price of mutton and beef (beef is not produced in the area). This market situation, along with the problems of inflation and instability, serve to lead to the depletion of stocks of the target species.

MARKETS

The markets at Puerto Madryn and Puerto Deseado mainly deal with fish for export whereas those at Rawson, Caleta Córdova and Comodoro Rivadavia are mainly domestic. Fish is processed fresh, frozen and canned at Puerto Madryn, fresh at Rawson and fresh and frozen at Comodoro Rivadavia. Four freezing or canning processors operate at Puerto Madryn and eight more at Puerto Deseado; all use fish obtained locally. Another plant, at Caleta Córdova, uses fresh fish from Comodoro Rivadavia.

HISTORY AND DEVELOPMENT OF FISHERY AND CURRENT TRENDS

Although coastal fishing at Rawson and Caleta Córdova using small wooden vessels was recorded 80 years ago, in 1964 Patagonia was still considered to be 'unexploited' (Richardson, 1964). The shrimp fishery developed rapidly after 1980, with new and larger vessels (freezing and factory ships) appearing. This increasing trend continues. Three new, technically advanced vessels are to be added to the Puerto Madryn fleet, where only two factory ships are operating today. Most of the catch is exported to Spain, Japan and Italy (especially from Puerto Deseado) with lesser quantities going to the Netherlands, Germany, Greece, Hong Kong, South Africa, and some to the USA, Puerto Rico, Iran, Israel and Singapore. Local markets consume only a small proportion of the overall catch of all species.

EFFORT DATA

An estimated 130 vessels are licensed by the Chubut Fishery Agency. This does not include 'legal' vessels from other provinces. Additionally, probably more than 200 foreign vessels operate near the border of the EEZ. Information on duration and number of trips is given under 'OPERATIONS' above.

INTERACTIONS WITH MARINE MAMMALS

Entanglements of the following marine mammal species have been reported: dusky, Peale's (*Lagenorhynchus australis*), Commerson's and common dolphins, southern sea lions and probably also spectacled porpoises. Long-finned pilot whales, *G. melas*, are reported to be seen by the fishermen, but the species has not been reported caught. Dolphins and sea lions have been seen coming into and out of the mouth of the net catching fish. It would seem that the animals die when the net is retrieved and are thrown away or (if requested) are returned to port. A superstition exists regarding dolphin deaths and there is no apparent use of the cetacean bycatch.

Evaluation of marine mammal mortality rates is difficult. Many fishermen informed us that no dolphins are caught, although others say the opposite. There is some information from a few boats but it is not sufficient to estimate annual mortality. One fishing vessel brings one or two dolphins for biological research every trip; out of 10 dolphins recovered in less than one year, there were eight dusky dolphins, one common dolphin and one Commerson's dolphin. One ship at Puerto Deseado (belonging to a Japanese/Argentine Company) caught five dolphins (unknown species) in only one trawl. Information from another fisherman suggested an average catch of one dolphin per 45 days for his vessel.

Although the limited information suggests that catch rates per trip appear to be low, absolute numbers caught

Table 5

Type of vessels operating at Puerto Deseado

Type of vessels	Length (m)	HP	Fish cap (kg)	Process	No. of trips	No. of vessels
Distant coastal	25-32	500-800	50,000	Fresh	8-12	10
Offshore ships	32-50	1,000-1,500	95,000	Frozen	15-25	7
Freezing ships	50-70	1,500-2,700	180,000	Frozen	25-35	12
Freezing ships	70-80	1,500-2,700	180,000	Frozen	45-55	4
Factory ships	80-110	3,500-4,000	900,000	Processed	70-80	5

Table 6

Price of fish landed in port and the local market (in US dollars)

	Price to fishermen in port (kg)	Price in local market (kg)
Merluza (*Merluccius*)	0.14	2.00
Salmon (*Pinguipes*)	0.45	2.33
Mero (*Acanthistius*)	0.36	
Abadejo (*Genypterus*)	0.53	2.33
Langostino (*Pleoticus*)	1.35	8.33
Calamar (*Illex*)	0.54	2.33
Calamarete (*Loligo*)	2.17	
Lenguado (*Paralichthys*)	0.83	
Anchoita (*Engraulis*)	0.07	1.66

may be high given the level of fishing effort in the region. No effort has been made to reduce the cetacean bycatch.

Interactions with southern sea lions have been recorded but seem to be rare and mortality rates are not known.

DISCUSSION (AREA II: NORTH AND CENTRAL PATAGONIA)

The study of fishery/marine mammal interactions in this region began during 1989 and investigation of the age, reproductive status, stomach contents and parasites of incidentally caught animals (mainly dusky dolphins) is in progress. There are no gillnet fishing operations from Viedma and San Antonio Oeste in the San Matías Gulf to Puerto Deseado Harbour, south to San Jorge Gulf (Fig. 8). The fishing industry in the area uses mid-water and bottom trawls. Although, in general, trawls are not as dangerous for dolphins as gillnets, the magnitude of the effort may pose a threat to certain populations; and it appears that the fishing effort will continue to increase, even though fishermen believe the fish resources in the area are being depleted.

Studies so far have identified the species affected by the fishery. We recommend, as for other areas, that projects be initiated to obtain good estimates of dolphin mortality and the stock identity and population size of the affected species. In this regard, illegal fishing is a major uncontrolled variable. Despite the existence of protected areas there is a lack of official control of fishing: the total number of ships operating is unknown and vessels fish in forbidden areas. Companies put pressure on fishermen to catch only shrimp and to disregard protected areas or closed seasons. The Coast Guard finds it difficult to control these activities. In addition, foreign ships (from Spain, Korea, Japan and China, Taiwan, etc.) not only fish on the border of the 200 n.miles EEZ of Argentina, but also fish illegally inside it, as the profit to be made is far larger than the risk of being captured by the authorities.

Area III. South of Patagonia (Santa Cruz Province) (Fig. 9)

The Province of Santa Cruz (46°S to 52°20'S) has some 1,000km of coastline. It is sparsely populated, with few large towns. In the southern part of the province, fishing takes place sporadically during the summer months with fixed gillnets set in the tidal zone, perpendicular to shore. Coastal fishing with gillnets set from small boats is common in the northern part of the province and in rivers such as the Río Gallegos. Gillnets operate south of Puerto Deseado, mainly for *róbalo* (*Eleginops maclovinus*). The fleet operating at Puerto Deseado is similar to that for Area II (Chubut Province) in terms of gear, operation, fishing grounds and fishing vessels.

Goodall and Cameron (1980) reported some catches of Commerson's dolphins in gillnets in this region. During brief coastal surveys in 1983 and 1986, 31 Commerson's dolphins were found taken in nets at Bahía Laura, San Julián, Bahía Media Luna, Angelina and Cabo Buen Tiempo. Recovered carcases of Peale's dolphins and spectacled porpoises found during those surveys are also suspected to have come from net fisheries (Goodall *et al.*, 1990).

Small numbers of vessels operate from the ports of Santa Cruz and San Julián, working over the continental shelf with mid-water or bottom trawls, mainly for shrimp, pink cusk-eel (*abadejo*) and hake.

In some of these fisheries, especially mid-water trawling for *abadejo*, some cetaceans (Commerson's and Peale's dolphins) have been taken incidentally (Goodall *et al.*, 1990).

Monitoring for incidental catch in this province has begun only recently and data are far from complete. As yet there is no systematic study of incidental captures and almost no information on either the fisheries themselves or levels of marine mammal mortality. We recommend that a project be established to: (1) describe the gear used; (2) estimate levels of fishing effort and; (3) establish the systematic recording of incidental catches.

Area IV. Tierra del Fuego (Fig. 9)

There are three major fisheries off Tierra del Fuego (52°35'S to 55°10'S): coastal fishing with gillnets, mainly in the northern part of the island; trap fishing for king crabs *centolla* (*Lithodes antarcticus*) in the Beagle Channel; and offshore fishing with trawlers north of Tierra del Fuego (Goodall *et al.*, 1994).

Coastal fisheries use three types of nets: (a) gillnets 25–100m in length with a mesh of 10–14cm for *róbalo*, hake (*M. australis*) and trout (although fishing for trout (*Salmo salar* an introduced species for farming) with nets is illegal); (b) finer-meshed (3cm) gillnets for *pejerrey* (silversides) and small *róbalo*; and (c) three-walled trammel nets for all the above species (Goodall *et al.*, 1994).

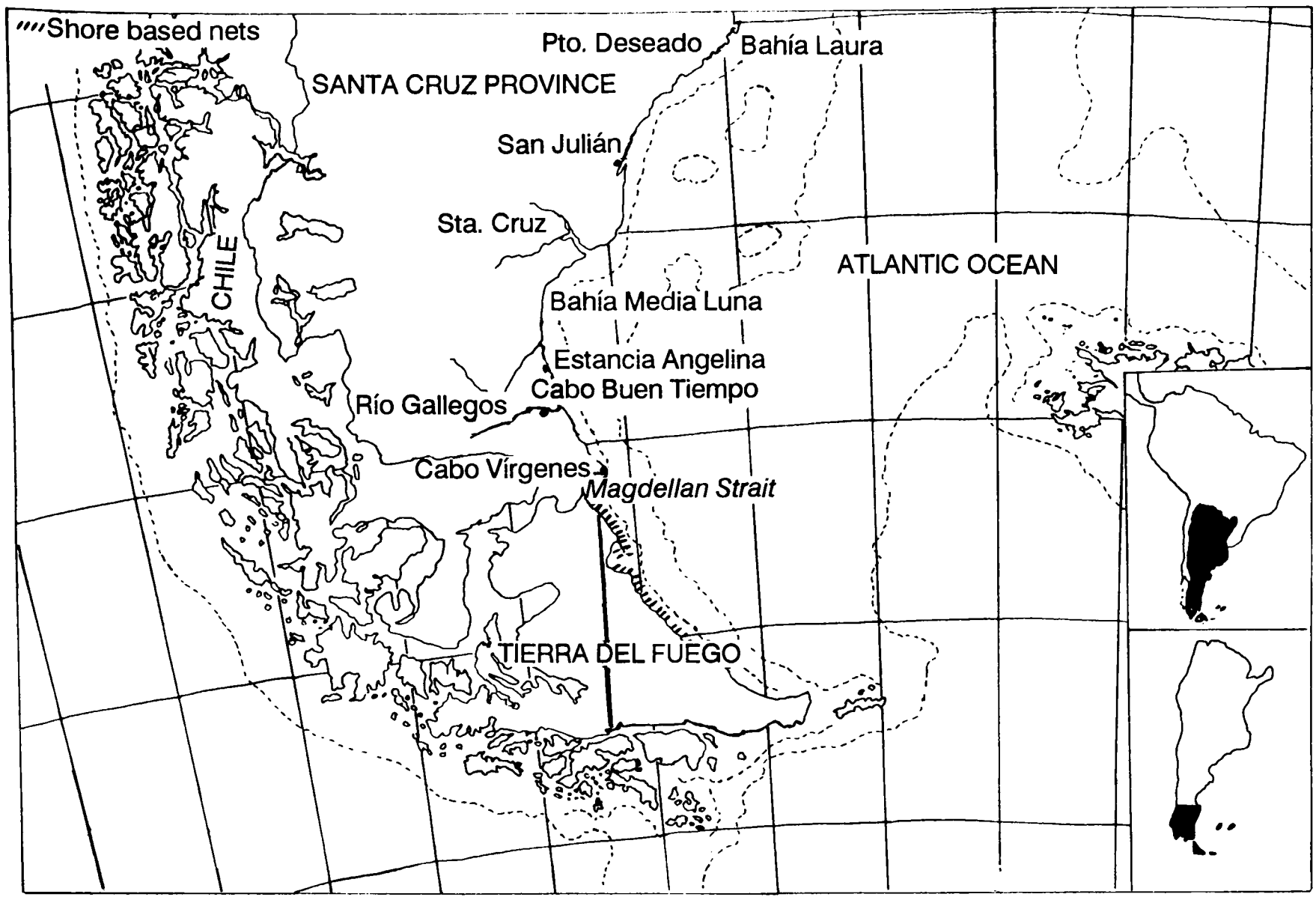

Fig. 9. Fisheries and fishing areas of southern Patagonia and Tierra del Fuego.

The nets are set perpendicular to the coast on stakes fixed in the tidal zone. They lie exposed at low tide and are lifted by the sea at high tide. Occasionally small boats are used, especially near river mouths, either with one end of the net held on shore or with two boats.

Coastal fishing takes place between October and April, with that for silverside extending into the austral winter.

The reported small cetacean species incidentally taken by this fishery during the last 15 years are, in decreasing order of importance: Commerson's dolphins, spectacled porpoise, Peale's dolphins and Burmeister's porpoise. Cetaceans are not trapped in the finer-meshed silverside nets, but they are trapped in nets for *róbalo*. Pinnipeds are taken occasionally, but usually break through the nets. Coastal fishing has recently increased due to the economic situation of the country (Goodall *et al.*, 1994).

In the past it has been reported (e.g. Goodall and Cameron, 1980) that marine mammals were caught for use as bait in the trap fishery for *centolla*, *Lithodes antarcticus* (southern king crab). This fishery has declined in recent years and now only two companies with three boats (some 1,500 traps) are working at present on the north coast of the Beagle Channel, although there is some clandestine crabbing. Cetaceans are not caught in the crab traps themselves. The use of marine mammals as bait is probably higher in the Chilean section of Tierra del Fuego, where *centolla* fishing is much more extensive.

Offshore fishing is increasing; four foreign ships operating with Argentine permission and with mixed crews are based in Ushuaia at present. These fish with trawl nets on the continental shelf off Patagonia, usually north of Tierra del Fuego, mainly for squid, octopus, hake and pink cusk-eel, southern blue whiting *Micromesistius australis*, producing tinned caviar and frozen fish. There is no recorded information on possible cetacean mortality in this fishery, but if the situation is similar to that in the north of Patagonia (Chubut Province) it is probable that a small take of dolphins exists.

DISCUSSION (TIERRA DEL FUEGO ISLAND)

The situation on the northeast coast of the island is similar to that in southern Patagonia, in part due to the use of gillnets for *róbalo*. Therefore, the same considerations should be addressed and the systematic recording of the same data recommended above for Area III is strongly recommended.

An overall review of the *centolla* fishery is required that should include the possibility of developing substitutes for the bait and obtaining information on the abundance of the affected marine mammal populations.

SUMMARY AND CONCLUSIONS

Gillnet interactions along the coast

The study of incidental mortality in gillnets started in the mid 1980s in many areas of Argentina and this work should be encouraged. Fishermen's distrust of researchers, an important factor of bias in obtaining mortality estimates, is more likely to be removed if the same researchers work at the same locality for several years. This continuity may be much more valuable than a single, expensive, short-term research effort.

Abundance estimates of affected cetacean species are essential if one is to evaluate the impact of gillnet mortality. This is true for both the franciscana and the

Burmeister's porpoise in Necochea, even if the latter appears to be less affected by gillnet mortality. The possibility that an off-shore shift of the fishing effort may change the species composition of the bycatch requires attention and the location of fishing effort should be monitored.

Studies of the bycatch similar to those being undertaken at Necochea-Claromecó should be encouraged for other areas. Stock identity is an important factor and genetic and other studies should be carried out using samples from southern Brazil, Uruguay and Samborombón Bay, Necochea and Bahía Blanca in Argentina. Pollution and parasitism studies are under way at Necochea and should be enhanced to cover the ability of franciscana and other dolphins to cope with mortality and/or potential reproductive failure. Pollutant analysis of franciscana caught in the Bahía Blanca estuary is required, given the intensive petrochemical industry in this area.

Gillnets are also used in southern Argentina, from Puerto Deseado to the northeast coast of Tierra del Fuego. The lack of information requires the establishment of a project to: (1) complete descriptions of the fisheries operations and the gear used; (2) begin systematic monitoring of mortality rates of marine mammals; and (3) estimate the abundance and stock identity of the species affected.

Purse seining, trawling and other gear

In Necochea, the area most closely examined to date, purse seining appears to affect mainly dusky dolphins. Other fisheries in the Buenos Aires Province should be examined to see if similar situations exist elsewhere. Once more the impact on populations cannot be assessed without knowledge of stock identity and good estimates of mortality and abundance.

Mid-water and bottom trawling operations do not seem to pose a threat to the small cetacean populations in Buenos Aires Province. Nevertheless, given that it is the most important gear along the coast of Patagonia (from San Antonio Oeste to Puerto Deseado) and that fishing effort is large and increasing (no less than 130 legal ships operate in a yet poorly defined fishing area), even a small number of catches per trawl may result in a large absolute number of dolphins deaths. Studies on the age, reproductive status and stomach contents of incidentally caught animals in the area are underway and should be encouraged. However, the most important needs are to obtain good estimates of mortality and abundance in conjunction with information on stock identity.

Pollution studies do not seem to be a priority for the area in the short term unless special cases are considered, such as Golfo Nuevo where industrial development is increasing. Nevertheless, oil and gas exploration and exploitation has just started along the continental platform of the country.

Marine mammals as crab bait in the Beagle Channel

Fishermen have used marine mammals as crab bait in the extreme south of the country for many years. This may have affected dolphin, fur seal and sea lion populations. Recent information suggests that these activities are decreasing at least on the Argentine side of the Channel, but catch data are lacking. In addition to the review of the crab fishery recommended above, a regional collaborative research program should be developed given the greater fishing effort in Chilean waters.

Other factors to be considered in addressing problems of incidental captures

One important obstacle to successfully addressing incidental catch problems is the lack of fisheries control by government agencies even if adequate regulations are adopted.

Inflation and economic and political instability are important variables in the use and management of resources in less developed countries. Fishermen themselves recognise that these factors lead to an undesirable depletion of fish stocks and many have declared their concern about depletion of the fish populations. An important factor here is that if the fishing companies are interested in short-term rather than long sustainable profit and thus deplete target species, how can we expect them to worry about marine mammals to whom the fishing effort is not directed? Before conserving dolphins, the fishermen must be interested in conserving the target species at sustainable levels of exploitation, in order to preserve their source of income. Only in an economically stable system will there be an acceptable basis to adjust fisheries to reduce the marine mammal catch. One aspect of this might be to achieve a more equitable ratio in the price of fish paid to fishermen and the price of fish in the market.

There are also social and cultural aspects to the problem. Many fishermen live in poor conditions, far from the large profit of large fishing companies. This kind of fisherman can be found along the coast of Uruguay and many places in Buenos Aires Province where gillnets are used. Market conditions should be studied along with the mortality of dolphin species in order to find ways to preserve the way of life of the fishermen while reducing the catch of cetaceans.

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Interactions Between Marine Mammals and the Coastal Fisheries of Necochea and Claromecó (Buenos Aires Province, Argentina)

Javier Corcuera

Museo Argentino de Ciencias Naturales 'B. Rivadavia' (MACN)-CONICET and Estación Hidrobiológica de Puerto Quequén, Av. A. Gallardo 470, 1405 Buenos Aires, Argentina

Florencia Monzon

MACN and Estación Hidrobiológica de Puerto Quequén, Buenos Aires, Argentina

Enrique A. Crespo

Centro Nacional Patagónico-CONICET, Blvd. Brown s/n, 9120 Puerto Madryn, Chubut, Argentina

Alex Aguilar

Depto. de Biología Animal (Vertebrats), Universitat de Barcelona, 08071 Barcelona, Spain

J. Antonio Raga

Depto. de Biología Animal (Zoología), Universidad de Valencia, Burjasot 46100 Valencia, Spain

ABSTRACT

Coastal and pelagic fishing activities in the area of Necochea harbour, where high mortality of franciscanas (*Pontoporia blainvillei*) in gillnets had been previously reported, and at Claromecó, a small gillnet fishing camp, were monitored in 1988–90 and 1989–90 respectively. Necochea has three main types of fishing operations: gillnetting (target species: sharks), purse-seining (target species: anchovy and mackerel) and trawling. In Claromecó, only gillnets are used. Gillnet and purse-seine operations cause dolphin mortality. Gillnet fishing effort has increased in Necochea since 1984. In Claromecó, the fishing effort also seems to be increasing. The estimated number of cetaceans killed by gillnets at both localities varied between 50.9 to 68 individuals per year (lower 95% CI 32.7-45.1; upper 95% CI 67.5–125.1). The main species affected are franciscanas (76.5%), Burmeister's porpoises, *Phocoena spinipinnis* (18.7%), dusky dolphins, *Lagenorhynchus obscurus* (2.2%) and common dolphins, *Delphinus delphis* (2.6%). Although the gillnet fishing effort in Claromecó is smaller, 75.4% of the 1989 and 94.9% of the 1990 estimated franciscana captures were in this locality. This may be because in Claromecó gillnets are set at lower depths and shorter distances from the coast, where franciscanas appear to be more common. Thus fishing from several similar small fishing camps, located all along the coast of Buenos Aires Province, might be more dangerous to the franciscana population than vessels from larger harbours. Mortality of dusky and common dolphins in the purse-seine fishery was also observed. The kill due to this fishery in the Necochea area is estimated at 68–102 individuals in 1989 and 5 in 1990.

KEYWORDS: SOUTH ATLANTIC; INCIDENTAL CAPTURE; FRANCISCANAS; BURMEISTER'S PORPOISE; DUSKY DOLPHIN; COMMON DOLPHIN

INTRODUCTION

Interactions between franciscanas (*Pontoporia blainvillei*) and gillnets set in the area of Necochea have been reported by Pérez Macri and Crespo (1989). Necochea harbour is the base for one of the largest gillnet fisheries of the western South Atlantic. From information provided by fishermen, those authors estimated that the potential annual mortality of franciscanas in the area could be around 260 individuals. Other small cetacean species known to be abundant in the region (Goodall and Cameron, 1980) may also be subject to incidental mortality.

Given the potential magnitude of the conflict in Necochea, a survey to ascertain the nature of these interactions was begun in 1988 (Monzon *et al.*, 1990). Studies on the age, reproductive status, physical maturity and nutrition of incidentally caught animals, and on other biological factors (e.g. pollutants and parasites) that might affect mortality or reproduction of cetaceans, began at the same time. This paper covers the period up to the end of 1990. Later developments are discussed in Corcuera (1994).

Purse-seine vessels also operate out of Necochea. A brief summary of the available information on interactions with marine mammals and this fishery is given in Appendix 1.

MATERIALS AND METHODS

Necochea

Fishing activities were monitored in Necochea (38°37'S, 58°50'W) during 1988 (22 September-17 October), 1989 (29 October-25 December) and 1990 (1–12 January; 14 October-25 December). Collected data included number of boats operating per day, type of fishing operation and fishing grounds (Fig. 1), type and length of nets employed, distance to the coast and number and species of dolphins caught. One of us (JC) interviewed five captains of fishing vessels in 1989 and twelve in 1990. Data on cetacean mortality, fisheries economics, fishing effort and related subjects were recorded. The same person also went out occasionally with the fishermen during fishing operations. We monitored 7 of the 17 gillnet boats in 1988 (41%), 17

out of 21 in 1989 (81%) and all 21 in 1990. For each dolphin caught, fishermen were asked to provide data on location, water depth and distance to the coast and, whenever possible, to bring the dolphins back to port. Since 29 November 1989, a small fee (US$10) was paid to cover the transportation and handling costs of each dolphin. From the obtained specimens, morphometric and life history data were collected together with samples for studies on parasites, pollutants, nutrition and feeding.

Claromecó

While working in 1989 in Necochea, we learned of incidental mortality of dolphins in Claromecó (38°52'S, 60°05'W), a small fishing camp about 140km away. Monitoring of the three to five boats that operated there was carried out from 9 December 1989 to 12 January 1990 and from 14 October to 20 December 1990. A US$15 retrieval fee was paid for each dolphin from this fishery brought to Necochea.

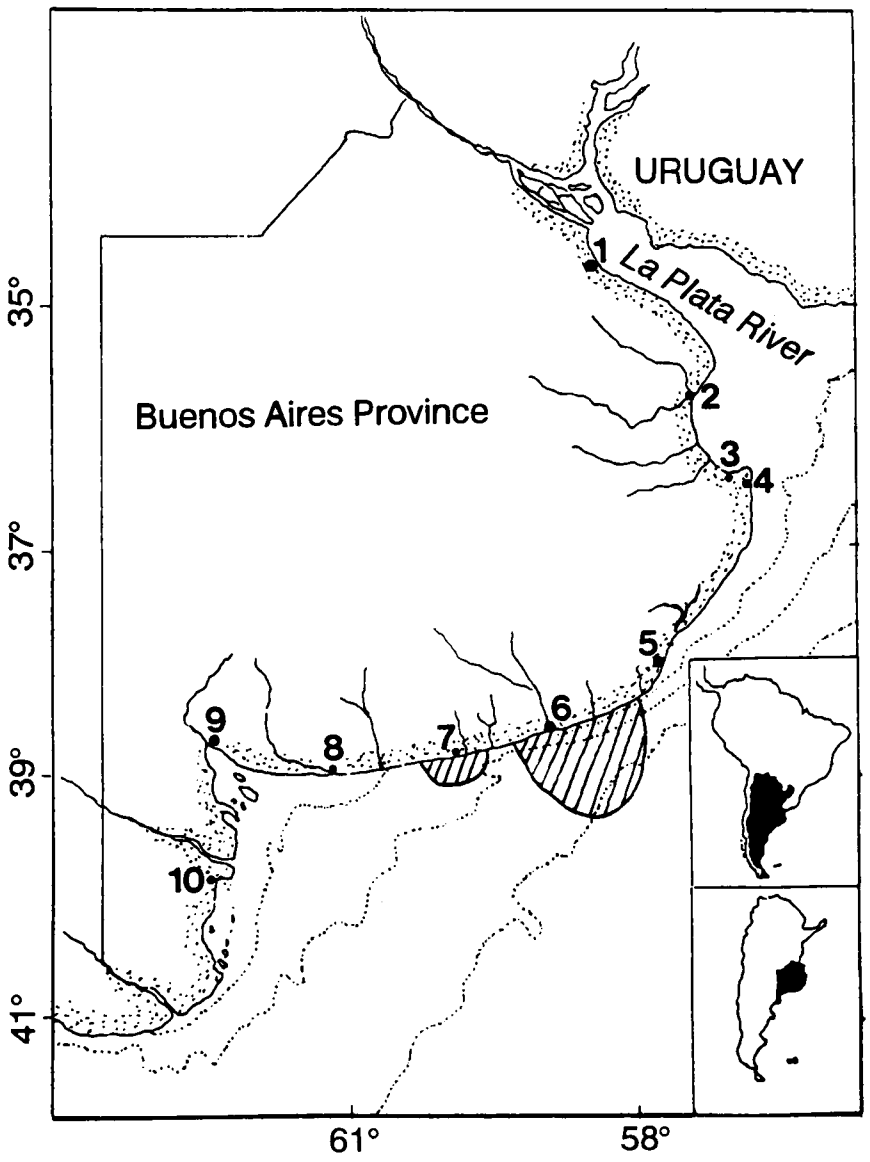

Fig. 1. Main fishing harbours of the Buenos Aires Province. All except Buenos Aires city have boats fishing with gillnets. Only Mar del Plata and Necochea have a purse-seine fleet. 1 = Buenos Aires city. 2 = Boca del Salado. 3 = General Lavalle. 4 = San Clemente del Tuyú. 5 = Mar del Plata. 6 = Necochea-Puerto Quequén. 7 = Claromecó. 8 = Monte Hermoso. 9 = Bahía Blanca (Ing. White). 10 = Riacho Azul. The 20, 35 and 60m isobaths are shown. Hatched areas indicate primary regions of shark gillnet fisheries.

Annual mortality estimation

Mean annual mortality estimates by species caught were obtained for the years 1988–1990. In order to estimate the annual catches it was assumed that mortality is constant throughout the whole fishing season and that the fishing season lasted 70 days. The previous mortality estimate of Perez Macri and Crespo (1989) for 1984 was recalculated using these assumptions. In order to compare annual mortalities we estimated 95% confidence intervals (CI) of each estimate using a Poisson model which assumes that entanglement events occur randomly in time. This model, that of Pearson and Hartley (1976) as described by Zar (1984), is consistent with the occasional observation of dolphins being caught as pairs in the same net.

$$\text{Upper CI} = \frac{\chi^2(0.025,\ 2\ (c+1))}{2}$$

$$\text{Lower CI} = \frac{\chi^2(0.975,\ 2c)}{2}$$

where c = observed captures

Because the recorded data on cetacean captures were obtained from partial surveys (a variable proportion of the operating boats were monitored during a variable proportion of the fishing season), we adjusted each mean and its CI to account for both the number of boats and fishing season days not monitored as a straight proportional correction.

Catch per unit effort (CPUE) values by year, species and locality were calculated using the estimated annual mortalities. Confidence limits for each CPUE were obtained by dividing the confidence limits of the mortality estimates by the fishing effort recorded for the respective year and locality.

Age determination of the franciscana sample

Teeth of each available specimen were cleaned and immediately preserved in a 10% buffered formalin solution. Two complete teeth from each franciscana were then decalcified with 5% formic acid for 2–12 hours. Longitudinal sections of 18–30μm thick were obtained using a freezing microtome. The sections were stained with Hematoxilin and then dehydrated and mounted. Annual growth layer groups (GLGs) as defined in IWC (1980) were counted under transmitted light with a 50cm screen microprojector (30x) and a compound microscope (120x) and analysed following Kasuya and Brownell (1979). Three investigators (JC, FM and EAC) independently counted GLGs in tooth sections from each specimen. The 'determined' age was the majority opinion of these readers. If all three disagreed, biological data of the specimen were taken into account to reach consensus on the age. As the parturition of franciscanas in the Necochea area seems to occur around mid-November to mid-December (Corcuera *et al.*, 1990), ages were estimated as fractions of years relative to these months.

RESULTS

Three major types of fishing activities are carried out in the Necochea area: bottom trawling, purse-seining and gillnetting with bottom set nylon monofilament gillnets. *Nasas* (traps, fishing baskets) are also used, but only sporadically and by few boats. In Necochea the boats use different gear according to the species harvested and the season; in Claromecó only gillnets are employed.

Two types of fishing activities produce dolphin mortality: purse-seining (target species: anchovies, *Engraulis anchoita* and mackerel, *Scomber japonicus*) and gillnets set for sharks (the houndsharks, *Galeorhinus*

galeus and *Mustelus spp.*, the sandtiger shark, *Eugomphodus taurus* and the Argentine angel shark, *Squatina argentina*).

General description of the gillnet fishery

Panels are set together in pieces called *postas*, each carrying 5–10 panels. In Necochea, a mean *posta* has 547.8m (range = 394–727m) of almost continuous (space intervals = 5–10m) gillnet with a mesh size of 18-21cm, or for the sandtiger and other large shark species, 28cm. Although the panel length and the number of panels per *posta* used in Claromecó do not differ significantly from those in Necochea, the number of *postas* set is smaller. A mean of seven *postas* (range = 4–9) are used by Necochea vessels, while a mean of two (range = 1–3) *postas* are set in Claromecó. Necochea's boats are larger and have a greater cruising radius, and usually set more nets.

Field observations indicate that up until 1989, a mean gillnet panel was 66m long, whereas one made in 1990 was 70–100m. The mean depth of gillnets has also increased with time. Gillnets made *ca* 1980–85 were, according to fishermen, 2.2m deep. In 1989 they were 3.8m deep while 1990-made gillnets had a depth of 4.6m. However, the underwater gillnet depth is less (around 40% of the dry depth), because the perpendicular coastal currents tend to deform the vertical gillnet into a semi-tubular shape.

Fishermen examine the gillnets each day or every other day, depending on the size of the last catch and weather conditions. The operation begins early in the morning, when they locate their *postas* visually. The ends of each posta are marked with canes that carry pieces of colored cloth called *banderas* (flags), kept straight by means of buoys and weights. The gillnet is then hauled on board by hand, with the help of a rotating cylinder system powered by the vessel's motor. The whole trip takes 6–12 hours. If the catches have not been satisfactory, the net location is changed.

The gillnet fishing season lasts from September to December (around Christmas) in both localities. The estimated mean length of an active gillnet fishing season is 70 days (from September to December) with a mean of 17.5 active days per month.

Gillnet fishing effort

The gillnet fishing ground around Necochea covers about 4,800km^2 (Fig. 1). Direct observations and interviews with fishermen indicate that gillnet location has changed in recent years. While most of the nets were set in shallow waters close to the coast in 1988 (approx. range = 1–10 n.miles), an offshore shift occurred in 1989, when gillnets were set at a mean distance of 7.6 n.miles (SD = 6.3, range 1–19 n.miles) from the coast at a mean depth of 38.5m (SD = 14.6, range = 18–57m). This trend continued in 1990 (approx. range = 8–25 n.miles).

In Claromecó, only three to five (usually four) boats operate. Gillnets are set 1.6 n.miles (SD = 0.4, range 0.2–2.2 n.miles) from the coast at a mean fishing depth of 21.6m (SD = 6.6, range = 4–35m). The fishing ground in Claromecó waters only covers around 200 km^2 (Fig. 1).

Gillnet fishing effort by year is shown in Table 1. The higher mean net-length per boat for Necochea is due to the fact that the boats are larger and carry more *postas*. The mean net-length per boat for both Necochea and Claromecó has not changed significantly between 1984 and 1990 but the mean obtained for 1988–89 may be an overestimate due to the extrapolation from the smaller sample size.

Cetacean mortality

Gillnet incidental mortality in the study area affects mainly the franciscana dolphin (76.5% of the estimated mortality), but the Burmeister's porpoise, *Phocoena spinipinnis*, is also involved (18.7%). Catches of common dolphins, *Delphinus delphis* (2.6%), dusky dolphins, *Lagenorhynchus obscurus* (2.2%) and other species (e.g. killer whales, *Orcinus orca*) seem to be only sporadic. According to fishermen, dolphins get entangled in any part of the net.

The total number of dolphins retrieved from gillnets and brought back to both localities was 8 in 1988, 23 in 1989 and 28 in 1990; the *minimum known catch* (number of dolphins brought back to port + verified number of dolphins thrown overboard) was 10 in 1988, 31 in 1989 and 48 in 1990. However, in 1988 and 1989 the number of monitored boats was less than the total operating with gillnets. If the minimum known catches are corrected for this, the estimated minimum catches are 24.3 for 1988 and 38.3 for 1989. The total estimated minimum is thus 110 small cetaceans for those three years of which 59 (54%) were retrieved.

Table 2 shows the mortality estimates by species and locality for 1984 and 1988–90. Pérez Macri and Crespo (1989) estimated a mortality of 260 franciscanas for 1984; our estimate of 303.3 is different only because we assume a longer fishing season (70 days instead of 60). The 1984 estimate may be upwardly biased because the only one of the five vessels recorded as actively fishing with gillnets monitored was a small boat that might have operated in a similar manner to the Claromecó boats (see below). The proportion of the small vessels that operated during 1984 is unknown. The franciscana was the only species monitored in 1984 and 1988 and so there are no mortality estimates for Burmeister's porpoise and delphinids in those years.

Table 1

Gillnet fishing effort by day and locality. Necochea's data for 1984 is obtained from Pérez Nacri and Crespo (1989). Net-meters/boat assigned to Necochea in 1988 (*) are assumed the same as 1989.

	Mean net-meters/boat		No. of boats		Total net-meters	
	Necochea	Claromecó	Necochea	Claromecó	Necochea	Claromecó
1984	3350.0	?	5	?	16750	?
1988	3811.5*	?	17	3-5	64796	?
1989	3811.5	1089.0	21	4	80042	4356
1990	3088.3	2275.0	21	4	64854	9100

* Because the data for 1988 were scarce, the mean value obtained for 1989 was used.

Table 2

Mean estimated mortality and Poisson 95% confidence limits of the small cetaceans caught by gillnets in the Necochea area (1984-1990). Data of 1984 mortality recalculated from Pérez Macri and Crespo (1989). PBLA = *P. blainvillei*, PSPI = *P. spinipinnis*, DDEL = *D. delphis* and LOBS = *L. obscurus*. ND = No data available.

Year		Necochea				Claromecó				All areas and species
		PBLA	PSPI	DDEL	LOBS	PBLA	PSPI	DDEL	LOBS	
1984	Estimated mortality	303.3	ND	ND	ND	ND	ND	ND	ND	303.3
	Upper 85% CL	444.5								444.5
	Lower 95% CL	198.1							198.1	
1988	Estimated mortality	88.0	ND	ND	ND	ND	ND	ND	ND	88.0
	Upper 95% CL	125.1								125.1
	Lower 95% CL	32.7								32.7
1989	Estimated mortality	11.9	13.4	0	1.5	36.5	0	3.0	0	66.4
	Upper 95% CL	23.5	25.5	-	8.3	63.8	-	17.0	-	94.2
	Lower 95% CL	5.1	8.1	-	0.04	18.9	-	0.08	45.1	
1990	Estimated mortality	2.1	7.4	0	1.1	39.2	1.1	0	0	50.9
	Upper 95% CL	7.7	15.3	-	5.9	54.1	5.9	-	-	67.5
	Lower 95% CL	0.3	3.0	-	0.03	27.6	0.03	-	-	37.6

Incidental catch positions

Fig. 3 shows the depths at which gillnets were set that entangled small cetaceans between 1988 and 1990. Reliable catch locations were available for 53 dolphins retrieved from fishermen. Most (47.5%) franciscanas were killed at depths between 2–10m, with an estimated 95% caught between 2–40m, suggesting that this depth interval is the preferred habitat for franciscanas (the 35m isobath is shown in Fig. 1). Burmeister's porpoises were caught at greater depths (range = 30–60m). The two dusky dolphins were caught at depths of 50–60m.

Fig. 4 shows the distance offshore that incidental captures were made. Almost all (87.8%) franciscana entanglements occurred between 0.2 and 5 n.miles of the coast. The equivalent values for Burmeister's porpoise were 0–25 n.miles. The two entanglements of dusky dolphins were between 15–20 n.miles offshore, where they appear to be frequently seen by purse-seine fishermen.

Biological data on the incidental catch

The sex and standard length of 47 individuals collected during the 1988–90 study were recorded (a female caught in 1986 is included) and the length distributions are given in Fig. 5.

Age data for 42 franciscanas (28 males and 14 females) are presented in Table 4 and Fig. 6. The maximum age recorded in our sample is 8–9 years for a 133.5cm male; the large (167cm) female caught in 1986 was not aged. The modes of the age-group frequencies are 0–2 years and 3–7 years for males and about 0–3 years and 6–7 years for females. The 0 to 1 age-group of both sexes seems to be over-represented. All the animals of this age-group were about to complete their first GLG. No newborns have been found in gillnets since the sampling started.

The sex ratio of the total sample of franciscanas caught is 1.61 males/female. The proportion of females is greater at body lengths >145cm, but males are more abundant in nearly all the smaller length groups.

DISCUSSION

Distribution of the fleet

The fishermen say the offshore movement of gillnetting operations from Necochea is because the target sharks have now moved further away from the coast. A similar

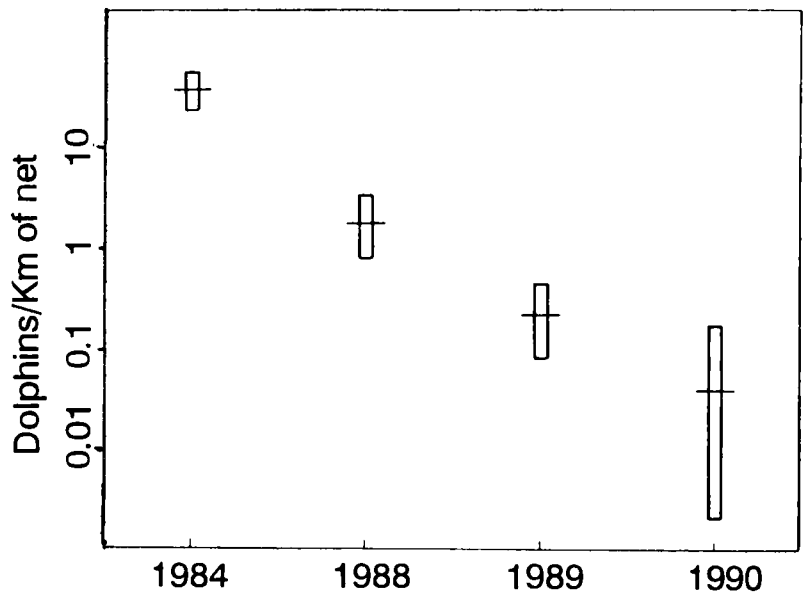

Fig. 2. Mean and 95% CI CPUE for franciscanas in Necochea gillnets (1984–1990). The estimate for 1984 is based on data in Pérez Macri and Crespo (1989). The Y axis is a logarithmic scale.

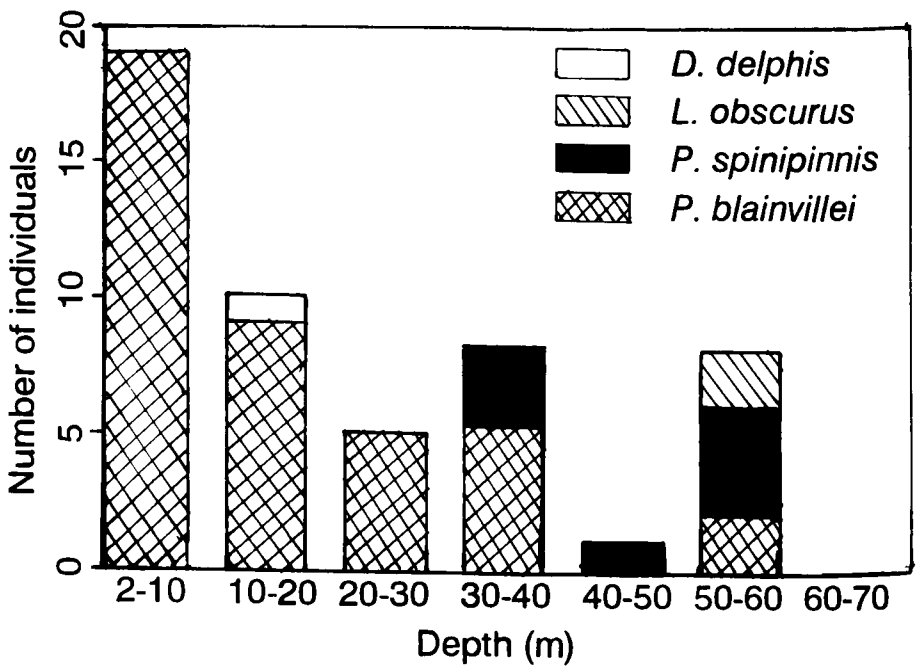

Fig. 3. Small cetacean (absolute) by-catches by depth in Necochea and Claromecó (1988–1990).

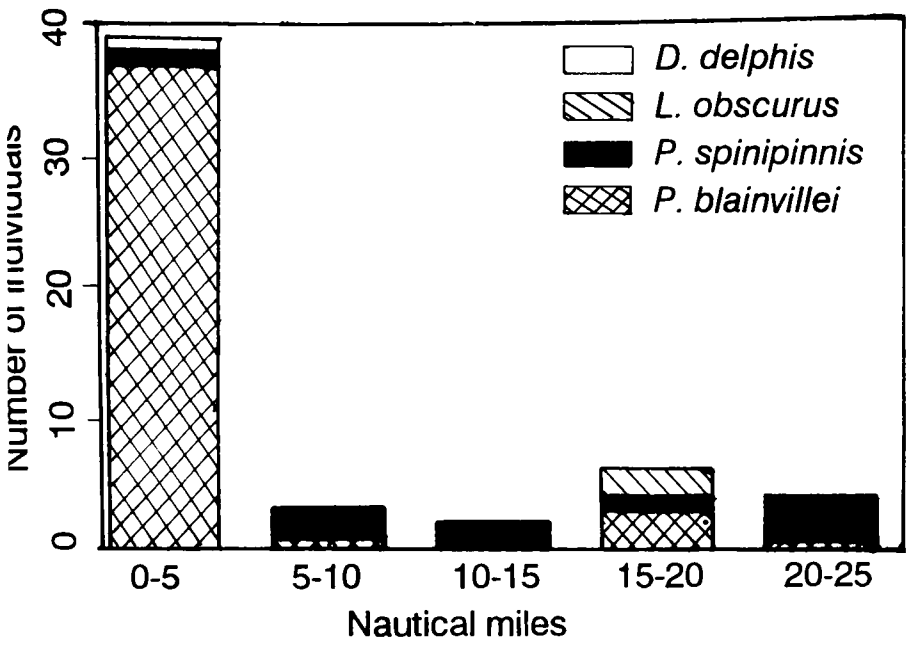

Fig. 4. Small cetacean (absolute) by-catches by distance from the coast in Necochea and Claromecó (1988–1990).

phenomenon and explanation has been described by Brownell (1981) for the Uruguayan gillnet fishery. Of course, an alternative explanation might be that inshore stocks of sharks have been overexploited but no data exist to confirm or deny this. In Necochea the high potential cruising radius of the boats suggests that fishing effort will not decrease for logistic reasons as it did in Uruguay. Fishing effort here will depend primarily on the shark market and the size of the catch.

Fishing effort

The increasing number of boats operating with gillnets in Necochea has resulted in an increase in total net-length fishing effort from around 17,000 to 65,000–80,000m used per year (Table 1). In addition, several boats are being constructed in Necochea at present. It is clear that gillnet fishing effort is growing in Necochea, whereas it has remained reasonably stable in Claramecó since the 1980s at between 5% and 14% (mean 10.8%) of that of Necochea.

Cetacean mortality

The absolute number of deaths of franciscanas for the Necochea fleet and the CPUE have decreased considerably in recent years (Table 3 and Fig. 2); this can be explained by the movement of the fleet to more off-shore grounds, away from the preferred habitat of the franciscana.

The estimated franciscana CPUE is considerably higher in Claramecó, with about 75% of the 1989 and 95% of the 1990 estimated captures in this locality. This is because the boats operating from Claromecó are smaller and have a shorter cruising radius, so they set their nets mostly within the 0–5 n.miles range, where franciscanas are more abundant (as shown by the analysis of the overall gillnet catch, Figs 3 and 4). The high CPUE value in Claromecó emphasizes the potential importance of small scale, inshore fishing along the coast of Buenos Aires province in causing franciscana mortality. The impact of other such fishing camps (some of them shown in Fig. 1) may be considerable. It should also be noted that in Claromecó, where more nets were used in 1990, the franciscana CPUE also decreased from 1989 to 1990, although the absolute number of deaths and the fishing areas remained similar.

There are a number of factors to be borne in mind when considering the available CPUE data. During 1988, only 25 of the (mean) 70 active fishing days (mid-September to mid-October) were monitored. This period, according to fishermen, usually has lower cetacean mortality than November-December. However, as our data did not allow us to confirm this pattern we assumed constant mortality throughout the season. Future studies will serve to determine the validity of this assumption, and thus our estimated CPUE series.

In addition, all our mortality (and thus CPUE) estimates were based on 'known' mortality, i.e. retrieved plus discarded dolphins. However, the number actually thrown away is probably larger than reported to us. For example, it seems that heavy, difficult-to-handle dolphins were brought back to port less frequently; obviously, fishermen preferred not to mention this selection. More directly the existence of national laws restricting cetacean catches may have led fishermen to have concealed some of the catches. The total estimated catch of small cetaceans, particularly that of larger animals (e.g. adult female franciscanas and adults of both sexes of Burmeister's porpoise) may have been underestimated. If there has been a change in under-reporting over time this will affect the validity of any conclusions from our estimated CPUE series.

It is thus not possible from the very limited CPUE data available to reach any firm conclusions. However, comparison of the two CPUE values of Claromecó with each other and with the 1984 Necochea value (when the number of boats was similar to the number operating at present from Claromecó) suggests that the CPUE (and thus abundance) of the franciscana preferred habitat might have diminished.

The mean CPUE value for Burmeister's porpoises at both locations remains low. An analysis of the catch

Table 3

Catch per unit of effort (CPUE) of franciscanas and Burmeister's porpoises in gillnets of the Necochea area, by year and locality. Catch numbers are the mortalities shown in Table 2. The effort unit is based on 1km of gillnet set for one day.

						CPUE					
	Effort (1km of net)					PBLA				PSPI	
	1984	1988	1989	1990		1984	1988	1989	1990	1989	1990
Necochea	16.8	64.8	80.0	64.9	Mean CPUE =	18.11	1.05	0.15	0.03	0.17	0.11
					Upper 95% CL =	26.54	1.93	0.29	0.12	0.32	0.24
					Lower 95% CL =	11.83	0.50	0.06	0.00	0.08	0.05
Claromecó	?	?	4.4	9.1	Mean CPUE =	?	?	8.38	4.31	?	0.12
					Upper 95% CL =			14.64	5.94		0.65
					Lower 95% CL =			4.33	3.04		0.00

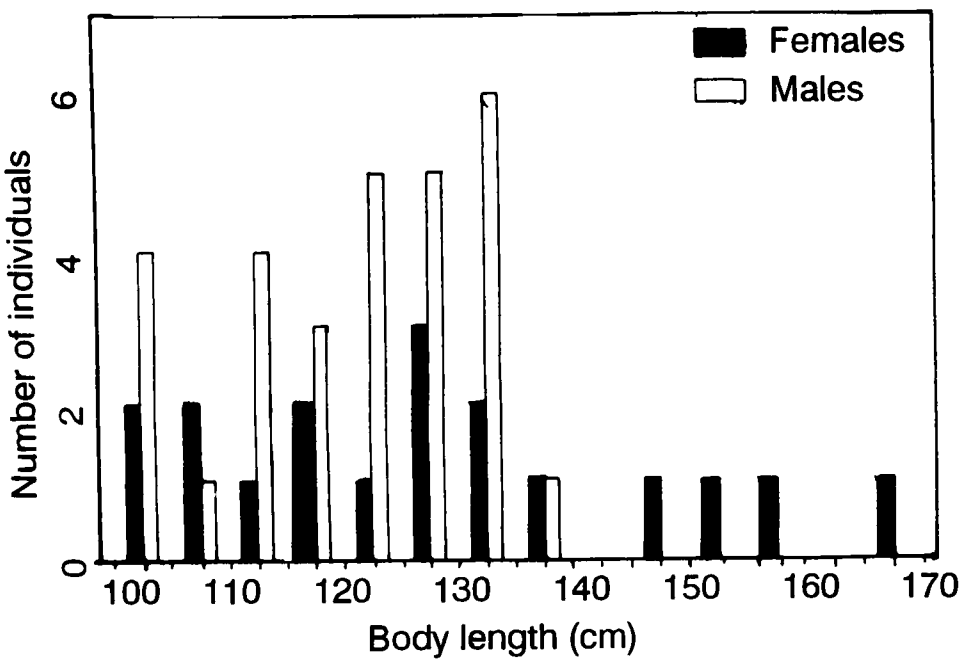

Fig. 5. Length distribution for the franciscana by-catch in the Necochea area (1988–1990). A large female (167cm) caught in 1986 is also included.

positions confirms the suggestion of Brownell and Praderi (1982) that this species is found at a wide range of water depths. It does not seem, therefore, that the species in this area is at risk at present, but the offshore movement of the fishery may change this situation in the future.

Larger cetaceans are rarely caught in gillnets in this area. On 8 October 1990, one killer whale was caught in a Necochea gillnet. It was heavily coiled and the net was lost. This is the first record of a killer whale incidentally killed by gillnets along the Argentine coast. Fishermen from Claromecó reported the entanglement of an adult sperm whale, *Physeter macrocephalus*, sometime between 1980–82. They described the animal accurately enough to differentiate it from a southern right whale; it breached with the gillnet coiled around its head and escaped with the net still entangled.

Analysis of biological data

An examination of the length and age frequency data for the franciscanas retrieved from gillnets reveals an apparent under-representation of large females. It seems likely that this may be due to the selective 'discarding' of difficult-to-handle animals discussed above. However, the lack of 3–6 year old females is difficult to explain solely in terms of the small sample size or any sampling bias.

Pérez Macri and Crespo (1989) described a lack of old, large individuals in their sample (mainly collected at San Clemente in 1984–86). One explanation is that this population structure reflects overexploitation of the stock in the Buenos Aires region. This may lead to a reduction in the reproductive capacity of females, as proposed by Read and Gaskin (1988) for the harbor porpoises in the Bay of Fundy. Further examination of the franciscana by-catch is required to test this hypothesis.

A preliminary comparison of reproductive parameters from the small Argentinian sample with those from Uruguay given by Kasuya and Brownell (1979), suggests that the male reproductive parameters are similar (Monzon and Corcuera, 1990). In contrast, the apparently high proportion of pregnant and simultaneously lactating females suggests that females in the Necochea area may not have the two-year breeding cycle (Corcuera and

Table 4

Body length, age (GLGs) and date of capture of the sample of franciscana dolphins caught in Necochea (NEC) and Claromecó (CLA) (1988-1990) by sex. A female caught in 1986 is included. NA = Teeth not available.

Females					Males				
Field no.	Body length (cm)	Age (GLG)	Date of capture	Loc.	Field no.	Body length (cm)	Age (GLG)	Date of capture	Loc.
N90-08	101.0	0.8	17/10/90	CLA	N90-07	100.2	0.8	17/10/90	CLA
N90-15	103.2	0.8	28/10/90	CLA	N88-05	101.0	0.8	01/10/88	NEC
N90-05	106.4	0.8	29/10/90	CLA	N89-18	101.0	1.2	18/12/89	CLA
N90-14	109.0	0.8	28/10/90	CLA	N88-04	102.0	0.8	30/09/88	NEC
N89-19	114.5	2.2	20/12/89	CLA	N90-25	105.0	1.8	18/10/90	CLA
N88-01	116.0	NA	18/09/88	NEC	N90-01	111.0	1.8	15/10/90	NEC
N90-04	116.3	1.8	17/10/90	CLA	N90-12	111.5	NA	17/10/90	CLA
N89-10	120.5	2.0	11/12/89	CLA	N90-19	113.4	0.8	28/10/90	CLA
N89-21	127.0	2.2	22/12/89	NEC	N90-26	113.5	0.8	22/10/90	CLA
N90-02	128.5	1.8	17/10/90	NEC	N89-15	115.0	1.0	13/12/89	CLA
N89-24	129.0	2.9	20/12/89	NEC	N89-16	115.0	2.0	13/12/89	CLA
N88-08	131.5	NA	07/10/88	NEC	N90-09	117.0	1.8	17/10/90	CLA
N88-06	132.5	NA	01/10/88	NEC	N89-22	120.0	1.0	23/12/89	NEC
N89-17	135.0	5.0	18/12/89	CLA	N90-21	122.0	1.8	17/10/90	CLA
N88-03	147.0	6.8	30/09/88	NEC	N90-16	122.7	5.0	15/11/90	CLA
N89-12	151.0	7.0	13/12/89	CLA	N90-10	123.0	4.8	17/10/90	CLA
N88-07	157.0	6.8	01/10/88	NEC	N89-23	124.0	6.0	23/12/89	NEC
N86-01	167.0	NA	22/09/86	NEC	N89-08	125.0	5.9	25/11/89	NEC
					N90-18	126.0	3.8	28/10/90	CLA
					N89-20	127.0	5.0	20/12/89	NEC
					N89-14	128.0	6.0	13/12/89	CLA
					N88-02	128.0	3.5	30/09/88	NEC
					N90-11	130.0	6.8	17/10/90	CLA
					N89-02	131.0	3.8	10/11/89	NEC
					N90-17	131.7	6.0	14/11/90	CLA
					N89-13	133.0	7.0	13/12/89	CLA
					N89-07	133.0	2.0	11/12/89	CLA
					N90-06	133.5	8.8	19/10/90	CLA
					N90-22	137.0	4.8	16/10/90	CLA

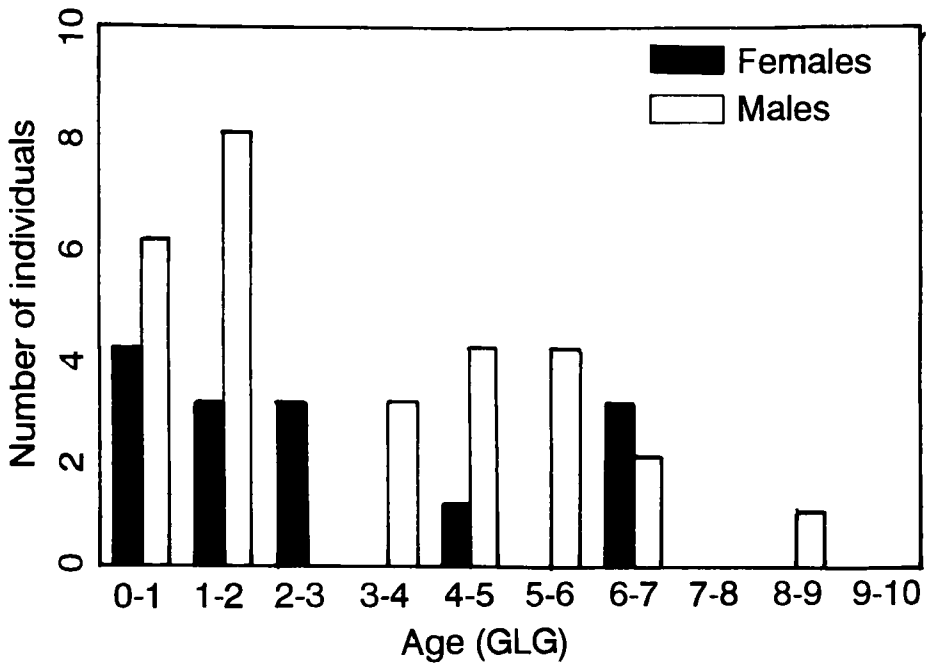

Fig. 6. Also distribution for the franciscana by-catch in the Necochea area (1988–1990).

Monzón, 1990) proposed by Kasuya and Brownell (1979) for Uruguayan animals. Corcuera *et al.* (1990) also found some apparent differences in attainment of physical maturity. In all cases, however, further data are required before firm conclusions can be reached.

Economic damage caused by marine mammals to gillnet operations

The carcass of an entangled dolphin causes damage to the nets when it is hauled up and so fishermen try to free the carcass while it is still in the water. Fishermen report that the cost of repairing nets damaged in this way or losses due to lost fishing days are less than caused by other factors producing gillnet damage (e.g. weather or shark bites).

Southern sea lions, *Otaria flavescens*, are known to prey on sharks caught in gillnets, but they do not get entangled. The sea lions always bite the sharks' belly, expose the viscera and eat only the liver. Such damaged sharks are often brought aboard in less fresh condition and then cannot be processed for export; fishermen are paid US$ 0.6–1.3/kg of shark for export but only US$ 0.2–0.8/kg for damaged sharks. During one 1989 fishing trip, around 60% of sharks recovered from one *posta* had been damaged by only one male sea lion.

However, fishermen agree that *Mustelus spp.* sharks are the main cause of damage to shark carcasses because they attack more frequently than pinnipeds and bite any part of the shark's body.

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Appendix 1

PURSE-SEINE OPERATIONS

Fishing effort

Although mortality of dusky and common dolphins in gillnets is sporadic, they are more frequently entangled during purse-seine operations. In 1989, 17 boats from Necochea operated with purse-seines but the number can vary widely depending on the demand for anchovies. The fishing season usually lasts between 2–3 weeks during the austral spring (mid-October to mid-November), although it can be much shorter (as little as 1 day) or even not occur in some years, depending on market demands.

Purse-seine nets (approx. 150m long) are operated by two co-operating vessels. The fishing distance from the coast ranges from 0.5–30 n.miles. Fishermen primarily locate anchovy schools visually or with sonar but when this is not possible they search for gulls, penguins or dolphins. Sometimes vessels will pursue dolphin schools for several hours. Fishermen report that dolphins move in tight schools distributed over a large area while searching for food. Once they find food, some individuals dive and herd the fish school to the surface by swimming around and under, in an ever-tightening formation. This behavior has been previously described by Würsig and Würsig (1980). Fishermen do not usually set the nets until dolphins drive the fish shoal to the surface.

Dolphins are usually killed when they get entangled in the sides of the net (where the mesh size varies from 30 to 60cm) while it is being retrieved.

Cetacean mortality

According to fishermen's logbooks and recollections, the percentage of trips with dolphin interactions was low (1–5%?) between 1960 and 1980, increased to approximately 5% between 1980–85 and reached 20–30% during 1988–89.

About 25–30 delphinids were caught per co-operating boat during each purse-seine trip with interactions in the 1960–70 period. This decreased to 10–15 in the next decade, except in 1972 when around 100 dolphins were caught by one vessel-pair. On one occasion in 1989, an encounter with 16 boats resulted in a by-catch of 4–8 dolphins per pair or a total kill of 32–64 dolphins. Two more encounters took place during that fishing season. In 1990, only one boat operated for a single day. At least five common dolphins were killed of which two were brought back to port.

Dolphin encounters can result in substantial economic losses to the vessels; a catch of more than 20–30 dolphins can destroy a purse-seine net. The main economic factor however, is the time wasted repairing damaged nets rather than the cost of the gear itself. In addition, bottlenose dolphins, *Tursiops truncatus*, have been reported to pierce the purse-seine nets to catch the fish contained inside, although no dolphin deaths have been recorded to date during such encounters.

It appears that overall dolphin mortality in purse-seine nets may be as high as that in gillnets. Most fishermen agree that dolphins get entangled in purse-seine nets at least once or twice per season, giving an estimated total kill of roughly 64–128 in 1989 and 4–8 in 1990. The high variability in purse-seine effort due to the fluctuating international demand for anchovy makes prediction of future fishing effort impossible.

Despite the short fishing season, small cetacean mortality in Argentine purse-seines may be large (the same fishing gear is also used in Mar del Plata harbour). The lack of information on stock identity and abundance of the affected dolphin species in these waters make it impossible to assess the impact of incidental catches at the population level.

SC/46/SM25

Incidental Mortality of Franciscanas in Argentine Waters: The Threat of Small Fishing Camps

Javier Corcuera

Museo Argentino de Ciencias Naturales 'B. Rivadavia' and Estación Hidrobiológica de Puerto Quequén-CONICET. Av. A. Gallardo 470, (1405) Buenos Aires, Argentina

ABSTRACT

Previous studies have shown that artisanal fishing camps along the Buenos Aires Province (BAP) are responsible for higher franciscana mortality than large fishing harbours. This paper presents a recent survey of the species' mortality along the southern BAP coast. The overall annual mortality estimate for this area is 230–250 individuals. Mortality and CPUE data suggest that higher mortality levels do not necessarily correspond to areas of higher dolphin densities. A five-year study of variation in mortality levels at one small fishing camp indicates that some difficult-to-control fishing variables (e.g. the preferred fishing ground of just one boat) may be the main factor in interannual mortality variation. A clarification of stock identity questions and estimates of franciscana population size are urgently required. If precautionary conservation measures are taken, they should allow for the particular situation of each fishery. A potential solution to the franciscana bycatch problem in a simple single target-species fishing camp is proposed and discussed.

KEYWORDS: SOUTH ATLANTIC; FRANCISCANAS; INCIDENTAL CAPTURE; MANAGEMENT

INTRODUCTION

The franciscana (*Pontoporia blainvillei*), an endemic small cetacean of the southwestern Atlantic coast, is the species most frequently caught by inshore gillnets along the Brazilian, Uruguayan and northern Argentine waters (Perez Macri and Crespo, 1989; Pinedo *et al.*, 1989; Praderi *et al.*, 1989; Crespo *et al.*, 1994). Previous studies have shown that in Argentina, artisanal fishing from camps situated along the Buenos Aires Province (BAP) pose more of a threat to cetaceans than operations from large fishing harbours (Corcuera *et al.*, 1994). This is primarily due to the fact that fishing is carried out in shallow waters close to the coast i.e. the preferred (inshore, 0–20m) habitat of the franciscana (Crespo *et al.*, 1994). This study presents recent data concerning franciscana mortality along the southern BAP coast.

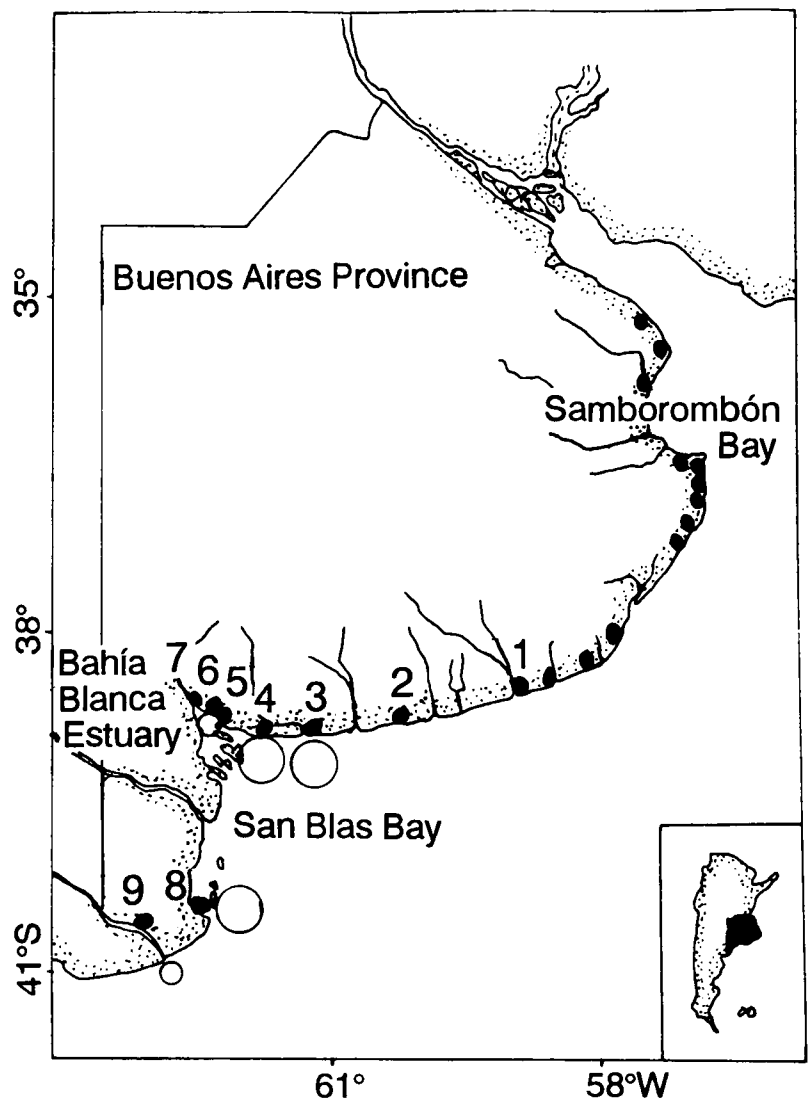

Fig. 1. Locations surveyed and CPUE relative levels (empty circles) of franciscanas caught.

MATERIALS AND METHODS

Monitoring

Between September 1988 and April 1994, a total of 299 days were spent monitoring commercial fishing harbours and fishing camps along the southern BAP coast (Fig. 1). During the 1988–92 period (Crespo *et al.*, 1994), studies concentrated on two localities: Puerto Quequén-Necochea (fishing location no.1) and Claromecó (no.2). In April 1994 we began a project to cover the whole BAP coast, starting with the southeastern area. Locations monitored were nos 1, 2, 3 (Monte Hermoso), 4 (Pehuencó), 5 (Puerto Rosales), 6 (Villa del Mar), 7 (Ingeniero White), 8 (San Blas) and 9 (Carmen de Patagones-Viedma). Locations 1 and 7 are considered fishing harbours, i.e. a dock is available to accomodate (usually) large vessels (>8m), the target species may be sold in regional, national and/or international markets and operations usually occur within 30 n.miles of the coast. Locations 2–6 and 8–9 are small fishing camps, with no dock, small (<8m) boats, a local market only for their target species and an operational area usually less than 10 n.miles from the coast.

Surveys performed until 1992 were based on interviews with fishermen and confirmed or corrected using the number of dolphin carcasses retrieved (Crespo *et al.*, 1994). The 1993 data were obtained from 24 selected fishermen found in the nine surveyed locations. They were interviewed (two to five hours for each interview) and asked to describe their fishing operations in terms of target species and their correspondent economical benefits, costs of fishing, types of gear, mean length of fishing season, effective fishing days during 1993, mesh size, metres of net

Table 1

Mortality and CPUE (x1000) of franciscanas in the southern Buenos Aires Province (1993).

Loc. #	Mortality			No. of boats (*N*)	Effort (*NxDxK*)	CPUE		
	Mean	95% Max.	95% Min.			Mean	95% Max.	95% Min.
1	4.7	11.0	1.4	18	1215.0	3.9	9.0	1.1
2	34.0	47.5	23.5	11	724.5	46.9	65.6	32.5
3	91.5	112.3	73.7	26	178.4	512.9	629.4	413.2
4	6.0	13.1	2.2	2	12.8	468.8	1020.3	171.9
5	9.0	17.1	4.1	3	52.5	171.4	325.5	78.5
6	14.0	23.5	7.7	6	187.5	74.7	125.3	40.8
7	76.5	95.7	60.3	23	1986.0	38.5	48.2	30.4
8	0 (14.9)	(24.7)	(6.4)	2	0(34.1)	0(437.0)	(724.3)	(246.3)
9	1.0	5.6	0.0	1	4.2	238.1	1326.2	7.1
All	236.7 (251.6)	268.9	207.5	80	4360.9	54.3	61.7	47.6

( ) = Data from 1991 included.

used, preferred fishing depths and distance from the coast of the operations. They were then asked to describe dolphin sightings within their fishing area. At this phase of the interview they frequently informed us of any dolphin bycatch and the frequency of the entanglements. A total of 80 of 111 considered vessels were using gillnets of mesh sizes (range 7–36cm) associated with franciscana entanglements.

Annual mortality estimation by year and location

Annual mortality estimates of franciscanas were obtained for 1993 for the 9 locations. These estimates were compared with 1988–92 data gathered in locations 1 and 2 (Corcuera and Monzón, 1993). The estimation procedure assumed that mortality was constant throughout the fishing season. Initially I compared annual mortalities by estimating 95% confidence intervals (CI) of each estimate using the Poisson model which can be used to describe relatively rare events (Zar, 1984). However, as this model assumes that each entanglement is independent, some bias may arise out of the fact that pairs are occasionally caught in the same net (Crespo *et al.*, 1994). I thus used a chi-square test of goodness of fit for the 1988–92 data for the number of dolphins caught per day (n=115, 71 dolphins with date of capture and 44 days with no dolphins caught) using both Poisson's expected values and with a negative binomial distribution of expected values, using Green's index test (Ludwig and Reynolds, 1988). The index of dispersion (variance/mean ratio) of the data was 1.49 (the Poisson model assumes an index of dispersion = 1). The correspondent chi-square statistic showed that there was no significant difference if a Poisson series was used (total chi-square = 2.42, d.f. = 2) whilst the Green's index (0.0071) was not significantly different from zero, confirming that the franciscana bycatch does not follow a binomial model. It is thus appropriate to estimate the 95% CI following the formulae given by Corcuera *et al.* (1994) according to Pearson and Hartley (1976), as described by Zar (1984). As the data were in some cases obtained from partial surveys (a variable proportion of the operating boats were monitored during a variable proportion of the fishing season), each mean and CI was adjusted to account for both the number of boats and fishing season days not monitored. In order to account for the boats not surveyed and the active fishing days not monitored, I scaled up those figures under the assumption that the catch rate of the missing vessels and the missing fishing days was the same as those that were surveyed.

Effort units and CPUE

Catch per unit effort (CPUE) data by year and locality were calculated using the estimated annual mortalities. The fishing effort unit used was = No. of boats (N) per day of active fishing operations (D) per gillnet km (K). Confidence limits for each CPUE were obtained dividing the 95% CI of the mortality estimates by the fishing effort recorded for the respective year and locality.

RESULTS AND DISCUSSION

Mortality of franciscana dolphins

Table 1 presents the estimated franciscana mortalities, the number of boats, the effort and the CPUE along the southern BAP coast (locations 1–9 in Fig. 1) for 1993. The highest estimated mortalities were found in locations 3 and 7, followed by location 2.

Location 3 is Monte Hermoso, a small fishing camp where 3 of the 28 boats catch most of the dolphins (74%). These boats are approximately 7m long and set 0.8–1.4km of 21cm mesh size gillnets for soupfin sharks (*Galeorhinus galeus*) and related species. Due to the prevailing strong winds in this area, the boats operate close (<5 n.miles) to shore. The fishing ground extends up to the Bahía Blanca estuary and generally follows the 10m depth line. Fishermen state that franciscanas are more frequent within this depth. The shark fishing season is short (September to October). The other 25 boats are smaller and although they operate at the same depth, carry fewer gillnets and operate only occasionally under light wind conditions.

Location 7 is Ingeniero White, a fishing harbour deep inside the Bahía Blanca estuary. The water circulation of this large estuary is regulated by a complex of tidal flats; its mean depth is 10m (Piccolo and Perillo, 1990). The 23 vessels operating there use 10.5cm mesh size gillnets for small sharks and 7cm gillnet for sciaenids. Little information on incidental captures was available before this survey for this important fishing area (Perez Macri and Crespo, 1989; Crespo *et al.*, 1994; López Cazorla, unpublished). The 10.5cm mesh gillnets are responsible for about 70% of the franciscana bycatch and are usually set in deeper areas such as main channels and the outer estuary. The 7cm mesh gillnets are set to block the mouths of up to 200m wide tide channels and are called *tapaduras* or *tapacanals*. Each boat carries up to ten of these nets. Fishermen say that franciscanas are sometimes blocked in 1m depth waters with this gear but they are not usually entangled. The fishing ground covers almost the entire

estuary. Two small fishing camps (nos 5 and 8) are also within the Bahía Blanca estuary, but they seem to have a low impact on franciscana dolphins.

Location 2 is Claromecó, the small fishing harbour previously studied by us (Corcuera *et al.*, 1994). Three to five relatively large boats (7–12m long) fish there with a high gillnet effort (mesh-size of 18–36cm) and a long fishing season (June to December). The fishing ground is typically around 6 n.miles from the coast in waters 12m deep.

Of approximately 237–252 franciscanas caught along the southern Buenos Aires coast, some 85% of the catches are due to these three fisheries.

There are some ten small-scale fishing locations from Puerto Quequén northwards to the La Plata estuary in Buenos Aires Province (black dots without numbers in Fig. 1) where mortality is known to occur but to an unknown extent. Some are located near or within the La Plata outer estuary in Samborombón Bay (a high density area of franciscanas) and we suspect their fishing operations may result in similar mortality levels to those in the Bahía Blanca estuary and its surroundings.

CPUE

In order to investigate whether locations 2, 3 and 7 simply coincide with higher densities of franciscanas, the CPUE at each location (Table 1) is presented as proportional circles in Fig. 1, on the assumption that CPUE is roughly proportional to density. The mean CPUE values are not consistent with the mortality levels previously discussed, apart from in location 3. Although there are several factors that may bias our 1993 CPUE estimations by locality, the CPUE data suggest estuarine, outer estuarine and near estuarine waters are areas of high franciscana abundance, i.e. around locations 3, 4 and probably 8 and 9. Outer estuaries are known to be highly productive ecotones and may allow opportunistic cetacean species to feed with a reduced risk of predation. The apparent high densities for locations 8 and 9, although based on only a few data, are consistent with recent knowledge of the franciscana's southern limit of distribution (Crespo and Harris, 1992).

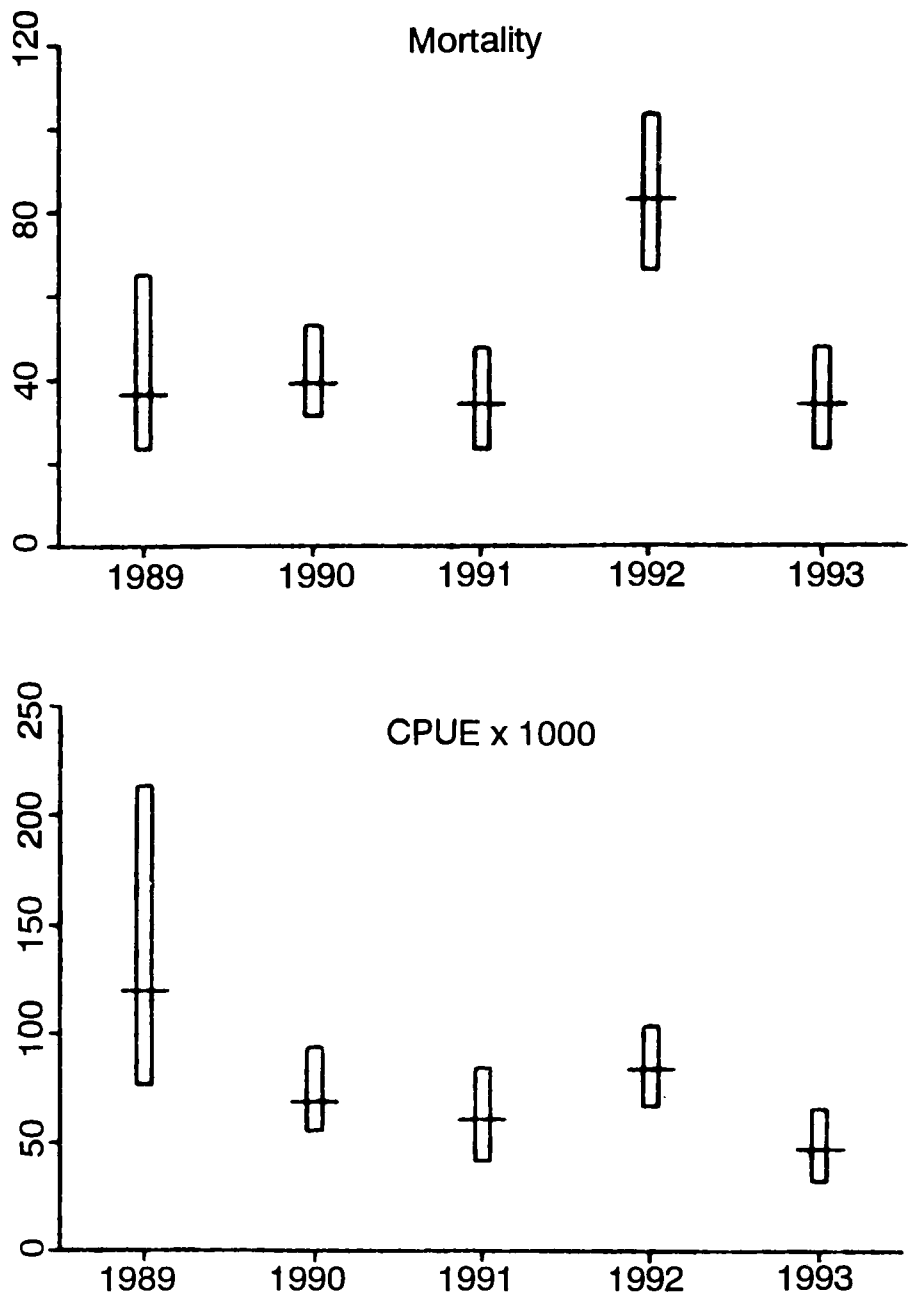

Fig. 2. Mortality and CPUE of franciscanas at Claromecó.

The case of Claromecó

An examination of the available CPUE and mortality data for Claromecó (location 2) provides some information on the different mortality levels by location. The 1989–93 CPUE estimations of Claromecó suggest a decreasing trend (Fig. 2), although the 1990–93 period was relatively stable in terms of CPUE. However, the actual mortality in 1992 was about double the usual levels. This increase and the subsequent 1993 decrease was due to only one vessel which operated in a particular area for a long time during 1992. Franciscana sightings were frequent there, as opposed to other areas where the boat had fished (also for long fishing periods) in previous years. In 1993, however, this boat was active only for one month, after which it ceased operation for economic reasons. This vessel was responsible for the highest incidental captures during the 1989–93 period.

Franciscana mortality levels seem to be extremely sensitive to qualitative changes in coastal fishing effort, particularly: (1) the use of large mesh size gillnets and (2) the geographical position of the nets (therefore implying a patchy distribution with perhaps site-fidelity). Franciscanas are associated more frequently with waters of 1–20m depth (Crespo *et al.*, 1994). Just one inshore fisherman setting his nets at the 'right' place may result in a greater mortality than that of a large fishing harbour fleet, which usually operates outside that depth range.

Urgent research needs

Other factors related to human activity (e.g. industrial, agricultural and sound pollution) in the La Plata River and the Bahía Blanca mid and outer estuaries could also affect the franciscana stocks and/or the fish nurseries upon which they probably feed. The probable existence of at least two different stocks of franciscanas (Pinedo, 1991) stresses the importance of separating different mortality estimates by areas, until stock identity questions are resolved. The impact of the BAP mortality can only be correctly evaluated if stock identification is determined and abundance estimates for each stock obtained.

Precautionary conservation measures

The use of large mesh gillnets and the definition of fishing grounds at the local level are highly variable factors and are difficult to control. Under such circumstances artisanal fishermen must be offered alternative non dolphin-lethal ways to catch their target species. For these to be acceptable, they must, at least maintain the historical relationship between fishing costs and benefits, if not be completely able to sustain the level of fish catches.

This approach seems possible in the case of those fishing camps almost exclusively devoted to the shark gillnet fishery, such as Monte Hermoso. Longlines could

successfully replace gillnets there if: (1) the longlines for soupfin and bigger shark species provide a better price/kg relationship than gillnets; (2) the longlines can be technically improved (e.g. an automated low coast baiting method is devised) to ensure their easy use; and (3) the artisanal fishermen can cooperate to fulfil foreign requirements in terms of levels of shark catches and quality of fish. Enhancing the acoustic reflectivity of gillnets by means of low-cost materials might provide another approach, although this perhaps is less promising as discussed elsewhere in this volume (e.g. IWC, 1994).

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Net Fisheries and Net Mortality of Small Cetaceans off Tierra del Fuego, Argentina

R. Natalie P. Goodall and Adrián C. M. Schiavini

Centro Austral de Investigaciones Científicas (CADIC), C.C. 92, 9410 Ushuaia, Tierra del Fuego, Argentina

Carlos Fermani

Museo del Fin del Mundo, 9410 Ushuaia, Tierra del Fuego, Argentina

ABSTRACT

There are five basic types of inshore fishing off Argentinian Tierra del Fuego: coastal fishing with gillnets or lines along the northeastern coasts; beach seining, use of wicker pots, and trapping for centolla (*Lithodes santolla*) in the Beagle Channel.

Northern coastal fishing uses three basic types of nets: (a) gillnets 25–100m in length with a mesh of 10–14cm for *róbalo* (*Eleginops maclovinus*), *merluza* (*Merluccius* sp.) and trout (although fishing for trout with nets is illegal); (b) finer-meshed (approximately 3cm) gillnets for *pejerrey* (Atherinidae) and small *róbalo*; and (c) trammel nets for all the above species. These nets are set perpendicular to the coast on stakes fixed in the tidal zone, where they lie exposed at low tide and are lifted by the sea at high tide. Occasionally small boats are used, especially near river mouths, either with one end of the net held on shore or with nets pulled between two boats. This fishery takes place between October and April; that for *pejerrey* extends into the winter.

We have monitored the mortality of small cetaceans in this fishery over the past 15 years. The species taken are, in order of quantity, Commerson's dolphin (*Cephalorhynchus commersonii*), spectacled porpoise (*Australophocaena dioptrica*), Peale's dolphin (*Lagenorhynchus australis*) and Burmeister's porpoise (*Phocoena spinipinnis*). Cetaceans are not trapped in the finer-meshed *pejerrey* nets. Pinnipeds are taken occasionally, but usually break through the nets. During 1989–1990, this fishery increased due to the economic situation of the country, but has since declined to former levels.

Fishing for *centolla* has lessened in the last few years, with only two companies with four boats (some 1,000 traps) working at present in the Argentine (northern) half of the Beagle Channel. Cetaceans are not caught in crab traps, but marine mammals may be harpooned for bait. Although illegal, there is some clandestine crabbing with nets in the Chilean section of Tierra del Fuego. Dolphins are entangled in these nets.

Offshore fishing is increasing; ten Argentine/foreign ships under Argentine permit and with mixed crews are based in Ushuaia at present. These fish with trawl nets or long-lines on the continental shelf off Patagonia, usually north of Tierra del Fuego, for squid, octopus, *merluza*, southern cod or *abadejo* (*Genypterus blacodes*) and others, producing tinned caviar and frozen fish. We have no information on possible cetacean exploitation in this fishery.

KEYWORDS: INCIDENTAL CAPTURE; COMMERSON'S DOLPHIN; SPECTACLED PORPOISE; PEALE'S DOLPHIN; BURMEISTER'S PORPOISE; PINNIPEDS

INTRODUCTION

Harpooning of dolphins for food in Tierra del Fuego began some 6,500 years ago with the arrival of the indigenous canoe peoples via the western channels. Direct exploitation probably reached its height during the early part of this century (Weber, 1920; Goodall *et al.*, 1988a and b), and now occurs only occasionally in Argentine waters, for bait for southern king crab *centolla* (*Lithodes santolla*) and false king crab or *centollón* (*Paralomis granulosa*) (Goodall and Cameron, 1980).

Incidental capture of the smaller cetaceans with nets in inshore waters during other fishing activities probably began in this century and has greatly increased in recent years. This type of fishing has been described for Tierra del Fuego and estimates given for numbers of dolphins taken (Goodall, 1978; Goodall and Cameron, 1980; Goodall *et al.*, 1988a and b; Goodall, 1990). It entails two types: (a) bottom netting for *centolla*, now illegal; and (b) netting for fish with fixed shore nets or nets used from boats near shore.

Cetaceans may also be captured in several kinds of fishing activities in offshore waters (the continental shelf off Argentina) by ships based in Ushuaia. This is a new fishery of which little is known.

The purpose of this paper is to describe the types and size of nets used and to review and update information on incidental and directed kills of cetaceans.

METHODS

Information on net fishing and cetacean takes in this area was obtained from review of the literature and from colleagues, fishermen and ship captains. In addition, much information was supplied by the Dirección de Recursos Naturales (DRN) of the Government of Tierra del Fuego.

We have carried out an on-going biological study of stranded and incidentally captured cetaceans along the coasts of Tierra del Fuego since 1975. We re-examined our collections and notes in order to re-estimate the number of cetaceans possibly taken in shore-based nets.

For comparative purposes, the Argentine coastline where netting occurs was divided into four sections (Fig. 1): (A) from Cabo Espíritu Santo to Cabo San Sebastián, the southeast end of Bahía San Sebastián; (B) from Cabo San Sebastián to Río Grande; (C) from Río Grande to Kaitush; and (D) the coast southeastwards from Kaitush. The latter coast has more cliffs and rocky shores, so shore fishing can be carried out only near river mouths; fewer expeditions were made to this area and it is under-represented in the sample. The crab and other fishing areas of the Beagle Channel are marked (E).

During 1990, we measured nets encountered on the beach and those confiscated by DRN because of illegal use. We also queried fishermen on net sizes and types.

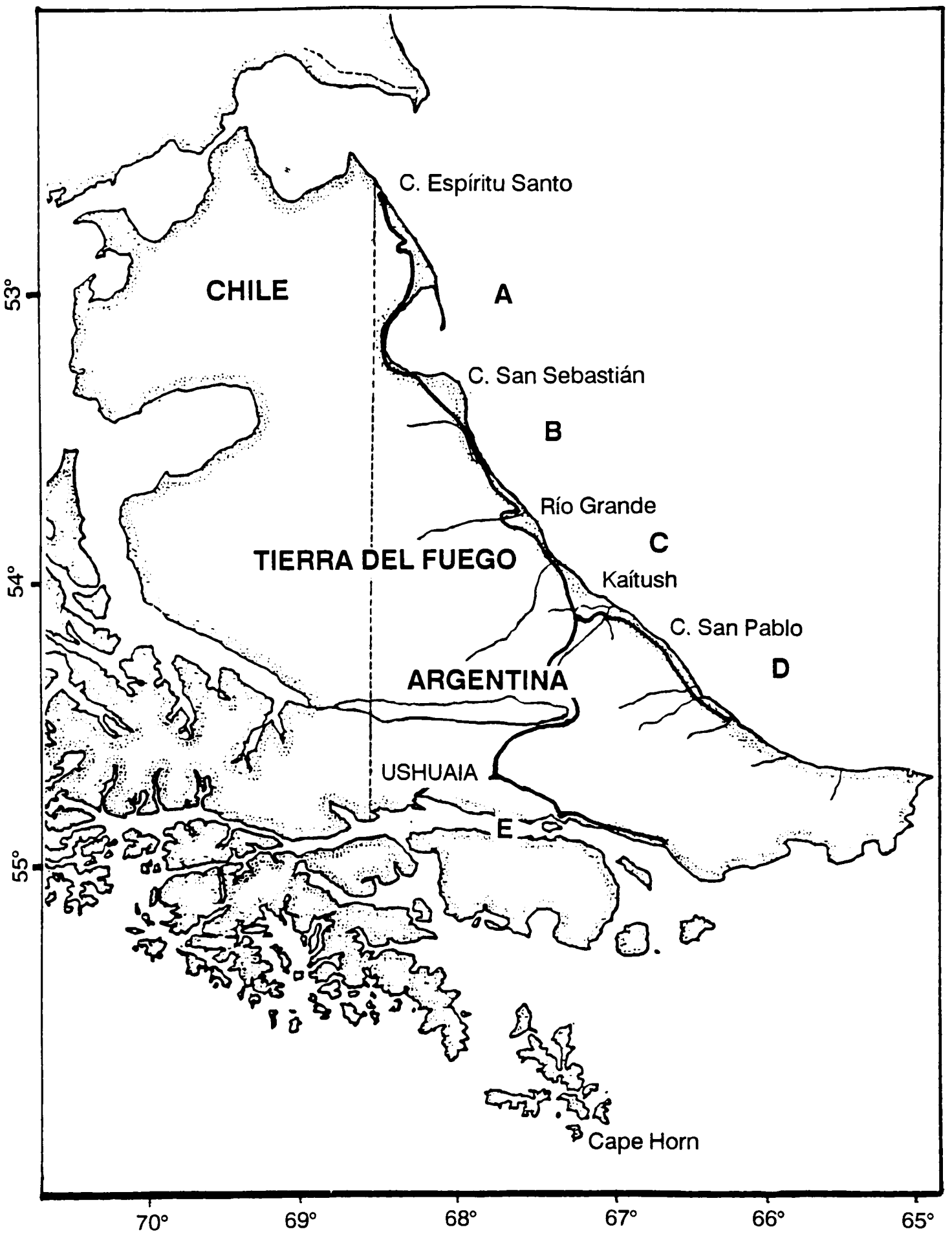

Fig. 1. Areas of Argentinian Tierra del Fuego where shore-based *róbalo* (A-D) and *centolla* fishing (E) take place.

TYPES OF FISHING

Nets set for centolla

Centolla occur in deep waters during most of the year but migrate to shallow waters near shore in late spring to moult. Females generally reach coastal moulting areas in November and males in December and January (J. Vinuesa, pers. comm.). From at least the 1950s until 1976, crabs were fished from October to about March while migrating (and a few in deeper waters in winter) with nets weighted to rest on the channel floor; the crabs would become entangled walking up the nets (illustrated in Goodall, 1975). The nets were usually 1.3m high, with sections joined to a length of 1,000m, marked on the surface with floats. They were checked once a day, weather permitting (Goodall, 1978). The mesh was usually 12cm square (stretched diagonally approx. 20cm). The nets were not baited.

This fishing usually took place in the Beagle Channel in Argentine waters and in many parts of Chilean Tierra del Fuego. On the northeastern coast of Tierra del Fuego, nets set on the mud flats could catch crabs only between late November and early December, when the crabs reached the tidal zone (they can be picked up by hand in tide pools on the lowest November tide). Small cetaceans were often trapped in both types of crab netting.

Since netting took female and young crabs, it was outlawed in Argentina in 1976 and in Chile in 1977.

However, some clandestine artisanal netting still occurs in the Chilean Strait of Magellan area and southern Santa Cruz, Argentina. As far as we know, netting for crabs does not take place at present in Argentinian Tierra del Fuego.

Crab fishery with traps

Since 1976 in Argentina and 1977 in Chile, *centolla* have been fished with traps. Since this resource is overexploited, fishing in recent years in both countries has turned to the *centollón*. In Argentine Tierra del Fuego, the king crab fishery is regulated under Resolución 132 of the Secretaría de Intereses Marítimos as administered by the local DRN. The area covered includes the northern (Argentinian) half of the Beagle Channel from Bahía Lapataia (68°34'W) to the western cliffs of Isla Gable (67°33'W), about 344 n.miles^2, with a limit of 1,000 traps (Boschi *et al.*, 1984). Crabbing also occurs from Isla Gable eastward to Islas Becasses (66°39'W) (Fig. 2). False king crabs have no legal regulation at present.

As of 1990, only two companies, *Mar Frío* and *Pesquera del Beagle*, operate from Ushuaia (54°49'S, 68°13'W), using Almanza (54°42'S, 67°33'W) as an alternate port. Each company operates two 15–17m wooden ships with the wheelhouse on deck near the stern and a winch for lifting and lowering the traps (illustrated in Goodall *et al.*, 1988a). The boats are operated by a captain and two crew members, normally Argentine but sometimes including Chileans. A fishing expert sometimes accompanies the boats. Crab holding capacity for the two *Pesquera del Beagle* boats is 2,000kg each; that for *Mar Frío* boats is 3,000kg each.

The operational unit can be defined as the 'line'. Each line consists of a series of ten traps, spaced 20m apart on a cable with one or two buoys at one end. The trap is a truncated cone of 70–115mm mesh net over an iron frame composed of three rings joined by bars. The trap is 130cm high with a base diameter of 150–180cm and a 40cm opening in the top protected by a plastic ring which impedes the escape of the captured crabs. Each boat carries about 25 lines of traps for a total of approximately 1,000 traps in the area. Two additional fishermen occasionally take crabs by license, while a few people may dive for crabs or take them from others' traps.

Crab traps are baited with animal flesh, skin or bone placed in fine-meshed plastic bags (approximately 12 by 25cm) tied inside the traps and changed each time the trap is lifted. The companies sell bait (fish) to the fishermen, but they often prefer to get their bait free (see Directed catches for crab bait below).

Except for adverse weather conditions, trap checking trips are daily from either Ushuaia or Almanza. On the basis of 1990 data (10–31 May, July, August and 1–15 September), we calculate an average of 202 (±24) working days per year. All 25 lines are continually in the water and are checked every 2–3 days at a rate of 8-10 lines per day. The crabs are unloaded alive and processed at the plants in Ushuaia, where they are canned or frozen.

Crabbing is permitted eight months per year (January to August), but fishermen may take up to two months to lift and store the traps, effectively extending the season to ten months. The fishermen receive about US$1.00 per kg for *centolla* and US$0.50 for *centollón*. The market for crabs is locally in Tierra del Fuego and in Buenos Aires, Europe and Japan.

The catch of *centolla* has declined recently, from 130,544kg in 1988 to 84,239kg in 1990. That of the *centollón* has also declined, from 182,168 kg to 131,495kg. The tendencies in this over-exploited fishery are fewer males of legal size (carapace of over 12cm) and a larger proportion of juveniles in the catches. The present legislation does not effectively protect females (Bertuche *et al.*, 1989). However, catch per unit effort (CPUE), measured as individuals per trap, has not varied between 1975 and 1989.

According to the fishermen, there is a great loss of gear through loss of buoys by theft or weather. The lines thus lost continue to attract crabs which eat the dead ones in the trap and eventually die, forming a continuing cycle. The plastic mesh of the traps may endure indefinitely and these ghost traps, estimated to be some 500 lines since 1976, probably greatly deplete the resource. Only occasionally can a line be hauled from the channel floor and the traps retrieved. Crabs have been greatly over-fished for years and the industry is in decline; one company has now incorporated ships for offshore fishing.

***Nasa* fishing**

The *Mar Frío* Company has recently begun using *nasas* (wicker basket traps) to fish for *brótola* (*Salilota australis*) and southern cod or *abadejo* (*Genypterus blacodes*) in a deep section of the Beagle Channel east of Ushuaia. The fish thus obtained are used for crab bait or sold locally.

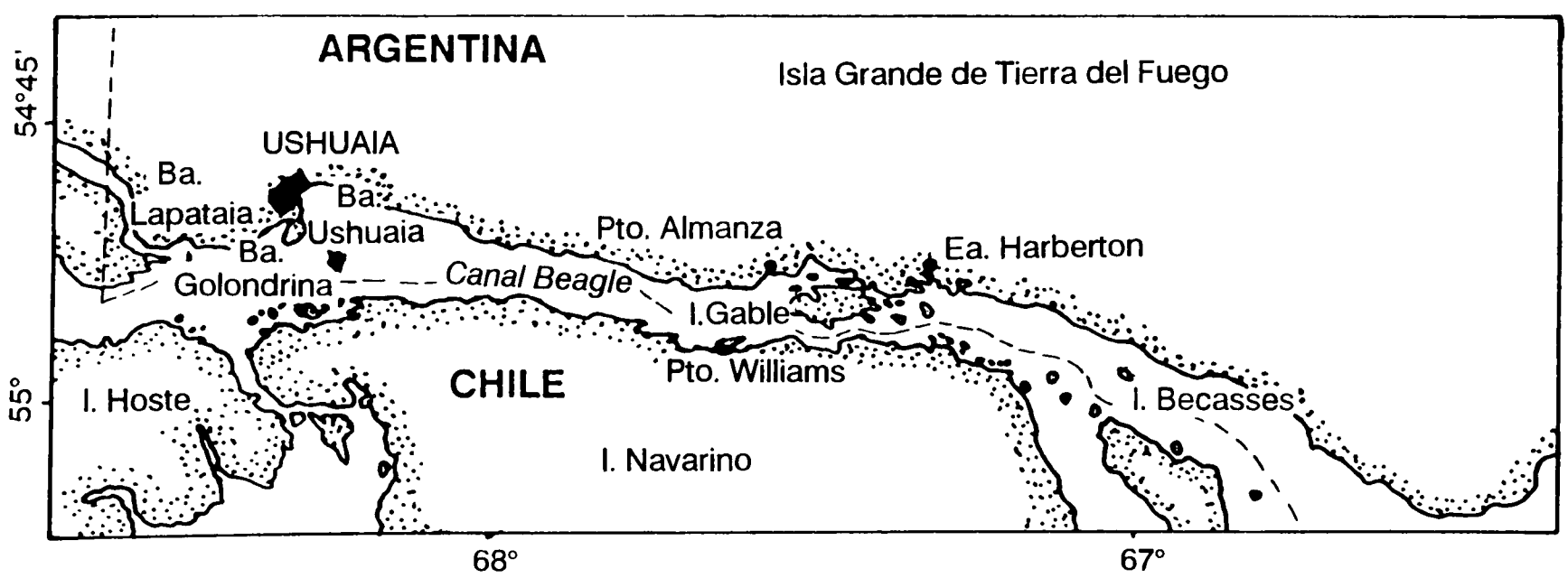

Fig. 2. Map of the Canal Beagle where *centolla* and scientific fishing is carried out, showing location of ports and the division of the channel between Argentina and Chile. Ba. = bahía, bay. I. = isla, island. Pto. = puerto, port. Ea. = estancia, farm.

Artisanal shore fishing

Shore-based fisheries which affect marine mammals are carried out on the northeastern coasts of Tierra del Fuego. These fisheries are controlled by DRN, which since 1987 has required licenses and has collected information, albeit many times partial, on catches. DRN has formed a group of volunteer wildlife inspectors in order to help control indiscriminant fishing, especially of the introduced trout, a major tourist attraction.

The species involved are those which normally swim near shore: Patagonian blenny or *róbalo* (*Eleginops maclovinus*), smelt or *pejerrey* (*Austroatherina nigrans*), and to a lesser extent southern hake or *merluza austral* (*Merluccius australis*), *abadejo*, *congrio* (*Pseudoxenomystax albescens*) and *palometa* (*Parona signata*) (nomenclature of Menni *et al.*, 1983). The latter two species are only rarely found in the nets.

These fisheries are carried out in three ways: by shore-based fixed nets, by a boat taking out a net hand-held on shore, and by operation of a net between two boats.

Shore-based set nets

This fishing is site-specific, limited to sand or clay beaches, bays or river mouths on the NE coast with gently sloping shores, a large tidal range (up to 10m at Bahía San Sebastián and about seven meters at San Pablo) and easy access by road.

Stakes are planted perpendicular to the beach in the intertidal area and nets are attached. Nets can vary from 20 to 100m in length and 140 to 200cm in height (Table 1). The nets are active only when the tide is in. This has been described as the world's laziest fishing; one must only wait for the tide to rise and fall again, then take the fish out of the net left exposed in the tidal zone. The nets are checked every low tide, both day and night, as the fish are quickly eaten by birds.

The nets are of three types: (a) *agalleras* (gillnets) for *róbalo* are set as far from the beach as tidal exposure permits and have a mesh size of 100-140mm; (b) gillnets for the smaller *pejerrey* or young *róbalo*, with a mesh of 20–40mm; and (c) *trasmallos* (trammel nets) (Table 1, Fig. 3). A simple 100m gillnet can cost US$1,000, if one buys the mesh, lines, floats and leads and puts it together oneself. The trammel nets are more expensive and seldom used. In some trammel nets, the center, finer-meshed panel is two to three times the height of the two outer nets, so that fish caught in its billows push through the larger meshes and become thoroughly entangled.

These three types of nets may be used in various combinations, with one or two *pejerrey* nets nearer shore and two or more *róbalo* nets attached to them or set separately further seaward (Fig. 4), depending on the site, the tides and the number of nets the fisherman has. Each fisherman may operate from one to four lines of nets, each set 50 to 200m apart, but many new fishermen have only one net. Trammel nets may be used as a last alternative when the gillnets fail.

Small groups of one to three men camped in shacks near the nets may fish all season (about October to April) and sell their catch to a buyer who comes every two to three days by truck. The fish are sold in Río Grande or Ushuaia and the excess or that which spoils is sold to the *centolla* packing plants in Ushuaia for bait for the crab traps. The more stable campsites are usually distant from towns.

Table 1

Types of nets used in shore-based fishing in Tierra del Fuego. Codes: r = róbalo nets; p = pejerrey nets; PE = polyethylene lines; PA = polyamide line, twisted (*hilo, sedal*).

No. nets joined	Net height cm	Length meters	Diameter twine, mm	Mesh size	Material: Mesh	Material: Floatline	Material: Leadline	Source or reference
Róbalo - gillnets (*agalleras*)								
2	140	25 each	0.24	140	-	-	-	Fernando Ravlik to RNP
1	140-150	25	0.24	140	-	-	-	F. Ravlik to RNP
2	140-150	25	0.24	120	-	-	-	F. Ravlik to RNP
1	±150	50	thicker	-	-	-	-	RNP obs.
1	±250	25	1.0	140	PA, white	-	-	RNP obs. dry on beach, floats yellow
2	±150	25-30	1.0	120	PA, white	-	-	RNP obs., floats yellow, floats gray
4	Observed three sets of nets with four 25m *'robaleras'* in each set							RNP obs.
1	180-200	100	1.0	120	PA, white	-	-	J. Varela to RNP, homemade
1	150-200	100	1.0	120	PA, white	-	-	J. Varela; most common net
1	200	70	1.0	120	PA 1mm	PE 6mm	PE 6mm	P. González to ACMS
Pejerrey - *agalleras*								
2	140-150	25	0.06	30	-	-	-	F. Ravlik to RNP
1	140+	25	0.06	30	-	-	-	F. Ravlik to RNP
1	200	12	0.18	30	PA	-	-	F. Ravlik to RNP
Róbalo and Pejerrey Agalleras *set in a row:*								
3(p,p,r)	-	120 total	-	p ±50	-	-	-	L. Benegas obs. to RNP
				p 'bolsa de hilo'	-	-		
				r ±90		-	-	
4 (p,p,r,r)	-	25 each	-	Similar to above		-	-	RNP obs.
Trammel nets (*trasmallos*):								
	150+	to 100m	1.0	120	PA	-	-	J. Varela to RNP
	450		1.0	20	PA	-	-	
	150	47	1.0	440	PA	PE 6mm	PE 6mm	CADIC 'Trammel 11'
			0.5	50	PA			
	240	60	1.0	440	PA	PE 6mm	PE 6mm	CADIC 'Trammel 3'
			0.5	40	PA			

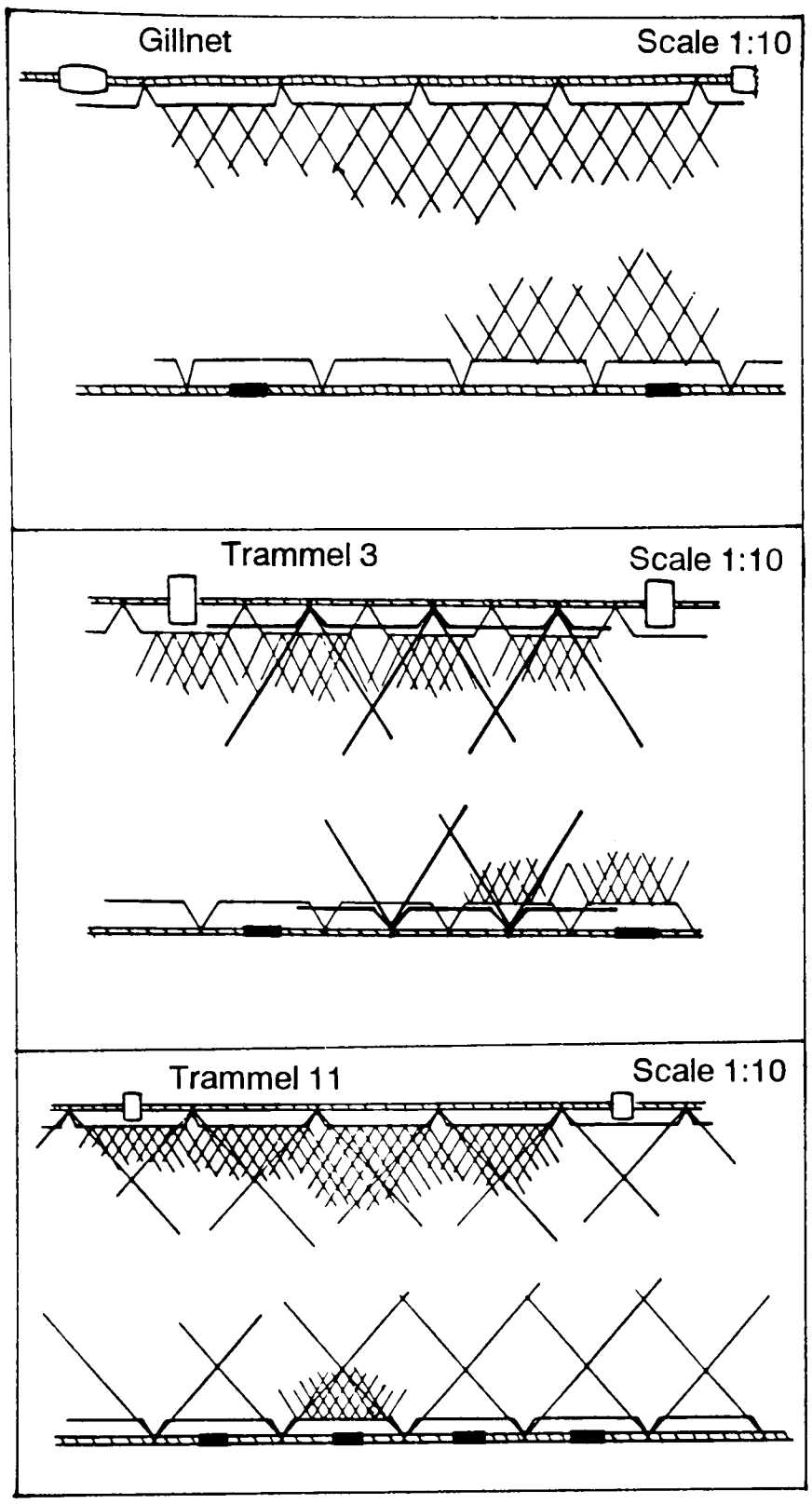

Fig. 3. Schematic drawings of the type of gillnets used in Tierra del Fuego and the trammel nets used by scientists at CADIC.

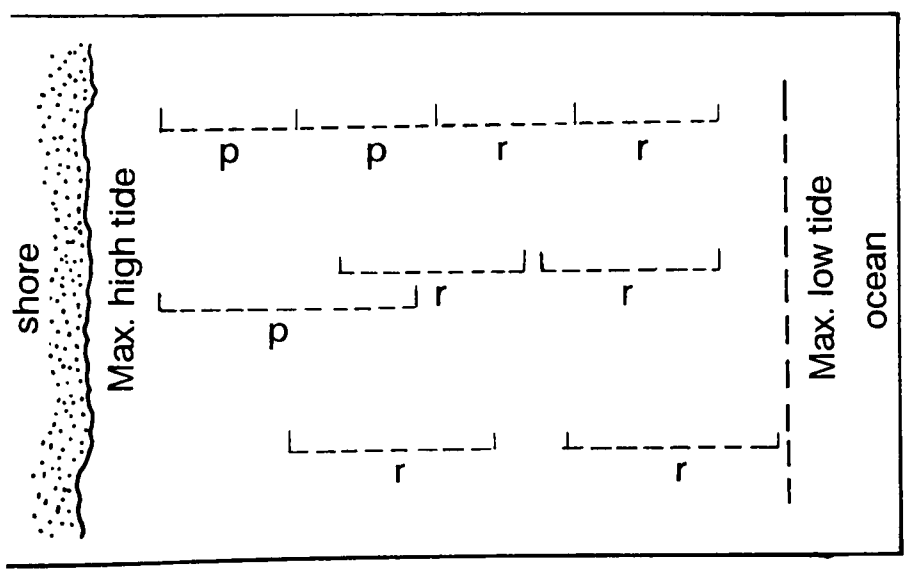

Fig. 4. Examples of net placement in shore-based fixed-net fishing on the NE coasts of Tierra del Fuego (*r* = *róbalo* nets, *p* = *pejerrey* nets).

Sporadic fishing is more common near Río Grande, with men fishing overnight or on weekends, bringing their nets and attaching them to permanently installed stakes.

The locality emphasis of this fishing changes from year to year, as fishermen claim that *róbalo* tend not to return to areas which are heavily fished. In the 1970s and early 1980s, most fishing was in the northern part of the zone (Bahía San Sebastián), but in 1988–89 most of it concentrated north of Río Grande (Fig. 5).

Boat-shore method

The exposed northeastern coasts of Tierra del Fuego, where *róbalo* fishing is also carried out, are extremely dangerous for boats due to the shallow shores, strong winds and waves. Boats are used by only a few fishermen and are normally kept on shore inside river mouths to be used on exceptionally calm days. The usual method is for one or two people in the boat to take one end of the net out in a large circle while another person(s) on shore holds the other end.

Boat fishing

One or two rowboats or inflatable boats may be used to drag the net out to encircle a school of fish. Both this and the former method require several people (as opposed to one man with his shore nets), good weather conditions and a river or other easy launching site. Most boat fishing is done in or near river mouths. Legally, no net fishing of any type is permitted in rivers or within 300m on either side of river mouths to protect introduced Atlantic land-locked salmon (*Salmo salar*) which have returned to the sea. However, clandestine fishermen find river mouths an excellent place to net large numbers of both *róbalo* and trout.

The information available on the coastal net fisheries is too incomplete to permit an estimate of effort. There are no official data on types of nets used, length of time each fishes, or the exact amount of landings. On the basis of fishing licenses given by DRN, we determined the number of licenses in use on the 15th of each month from September 1987 to September 1990 (Fig. 6). Until February 1989, the licenses were for three months, but since then are for six months.

The licenses given for the south coast (Beagle Channel and adjacent waters) are for *róbalo* (see below), mussels and other shellfish. Due to the severe economic situation of the country from 1989–1990 and the difficulty in finding work, more families resorted to fishing, as shown by the increase in licenses.

The catch may be as much as 400kg of fish per tide or as little as one or two fish. It is difficult to obtain more than two fish per m^2 of net even with large schools, because each captured fish tangles up at least 50cm of net. The *róbalo* begin to arrive in coastal waters in October, are most numerous in December to February and are gone by April or early May. *Pejerrey* are caught throughout the *róbalo* season. Only recently have fishermen discovered that *pejerrey* can also be caught in winter.

A fisherman may obtain about $US 0.50 per kilo of *róbalo* and $US 3.00 to 3.50 per kg of *pejerrey*, since these are usually sold directly instead of through a company like the *centolla*. We have no information on the price of *merluza*, the third most abundant fish caught. The fish are sold fresh to local homes, hotels, restaurants and markets.

On the basis of DRN data, we analyzed reported catch by species and area (Fig. 7). The area with most catch was

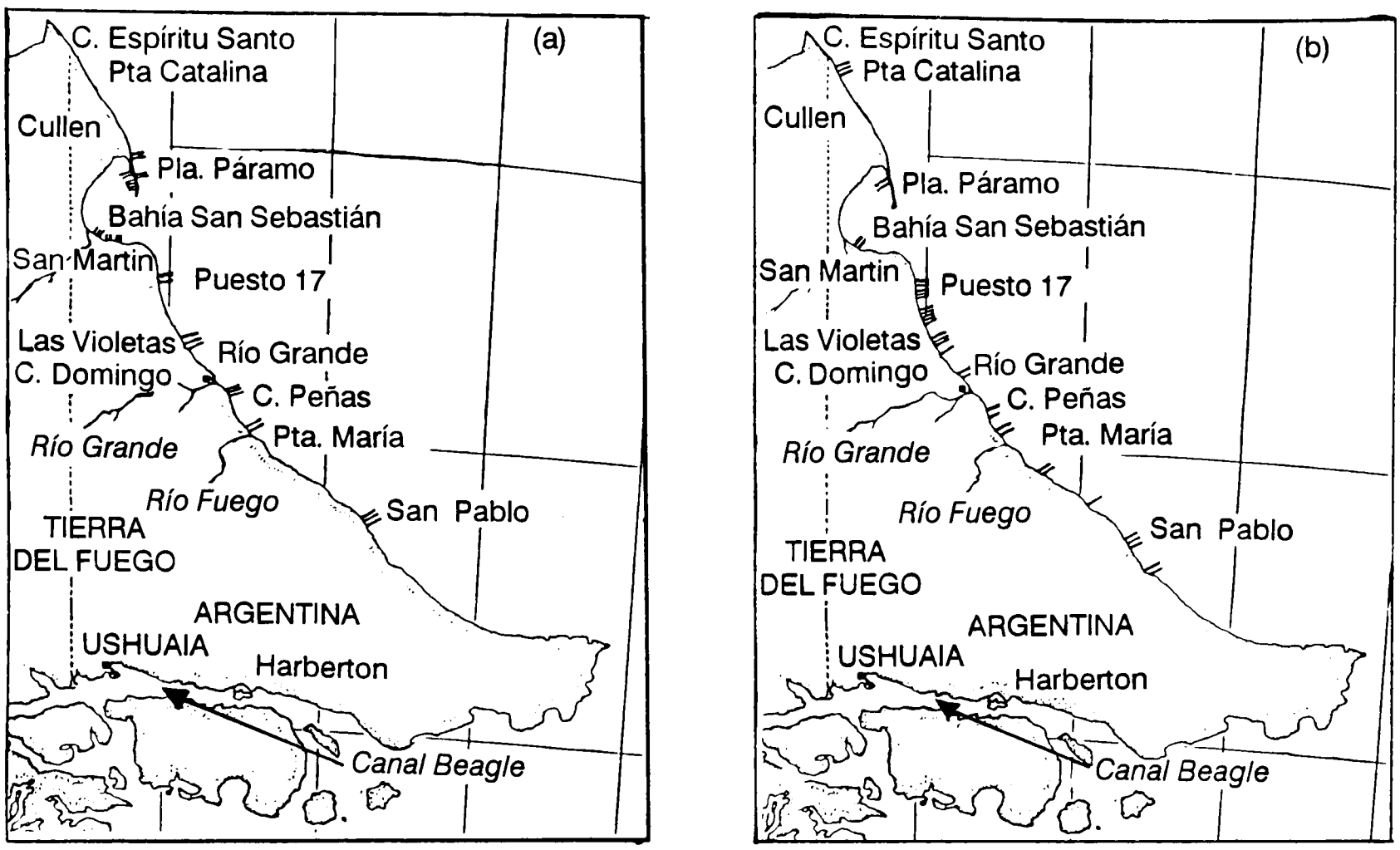

Fig. 5. Principal areas where shore-based nets were set (a: 1976–86; b: 1987–90). Each line represents 1–2 nets.

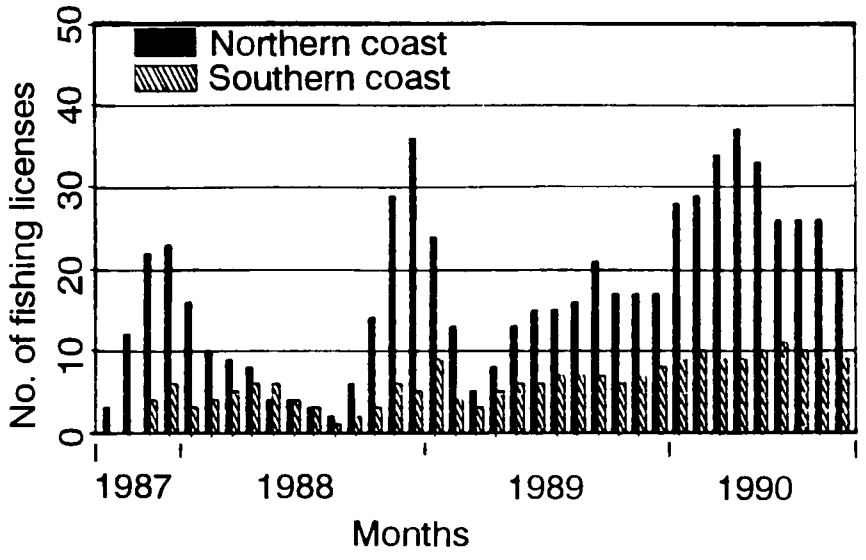

Fig. 6. The number of fishing licenses in use at mid-month for the NE and southern coasts of Argentinian Tierra del Fuego, since the licensing began in September 1987. These include licenses for mussels and other shellfish (mainly south coast).

B, the area with easiest access from Río Grande and for which most fishermen (58%) requested licenses.

This fishing requires a big investment in nets and produces a good return only one or two months a year. Extensive damage to nets is common through bad weather on the exposed coasts or from pinnipeds. The seals and sea lions go for the fish's head, ripping the nets. Nets are not often lost completely so as to become ghost nets at sea, but they may be damaged by waves, moving shingle or debris.

Beagle Channel net fishing

Róbalo enter the Channel mainly in summer but occasionally in spring. Waters in the channel are somewhat more protected than off the north coast, and *róbalo* are fished from inflated boats using a beach seine (*red de cerco*). A typical net is about 70m long, 150cm high, has approximately 30mm mesh and a 250 by 250 by 70cm bag in the center. Fish are located visually before setting the net around them with the boat. Up to 500kg may be taken in one set (J. Varela, pers. comm.).

Line fishing

From November to February some fishermen leave their nets and fish for *róbalo* with lines, either along the coast or more frequently at river mouths and up to 500m up the rivers, where the fish may remain at low tide. Four to five kg fish can be taken with rod and spoon (unbaited), or using a line wrapped around an empty tin can with a block of wood wedged inside for a handle. Some fishermen dig worms from the beach for use as bait.

Scientific fishing

A research program entitled 'Bioecology of Fish Resources of the Beagle Channel', sponsored by the Centro Austral de Investigaciones Científicas (CADIC) in Ushuaia, has been underway since February 1987. The researchers obtain the fish for their study through the use of trammel nets in Ushuaia, Golondrina and Lapataia Bays (all within 30km of Ushuaia) and occasionally in other areas, such as Bahía Aguirre and Río Irigoyen. The nets are set using 5m inflatable boats with 35 HP engines. The nets used (Table 1, Fig. 3) are usually set at depths of up to 20m in the zone near the coastal border of kelp (*Macrocystis pyrifera*). Most remain only one day in the water (96% of the sets, n = 291). Assuming the various types of nets as equal and that each net in the water one day represents one net/day, the fishing effort of the program to date is approximately 8 net/days per month (Fig. 8).

Offshore fishing

Seven ships (Argentine/Russian and Argentine/Japanese) based in Ushuaia since 1989 fish in Fuegian waters. Three others fish off Argentina beyond the 12 mile limit, over the wide continental shelf between Tierra del Fuego and the Malvinas Islands (about 55–53°S) and from there

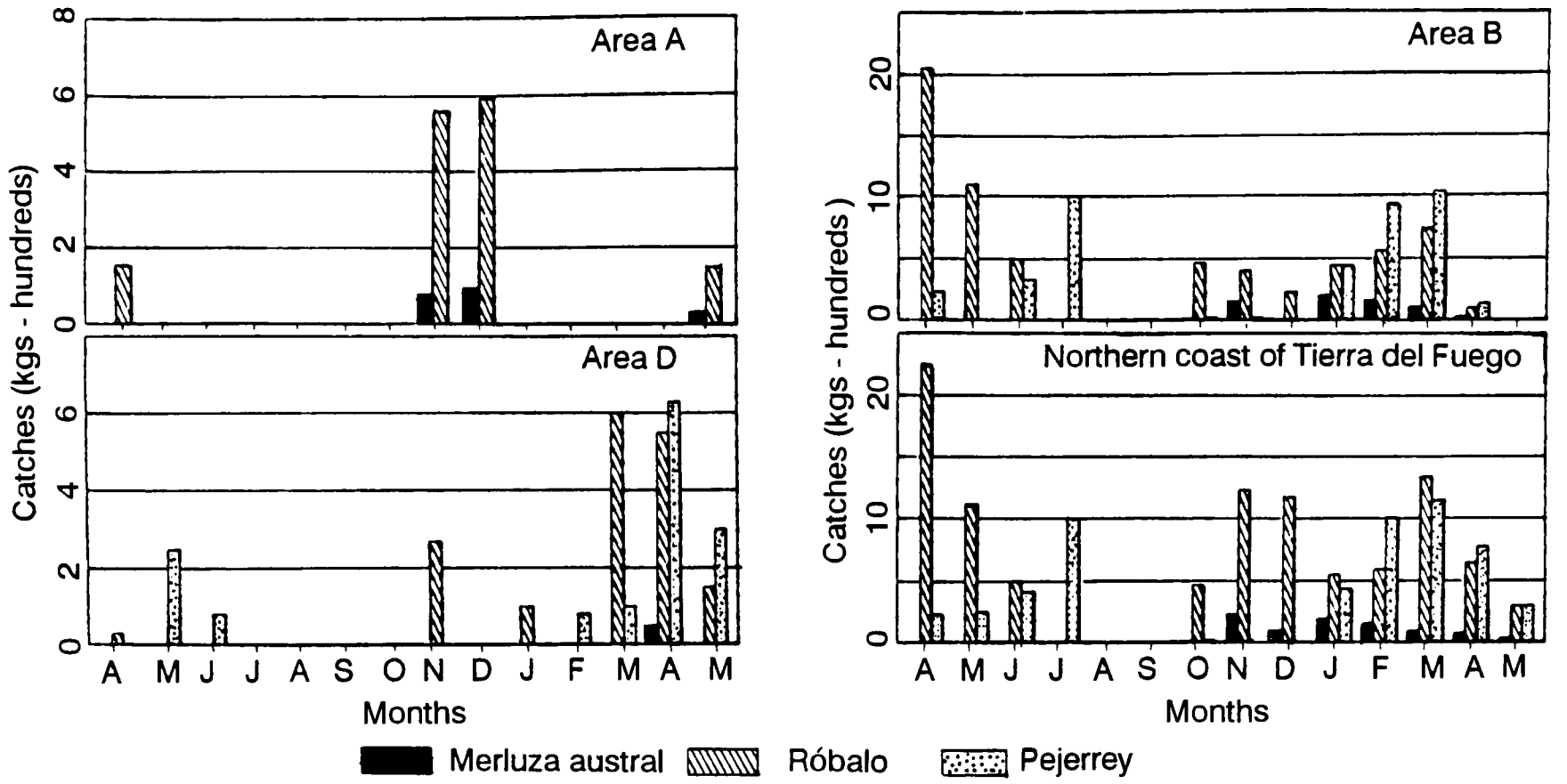

Fig. 7. Tentative data on catches of fish from Cabo Espiritu Santo to San Pablo. Data collection began in April 1989, but many fishermen did not report their catches.

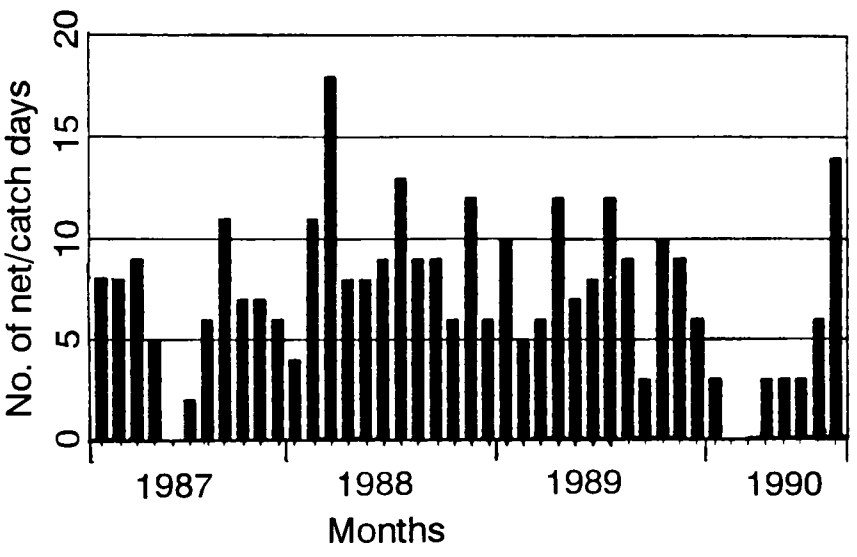

Fig. 8. The number of net/days of scientific fishing carried out per month in the Canal Beagle.

northward to about 45°S. The crews are part Argentine and part foreign. They fish for squid with long-lines (one squid ship was lost SE of Bahía Aguirre in August 1990) or for octopus, *merluza, abadejo* and other fish using trawls. The fish are trans-shipped to a freezer boat at Ushuaia; few fish are sold locally.

Some ships based at Río Gallegos and Puerto Deseado fish waters as far south as Tierra del Fuego, while others, especially foreign vessels based in Punta Arenas, Chile, may fish Fuegian offshore waters (J. Jordan, pers. comm.).

Some of these vessels buy fishing licenses from the UK as well as Argentina, so they have two quotas in the same ecosystem, increasing the fishing effort applied to the SW South Atlantic Ocean.

INCIDENTAL TAKES OF CETACEANS

Small cetaceans, seals and birds, as well as fish, are taken incidentally in the various types of nets, especially those set perpendicular to the shore. Marine mammals are unaffected by *nasa* or line fishing and are seldom if ever taken in beach seines, although one Commerson's dolphin, *Cephalorhynchus commersonii*, which had evidently been taken in such a net, was found on the north shore of the Beagle Channel in 1983. A summary of previously published information on cetacean mortality is given in Table 2.

Centolla nets

Incidental death of dolphins, porpoises and seals was probably extensive during the years when these nets were permitted. This was before our program was in operation, so we have no reliable information on this catch. One Burmeister's porpoise (*Phocoena spinipinnis*) trapped in 1974 was sent to the Museo Argentino de Ciencias Naturales in Buenos Aires, and four trapped in one week in December 1975 were reported to our program (Goodall and Cameron, 1980; Goodall *et al.*, 1990a). We examined a very young Commerson's dolphin taken in crab nets in 1972.

Crab netting continued for several years in Chilean waters after it became illegal; we picked up at least ten Commerson's dolphins which died in this manner along the shores of Bahía Inútil in two days in 1978. Fishermen there told us that 20–30 dolphins died per season in the nets set from two boats (Goodall *et al.*, 1988a).

Róbalo fishing

Marine mammals, especially small cetaceans, are often taken incidentally in shore-based *róbalo* nets (Goodall, 1978; 1989; Goodall and Cameron, 1980; Goodall *et al.*, 1988b).

The species most often taken in the nets is the Commerson's dolphin, which seems to follow the *róbalo* and *pejerrey* in their near-shore movements from October to April (although some fish may remain in the area year round) and have their young near shore in mid-summer (December to January) (Goodall *et al.*, 1988a). Of the coastal fishes, only *pejerrey* has been cited in a study of stomach contents of this species (Bastida *et al.*, 1988); the dolphins evidently follow the fish along the shore into the nets. They have often been observed feeding or playing in the breakers (Goodall *et al.*, 1988a). Fishermen consider

Table 2

Published references on cetacean mammal mortality through shore-based net fishing in Tierra del Fuego. Codes: N = specimens in our collection which were caught in nets; N? = specimens in our collection which were most probably caught in nets; R = incidental take reported by fishermen or others.

C. commersonii			*L. australis*			*A. dioptrica*				
N	N?	R	N	N?	R	N	N?	R	Notes	References
28	-	15	1	-	-	1	-	-	Number much higher	Goodall, 1978
69	-	-	1	-	-	2	-	-	= 72 animals 1975-1979	Goodall & Cameron, 1980
										Goodall *et al.*, 1988a
71	75	21	2	19	1	1	-	-	Jan. 1979 - May 1986	Goodall *et al.*, 1988b
Total 167			Total 22			Total 3				Goodall *et al.*, 1988b
Min. 70 - Max. 167			Total 22			Total 3			Jan. 1979 - May 1986	Lichter & Goodall, 1988
236			23			5				

the Commerson's dolphins stupid, as they become immobilized when caught in the net and make no attempt to get loose. Hence more die, but there is less damage to nets. Some dolphins are still alive when the tide recedes and are released.

Fishermen claim that the dolphins are not taken in the *pejerrey* nets because of their fine mesh and because they are set closer inshore.

The second species in numbers taken is probably the spectacled porpoise (*Australophocaena dioptrica*). At first we assumed that the many specimens of this species had stranded, but on mapping the specimens, almost all coincide with spots where nets are set (see map in Goodall, 1990).

Peale's dolphins may be in the area most of the year but they are more numerous in summer. According to the fishermen, when caught in a net Peale's dolphins usually struggle and get out, leaving large holes. Nevertheless, some die (Tables 3 and 4). One live dolphin was returned to the sea, a difficult task on the mud flats.

Burmeister's porpoises also get caught in the nets; other potentially-caught animals are the southern right whale dolphin *Lissodelphis peronii*, fur seals, leopard seals, elephant seals and southern sea lions (Tables 3 and 4).

Previous publications by our program reported about 236 Commerson's dolphins, 23 Peale's dolphins and 5 spectacled porpoises taken in nets from 1975 to 1986 (Table 3). In the present study we reviewed our field notes by year and area. We counted specimens that we know died in nets, specimens that we are fairly sure died in nets, and others reported by fishermen (for which we have no specimens). We arrived at a total of 313 Commerson's dolphins, 34 spectacled porpoises and 20 Peale's dolphins for the period 1975–1990 (Table 4). The area where most dolphins were caught was Bahía San Sebastián (Table 3). This is a minimum estimate; actual catches must have been much greater, perhaps three times as high, because as many animals are washed away by the tide or stripped of flesh by birds (we did not count skeletons unless they were obviously associated with a net) and because there were large gaps in our visits to the fishing areas. Spectacled porpoises especially may have a higher rate of incidental mortality; their carcasses tend to break up quickly and float inland. The mortality of the Commerson's dolphin may be at a dangerous level for a stretch of coast approximately 150nm long.

The cetaceans taken in nets are not used for food in Argentina. Generally they are left on the mud beside the nets, to be scavenged by birds or taken away by the tide. From 1976 to about 1986, fishermen often saved the dolphins for our study, but some were sent to the crab factories for bait. Since DRN has recently been issuing licenses and attempting to control catches, the fishermen now suddenly know nothing at all about dolphins and pretend that they just appear on the beach for unknown reasons.

Table 3

Total number of marine mammals taken by area in passive shore-based set nets in Tierro del Fuego between 1975 and March 1990. Key as Table 2.

	Cephalorhynchus commersonii			*Lagenorhynchus australis*			*Australophocaena dioptrica*			*Phocoena spinipinnis*		*Lissodelphis peronii*	*Arctocephalus australis*		*Hydrunga leptonyx*	*Mirounga leonina*	*Otaria flavescens*	
	N	N?	R	N	N?	R	N	N?	R	N	N?	N?	N?	R	N?	N?	N?	Total
(A) Cabo Espíritu Santo to San Sebastián																		
Total	61	18	40	6	1	3	3	11	1	-	1	4	3	-	-	-	-	152
(B) Cabo San Sebastián to Río Grande																		
Total	57	16	4	1	6	-	1	10	-	1	1	1	-	1	1	1	3	104
(C) Río Grande to Kaitush																		
Total	51	20	24	-	1	-	-	7	-	-	-	-	-	-	3	-	-	106
(D) Kaitush and Southeast[1]																		
Total	10	4	8	1	1	-	-	1	-	-	1	1	-	-	-	-	-	27
Total	179	58	76	8	9	3	4	29	1	1	3	5	3	1	4	1	3	388

[1] This area is greatly under-represented in the collection, as there are fewer suitable beaches for fishing and we made fewer expeditions.

Table 4

Total numbers of marine mammals taken in passive shore-based set nets in Tierra del Fuego. The year indicates the year found, not necessarily date of death. Key as Table 2.

	Cephalorhynchus commersonii			*Lagenorhynchus australis*			*Australophocaena dioptrica*			*Phocoena spinipinnis*		*Lissodelphis peronii*	*Arctocephalus australis*		*Hydrunga leptonyx*	*Mirounga leonina*	*Otaria flavescens*
	N	N?	R	N	N?	R	N	N?	R	N	N?	N?	N?	R	N?	N?	N?
1975[1]	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
1976[1]	1	-	15	-	1	-	-	-	-	-	-	-	-	-	-	-	-
1977	15	2	6	-	-	-	3	2	1	-	-	-	1	-	-	-	-
1978[2]	10	5	13	1	-	-	-	3	-	-	-	3	-	-	1	-	-
1979[2]	6	-	5	2	-	1	-	-	-	-	-	-	-	-	-	-	-
1980	15	3	16	-	2	-	-	3	-	-	1	-	-	-	-	-	-
1981	14	3	3	-	1	-	-	1	-	-	-	-	-	-	1	-	-
1982	29	2	-	1	-	1	-	6	-	-	-	-	-	-	-	1	-
1983	18	6	2	-	2	1	-	1	-	-	-	-	-	-	-	-	-
1984	11	7	3	1	1	-	-	2	-	-	1	-	-	-	-	-	-
1985	3	1	-	-	2	-	-	1	-	-	-	1	-	1	1	-	-
1986	6	7	-	1	-	-	-	1	-	-	1	2	-	-	-	-	-
1987	1	1	6	-	-	-	-	2	-	-	-	-	1	-	-	-	-
1988	23	9	3	-	-	-	-	3	-	1	-	-	1	-	-	-	3
1989[3]	11	2	-	2	-	-	1	3	-	-	-	-	-	-	1	-	-
1990[3]	16	9	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	179	58	76	8	9	3	4	29	1	1	3	6	3	1	4	1	3
Total per species			313			20			34		4	6		4	4	1	3

[1] Record incomplete - only one expedition to area; [2] Fishing and our expeditions curtailed due to near war with Chile; [3] Data to March only.

Scientific fishing

In three years of weekly sets of nets, only one cetacean has been captured during scientific fishing, a juvenile Burmeister's porpoise whose mother swam nearby until the calf was released unharmed, on 14 April 1988 (Sobral, pers. comm.; Goodall *et al.*, 1990b). This low figure of incidental take may reflect depletion of the dolphin populations in the area, mainly Peale's dolphins, by capture of dolphins for crab bait (described below).

Offshore commercial fishing

There are no laws in Argentina requiring reporting of cetaceans taken incidentally at sea, and we have no information on possible mortality in this new and expanding fishery. However, there have been a number of reports of dolphins being taken by similar ships off the Province of Chubut (E. Crespo, pers. comm.; A. Scolaro, pers. comm.; Goodall *et al.*, 1988b).

DIRECTED CATCHES FOR CRAB BAIT

Marine mammals are not taken incidentally in the traps used for *centolla*, but they are often used as the preferred bait for the traps. There is little information on deliberate exploitation in Argentinian waters, limited to the northern half of the Beagle Channel and waters immediately to the east. Any shooting or harpooning of marine mammals is clandestine, but we obtained information and some specimens of at least 23 Peale's dolphins harpooned for bait in July 1979 (Goodall and Cameron, 1980). Obviously the take has been high in past years; Peale's dolphins are no longer seen in the parts of the Beagle Channel where centolla fishing occurs (Goodall, 1978; Goodall and Cameron, 1980; pers. obs.). This is compounded by the fact that half the channel belongs to Chile, where fishermen are more experienced in harpooning dolphins.

In 1987, up to 60–70 sea lions from islets near Isla Gable were killed for bait and a newly established colony was eliminated. About the same time, we were informed of killing of sea lions on islets east of Gable Island on the Chilean side of the channel. There have been recent slaughters of Magellanic penguins and cormorants. The government of Tierra del Fuego, Argentina, enacted in 1989 a decree protecting all birds in the Territory.

Other animals killed and used for bait are sheep, cattle, horses, other sea birds and fish (Goodall and Jordan, 1986). The domestic animals are sometimes bought but often stolen. In 1990 crab companies bought fat, spoiled meat and beef bones from the slaughter house or meat markets for use as bait since the sale of beef has increased with the increase in population. Bones of cattle seem to make an acceptable, longer lasting bait than most of the others.

CONCLUSIONS

All types of fishing activities, except crab trapping, increased in Tierra del Fuego in 1989–90 due to the economic problems of the country as a whole, the lack of work on the island due to closure of factories, and the 'opening' of the Argentine economy. Control by DRN is limited because of understaffing and lack of funds. Offshore fisheries are under very little control, and there are no observers or reporting of captures of fish or incidental take of cetaceans.

In the *centolla* fishery, information on the current levels of capture of marine mammals as bait is needed for both Argentina and Chile. It is imperative to find an alternate type of bait. Methods need to be developed for recovery of ghost traps and for avoiding future loss of traps, or to assure the rapid degradation of lost lines.

The *róbalo* shore fishery takes a large number of coastal dolphins and porpoises. Better relations with the fishermen could result in more accurate data and recovery of carcasses for biological study. Plans are under way for better methods of obtaining data on catches and nets.

Studies are needed to develop methods of protecting coastal cetaceans.

The offshore fishery should be monitored for fishery effort assessment and incidental cetacean catches.

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Africa and Indian Ocean

Marine Mammals and Fisheries Along the West African Coast

Jacques Maigret

Museum National d'histoire naturelle, Cellule de préfiguration de la Galerie de l'Evolution, 36 rue Goeffroy St Hilaire, 75005 Paris, France

ABSTRACT

There are no studies of the relationship between cetaceans and fisheries for West Africa. The widely dispersed unloading centres along the coast make such study difficult. The artisanal fisheries which use a wide variety of gear, do not appear to have any major impact on cetacean populations. This report provides a preliminary review of West African fisheries with particular attention to the problem of catches of marine mammals. The five identified artisanal gillnet fisheries do not often catch cetaceans. Foreign industrial fisheries are more likely to have an impact on cetacean populations.

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; NORTH ATLANTIC; SOUTH ATLANTIC; BOTTLENOSE DOLPHIN; COMMON DOLPHIN; HARBOUR PORPOISE; HUMP-BACKED DOLPHIN; KILLER WHALE; PYGMY SPERM WHALE; DWARF SPERM WHALE; PYGMY KILLER WHALE; MELON-HEADED WHALE; STRIPED DOLPHIN; SPOTTED DOLPHIN; CLYMENE DOLPHIN; SPERM WHALE; LARGE WHALES-GENERAL

INTRODUCTION

Little information on West African fisheries, marine mammals or interactions between them is available. For this review I contacted people who are working in fishery laboratories, directly or through the relevant departments of international organisations (CECAF/FAO). I received answers from three countries (Mauritania, Senegal and Ivory Coast) where I have personal contacts and from two others (Sierra Leone and Nigeria). This report is the result of bibliographical research and personal experience of the area. It should be considered preliminary.

The data on the fishery activities in each country have been taken from reports, generally unpublished, by the French ministry for co-operation (Moal and Woitellier, 1984), ORSTOM (Fontana *et al.*, 1989) and FAO/CECAF. Little information on cetaceans is available in the literature apart from Cadenat's work in Senegal between 1945 and 1963 and Maigret's from 1970 until 1982. Some data have been published by IFAN (Institut Fondamental d'Afrique Noire, Dakar).

GEOGRAPHICAL AND ECONOMIC FRAMEWORK

West Africa, considered to represent the large region between Morocco and Angola, is characterised by its border with the Atlantic Ocean. The marine mammal populations there have been little studied. They can be divided into three categories:

(1) 'coastal' populations including bottlenose dolphins (*Tursiops truncatus*), common dolphins (*Delphinus delphis*), harbour porpoises (*Phocoena phocoena*), monk seals (*Monachus monachus*) in the North and hump-backed dolphins (*Sousa teuzsii*) and manatees (*Trichechus senegalensis*) in the Gulf of Guinea;
(2) 'migrating' populations including killer whales (*Orcinus orca*), pygmy and dwarf sperm whales (*Kogia breviceps, K. simus*), pygmy killer whales (*Feresa attenuata*), melon-headed whales (*Peponocephala electra*) and several balaenopterid species;
(3) 'pelagic' populations including striped dolphins (*Stenella coeruleoalba*), spotted dolphins (*S. attenuata, S. frontalis*), clymene dolphins (*S. clymene*), spinner dolphins (*S. longirostris*), sperm whales (*Physeter macrocephalus*) and several balaenopterid species.

The eastern Atlantic Ocean near Africa includes two quite different environments: subtropical and tropical. The subtropical zones along the desert coasts in both the Northern and Southern Hemisphere are subject to the regime of the trade winds which leads to the phenomenon of 'upwelling'. These areas, with relatively cold waters, are very productive (e.g. off Mauritania and Angola) with an enormous biomass of phyto– and zooplankton. The tropical zone, by contrast, on both sides of the Equator is characterised by warm water, with low salinity. Productivity is low and is associated with river estuaries. The icthyological fauna is limited.

Although coastal West Africa is largely non-industrial, a few industries are developing. Populations are concentrated in a few large towns such as Casablanca (Morocco), Dakar (Senegal), Lagos (Nigeria) and Abidjan (Ivory Coast), often without technical infrastructures. Although pollution is not thought to be a problem in the region, monitoring is non-existent in some areas.

The exploitation of marine resources is irregular but is increasing with the growth of the population and the economic crisis that is enveloping most African countries; as more food is needed, people are looking to the sea to supply their needs. Current fisheries off West Africa can be divided into three main types: artisanal; local commercial; and foreign.

Artisanal fisheries use small boats (pirogues and canoes) and a variety of gear: lines; purse seines; beach seines; traps and nets. The catches are primarily for local consumption.

Local commercial fisheries involve small boats (often in poor condition), operating under West African national flags and include trawlers, shrimp-trawlers, pilchard-seiners and tuna-liners. Catches may be for local consumption or export (shrimps, cephalopods or tuna).

In addition there have been commercial fishing fleets from foreign countries operating, generally using much larger vessels:

(1) bottom trawlers from Japan, Korea, USSR (now the Russian Federation), Spain and Portugal that take cephalopods, shrimp and seabream;

(2) mid-water trawlers from USSR (now the Russian Federation), Poland and Romania that take small pelagic fishes, mainly pilchard, horse mackerel and mackerel (a fleet of seiners working with factory ships for fish meal disappeared from the area between 1978 and 1980);
(3) oceanic tuna-clippers from France, Spain and the USA using large purse-seines;
(4) tuna bait-boats from Spain, France, Taiwan, Korea and Japan; and
(5) tuna long-liners from Korea and Taiwan (some use also driftnets).

These international commercial fleets do not unload in African ports and work within the framework of fishing agreements with each state. They are difficult to control and their catches are only known from the declarations of the country of origin. Although they are largely outside the scope of this report, some may have cetacean bycatches.

COMMERCIAL FISHERIES

It might be argued that all fisheries have some impact on cetacean populations in that they reduce the fish stocks. Small pelagic fishes and cephalopods are the main prey of cetaceans; FAO (1982) estimated their biomass in the area at approximately 3–4,000,000 tonnes and they have been overexploited in some areas. This factor must be borne in mind in any consideration of the relationship between marine mammals and fisheries.

Demersal fisheries probably have little direct interference with cetaceans, but others, including pelagic trawling and purse seining, do include cetacean bycatches.

It has sometimes been reported that the catches of dolphins (e.g. common dolphins and *Stenella* spp.) occur mainly at night, perhaps because at that time the animals are moving slowly near the surface and are less alert. We observed such catches on board Romanian trawlers. One night in May 1980, the trawler '*Otlet*' caught six common dolphins in its first haul and 22 in the second; all were dead when brought on board. The fleet working in the same area included 12 trawlers; all caught dolphins, but we could not determine the exact number. It is difficult to determine the exact numbers of pelagic trawlers from eastern Europe that operate in these waters and it is not possible to extrapolate these numbers to the total pelagic trawler fleet because catches are not made all year round and are dependent on fishing gear and, of course, on the presence of dolphins with the concentrations of pelagic fish.

The tuna fisheries in the area use several different techniques, as described below.

(1) *Pole and line boats with rods and living bait.* Boats from African coastal countries as well as Spain and France use this method. It does not appear to affect cetaceans. Dolphins are often used as a cue for detecting tuna as the two often coincide (although the relationship is not as strong as in the eastern Tropical Pacific).
(2) *Long-liners.* Vessels from Japan, Korea and Taiwan operate from the Canary Islands and Tema (Ghana). I have no information on the activities of these boats. That some of them use driftnets has been confirmed by observations in Mauritania (M. Ba, pers. comm.). Two large cetaceans were observed caught in nets in March and September 1989 by N.O. '*N'Diago*' off Cape Timiris (19°40'N, 16°30'W). The larger measured about 25m and the smaller 10m, but the species were not identified.
(3) '*Purse seiners*'. Vessels from the FIS fleet (France, Ivory Coast and Senegal), from Spain and sometimes clippers from the USA operate. Levenez *et al.* (1979) and Maigret (1981) have reported on the relationship between the Atlantic tuna fishery and marine mammals. The fishing techniques are different to those used in the eastern tropical Pacific and the captains do not use the dolphins to locate concentrations of tuna schools. Consequently, the catches in seines are less dramatic. After 1980, the FIS fleet was greatly reduced by the transfer of some vessels to the Indian Ocean.

COUNTRY ACCOUNTS

Morocco

The fish stocks of Morocco can really be considered as being 'European' and of the temperate Atlantic rather than African. Little information on Moroccan fisheries can be found in 'West African' literature and in spite of contacts in the Fishery Institute I did not obtain any additional information to that published.

There are several types of fisheries in the Moroccan zone.

Bottom-trawl fishery
Vessels from Spain and Portugal take seabream and shrimp and in the south vessels from Japan take cephalopods.

Pelagic fishery
The Soviet fleet sometimes caught pelagic fish species in the south, off western Sahara.

National fishery
A well-developed fishery exists that uses small bottom-trawlers, seines (pilchard) and some gillnets – although no quantitative information is available it is likely that a few cetaceans are caught.

TUNA FISHERY
In the northern ports of Morocco some small boats operate with driftnets. The fishery is also developing quickly in the south, where fishermen are replacing purse seines with driftnets. The total catches (including longlines and seines) are about 3,000 tonnes per year. No information on cetacean bycatches is available.

LOBSTER FISHERY
A coastal set net fishery for lobsters (*Panulirus regius*) in the south of Morocco (Western Sahara) with nets deployed in the evening (between 0 and 10m deep) was operated by France and Spain until 1975. It stopped between 1975 and 1980 because of the Polisario conflict, giving the lobster population time to recover. Exploitation started again in 1981 in the south (La Güera and Nouadhibou), this time using Senegalese pirogues and more recently has included larger vessels from Moroccan ports. The fishery takes place in the area of the most important monk seal colony. According to the fishermen, they do not catch seals in their nets but they sometimes do catch porpoises and dolphins (about ten per year between 1980/82 in Nouadhibou).

Mauritania (Table 1)

As noted earlier, common dolphins and *Stenella* spp. are caught by eastern European pelagic trawlers (42 trawlers in 1988). An estimated minimum of about 500 to 1,000 dolphins per year are caught. Harbour porpoises and other dolphins are taken by the artisanal lobster fishery in the

Table 1

Fleets operating and catches in Mauritania (1988). Coastline = 700km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	750	Lobster boats	18
Trawlers	133	Bottom trawlers	116
		Pelagic trawlers	42
		Seiners	2
		Tuna clippers	20
		Liners	5

Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	443,000	108,000	6,100

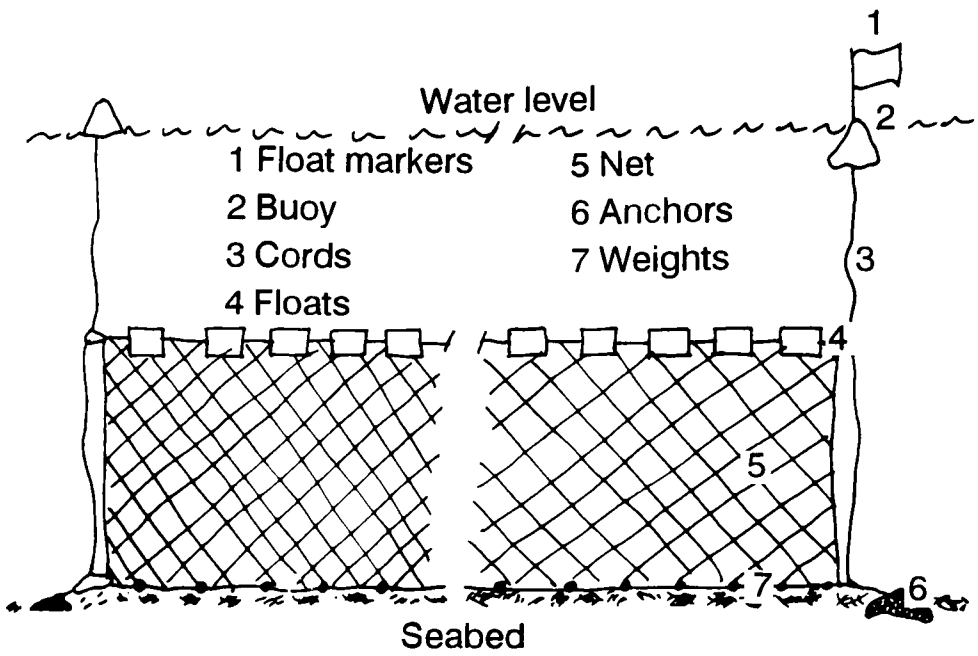


Fig. 2. Setnet used by the artisanal fishery in Mauritania and in other countries of Guinean Gulf (Diop and Mohammed, 1990).

border area between Morocco and Mauritania (estimated at less than 20 per year, but the population is thought to be small along the northwestern African coasts).

In the 1980s, the artisanal fishery (Fig. 1) numbered about 600 boats (it recently decreased from 770 boats in March to 450 in August 1989 – Diop and Mohammed, 1990) using different gear: lines, palangres, traps, pots for octopus and gillnets (Fig. 2). Since 1980, new gillnets (set nets) made with nylon monofilament have been given to the fishermen as part of a Japanese aid programme to Mauritanian fisheries. The nets, although very efficient for fishes, also entangle marine animals. Between 1980 and 1982 I observed the catches of ten dolphins (bottlenose and common dolphins), one monk seal, one female killer whale (perhaps not killed by nets but by a boat's propellers) and several turtles (*Caretta caretta* and *Dermochelys coriacea*).

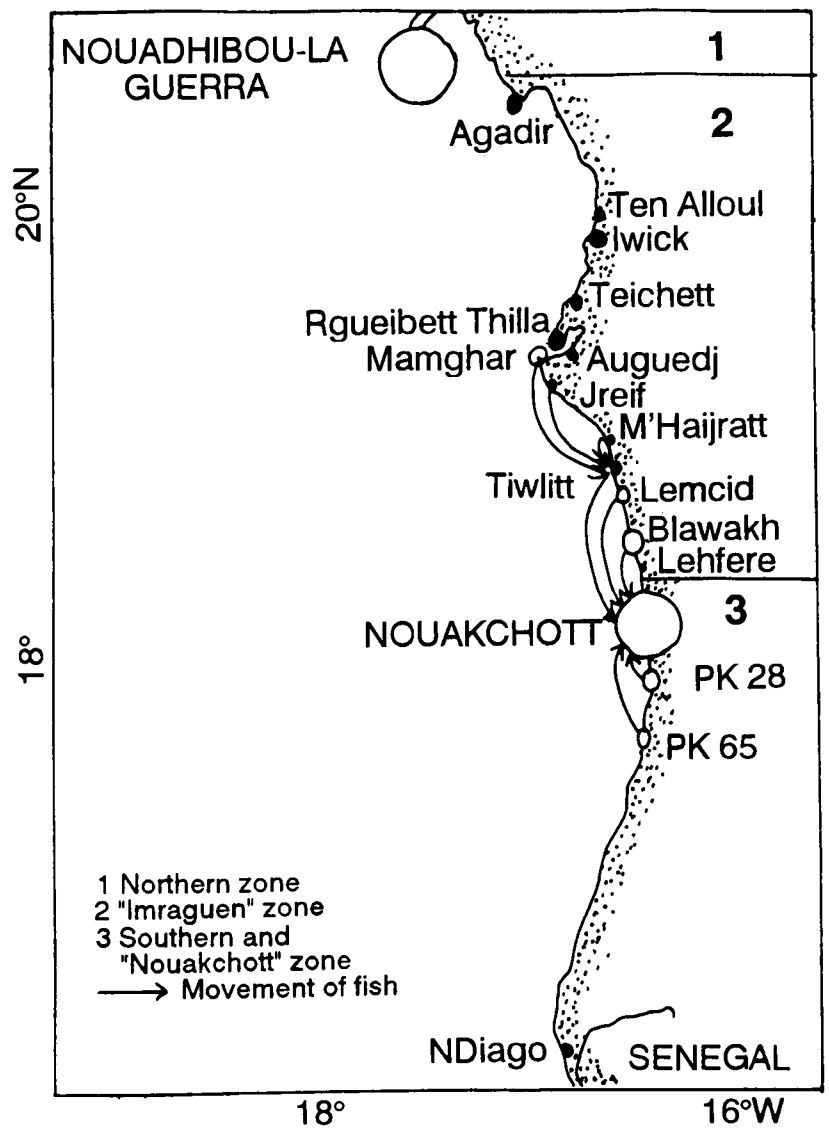


Fig. 1. Coast of Mauritania with the unloading centres for artisanal fishery (Diop and Mohammed, 1990).

The Imraguen fishery on the Banc d'Arguin uses the help of bottlenose dolphins to guide the mullet shoals to their nets. Around about 1980, they changed from their traditional fishery to the use of gillnets which increased the risk of catching dolphins. Although no captures have been reported, the Atlantic hump-backed dolphin is found in this area.

Senegal (Table 2)

The artisanal fishery comprises some 4,500 small boats (8 to 12m), in addition to the pirogues without engines which work in the estuaries and involves some 35,000 fishermen. There are more than 180 points of unloading along the coast. Catches of dolphins are prohibited in Senegal and are not declared; officially there is no catch of marine mammals (CRO Dakar-Thiaroye, pers. comm.). However, Maigret (1981) reported average catches of 2–3 dolphins each month in purse seines in M'Bour in 1977, the most important unloading point on the south coast. The animals are immediately cut up and eaten by the fishermen. About 30–50 dolphins (bottlenose dolphins, common dolphins and sometimes *Stenella* spp.) are caught each year in this part of Senegal. In the north, around Kayar, I found many marine mammal carcasses and skeletons, some of them probably relating to fishery activities far from the shore, but this area is a zone of mass stranding (Maigret, 1979). Despite the paucity of information, I believe that the total catches of the artisanal fishery in Senegal do not exceed 100 cetaceans per year.

Table 2

Fleets in operation and catches in Senegal (1988). Coastline = 700km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	4,500	Trawlers	41
Trawlers	750	Palangres	4
Seiners	5	Tuna seiners	39
Tuna seiners	3	Tuna liners	16
Tuna liners	2		

Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	182,000	83,000	17,200

Manatees (*Trichechus senegalensis*) are also caught on the estuaries of the rivers Senegal, Saloum and Casamance. Again, although their capture is officially prohibited, a few years ago I found manatee meat on the market in towns in the Saloum Delta.

Cape Verde Islands (Table 3)

About 4,000 fishermen work in Cape Verde; 60% use lines while the remainder use traps and set nets for lobsters or use beach purse seines. The continental shelf is too narrow to allow much development of an artisanal fishery. The industrial fishery is mainly for tuna with lines and purse seines but some driftnets (mesh 160mm) may be used off the coast to catch tuna and bonito (Prado and Smith, 1994). There is no information on bycatches of cetaceans but the Cape Verde Island area includes concentrations of sperm whales (*Physeter macrocephalus*) and possibly humpback whales (*Megaptera novaeangliae*) in winter.

Table 3

Fleets operating and catches in Cape Verde Islands (1988).

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	536 [1]	Tuna boats	4
Liners	59		
Tuna boats	10		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	3,800	920	6,200

[1] 120 without engine.

Gambia (Table 4)

The artisanal fishery includes 400 pirogues, 300 working in the open sea and the remainder in the estuary of the Gambia river, employing about 1,800 fishermen. There are 11 points of unloading on the coast. The number of coastal purse seiners decreased from seven in 1982 to three in 1988. These are Ghanaian vessels, as are all those operating in the Gulf of Guinea. There is no information on fishery/marine mammal interactions, although the situation is probably similar to that in Senegal.

Table 4

Fleets operating and catches in the Gambia (1988). Coastline = 100km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	400	Tuna seiners	37
Trawlers	3	Tuna liners	11
		Palangres	6
		Trawlers	33
		Seiners	3
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	10,500	10,000	280

Guinea – Bissau (Table 5)

Although the number of vessels in the foreign fleet appears large, the vessels do not work in Guinea-Bissau waters all year round. The artisanal fishery includes 400–750 pirogues, dispersed in the mangrove channels along the coasts; it is essentially a subsistence fishery for shrimps and pilchards. Nothing is known about interactions with marine mammals.

Table 5

Fleets operating and catches in Guinea-Bissau (1988). Coastline = 350km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	400	Trawlers	135
		Tuna seiners	11
		Tuna liners	45
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	91,300	36,000	2,600

Guinea (Table 6)

The bottom trawler fleet (there were 11 vessels in 1982) from east European countries is not controlled. Trawlers from the European Economic Community also operate, and often unload in Conakry. The artisanal fishery employs 8,000 fishermen, most of whom are foreigners (Sierra Leone, Ghana). Gear includes lines, palangres, set nets and dams in the mangrove channels. Driftnets may be used (Prado and Smith, 1994) to catch sharks (mesh 570mm) and barracuda (mesh 150mm). There are 80 unloading points along the coast. There is no information on fishery/marine mammal interactions.

Table 6

Fleets operating and catches in Guinea (1988). Coastline = 510km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	1,700 [1]	Trawlers	99
Trawlers	3	Palangres	8
		Tuna liners	11
		Tuna seiners	45
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:52,500	143,000	3,800	

[1] 400 with engine.

Sierra Leone (Table 7)

The number of pirogues appears to have decreased considerably during the 1980s (7,000 in 1982, only 700 in 1988). Over the same period, the number of Soviet mid-water trawlers decreased from 83 to 45. There are numerous unloading centres, especially for catches of the Madeiran sardinella (*Sardinella maderensis*) and the African ethmalosa (*Ethmalosa fimbriata*). I received some information from Tombo, one of the artisanal purse-seine fishery centres where a German fishery pilot project is operating (A.C.V. Forbe, pers. comm.). The fishery uses two kinds of pirogues: traditional pirogues, 13–15m long with an outboard engine (of the Ghanaian type) and a larger type, 15–20m long with a diesel engine. About 70 pirogues operate from the village. The fishermen (12–21

Table 7

Fleets operating and catches in Sierra-Leone (1988). Coastline = 510km

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	700	Trawlers	39
Trawlers	24	Pelagic trawlers	45
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	140,000	22,500	2,400

per boat) use polyamide ring-nets (mesh 35 to 45mm). Fishing effort consists of about 10,500 fishing trips per year of 4 to 8 hrs each. They catch about 8,000 tonnes, mainly *Sardinella maderensis* (47%) and *Ethmalosa fimbriata* (43%). Very infrequently (once or twice per year) 'porpoises' and manatees are entangled in the centre of the net; they are dead before being disentangled and are consumed locally.

Liberia (Table 8)

Almost nothing is known about the fishery activities in this country.

Table 8

Fleets operating and catches in Liberia. Coastline = 550 km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	Hundreds	Unknown	-
Commercial	18		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	2,000	5,700	4,300

Ivory Coast (Table 9)

The artisanal fishery (Fig. 3) employs 36,000 fishermen, of which almost 31,000 are foreigners. It includes some 400 pirogues and the use of 3,350 gillnets, 240 purse seines and 50 beach seines. The artisinal fishery appears to involve

Table 9

Fleets operating and catches in the Ivory Coast (1988). Coastline = 700km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	700	Tuna seiners	?
Trawlers	9		
Shrimp trawlers	3		
Seiners	19		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	66,000	10,600	7,000

few interactions with marine mammals (cf. Senegal). A driftnet fishery for tunas, swordfish and sharks was introduced in 1983 (F.X. Bard, pers. comm.). It developed in two ports, San Pedro and Abidjan, with respectively 10 and 20 pirogues (Fig. 4) from Ghana each fitted with 40HP outboard engines and a crew of eight. In the evening the nets are put out at the surface, in water deeper than 1,000m and retrieved during the same night. There are about 1,500 fishery trips per year and the catches (about 200 tonnes) are sold on the local market. Dolphins are caught incidentally but as catches of marine mammals are prohibited in the Ivory Coast, they are not declared but are consumed by fishermen or buried on the beach. The number of marine mammals caught is not known. Many coastal populations of the Gulf of Guinea worship marine mammals and they do not like catches of dolphins. When they find an animal dead on the beach, they bury it ceremonially.

Ghana (Table 10)

In contrast with other African countries, Ghana, like Senegal, has a strong maritime tradition and fishermen from Ghana have colonised the coast from Mauritania to the Congo, bringing their fishing techniques with them.

The pelagic fishery is well developed with pirogues and purse seiners, both of which probably cause some marine mammal mortality.

The origin of the swordfish fishery (cf. Ivory Coast) is Cape Three Points. F.X. Bard (pers. comm.) reports that he saw one dolphin caught in Dixcove (Western Ghana) in May 1988. There is no information on the number of marine mammals killed.

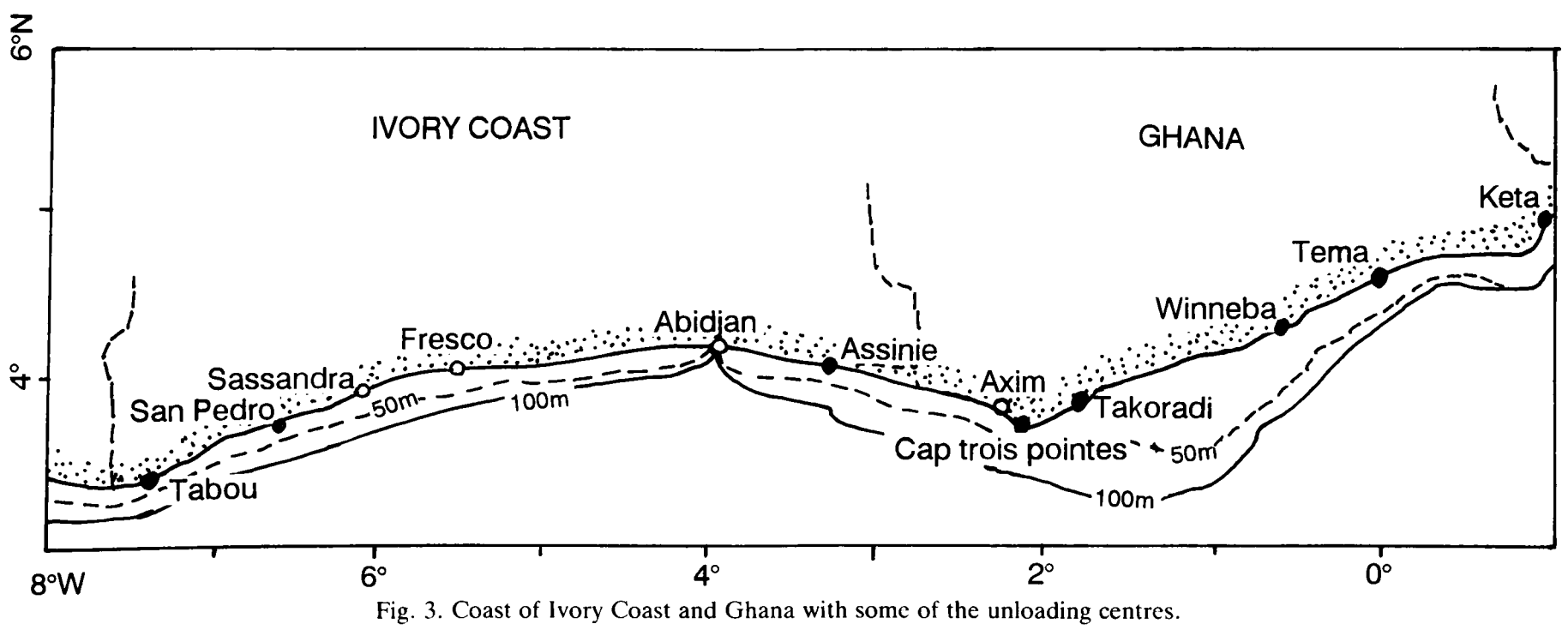
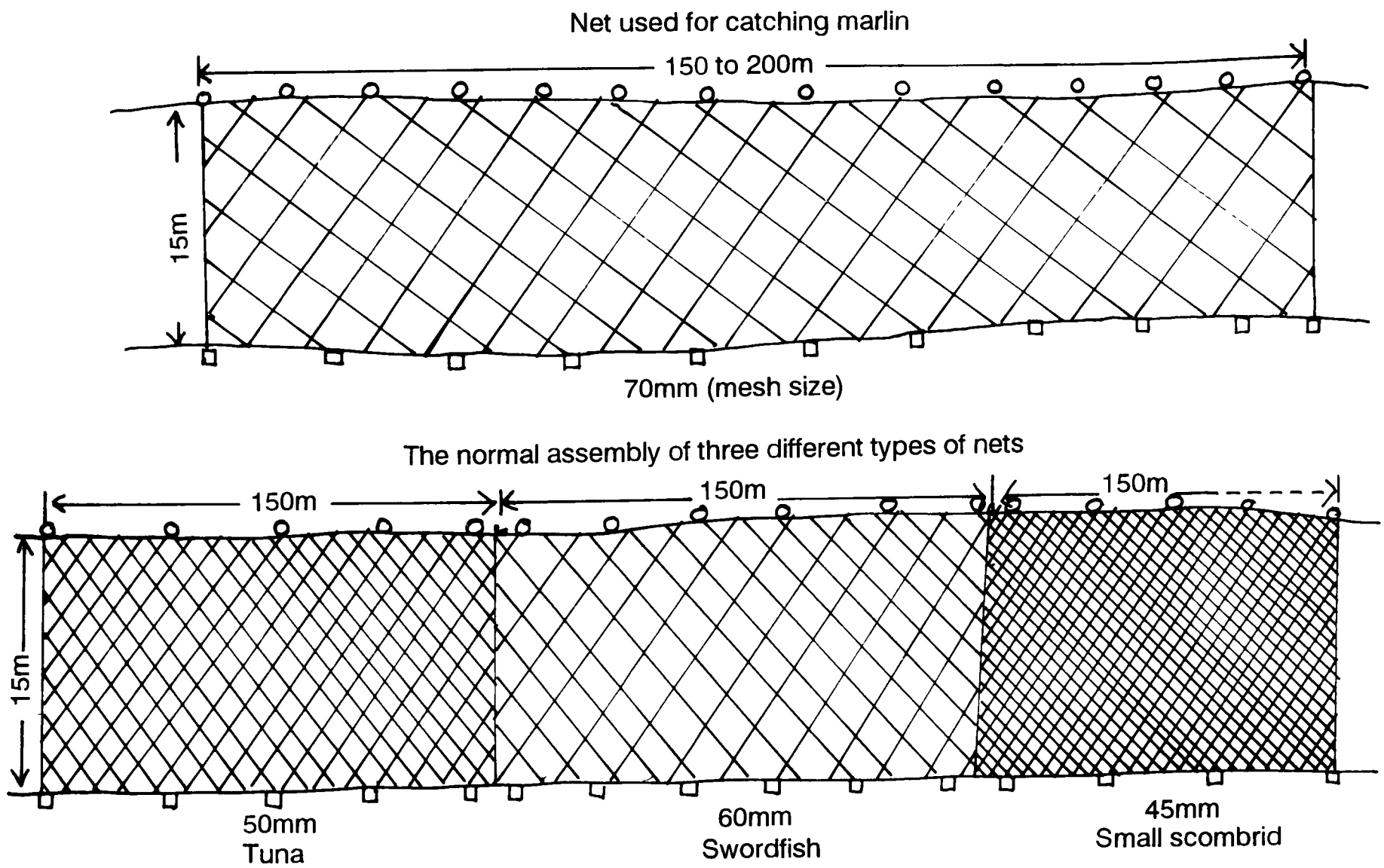


Fig. 3. Coast of Ivory Coast and Ghana with some of the unloading centres.

(a) DRIFTNET



(b) PIROGUE

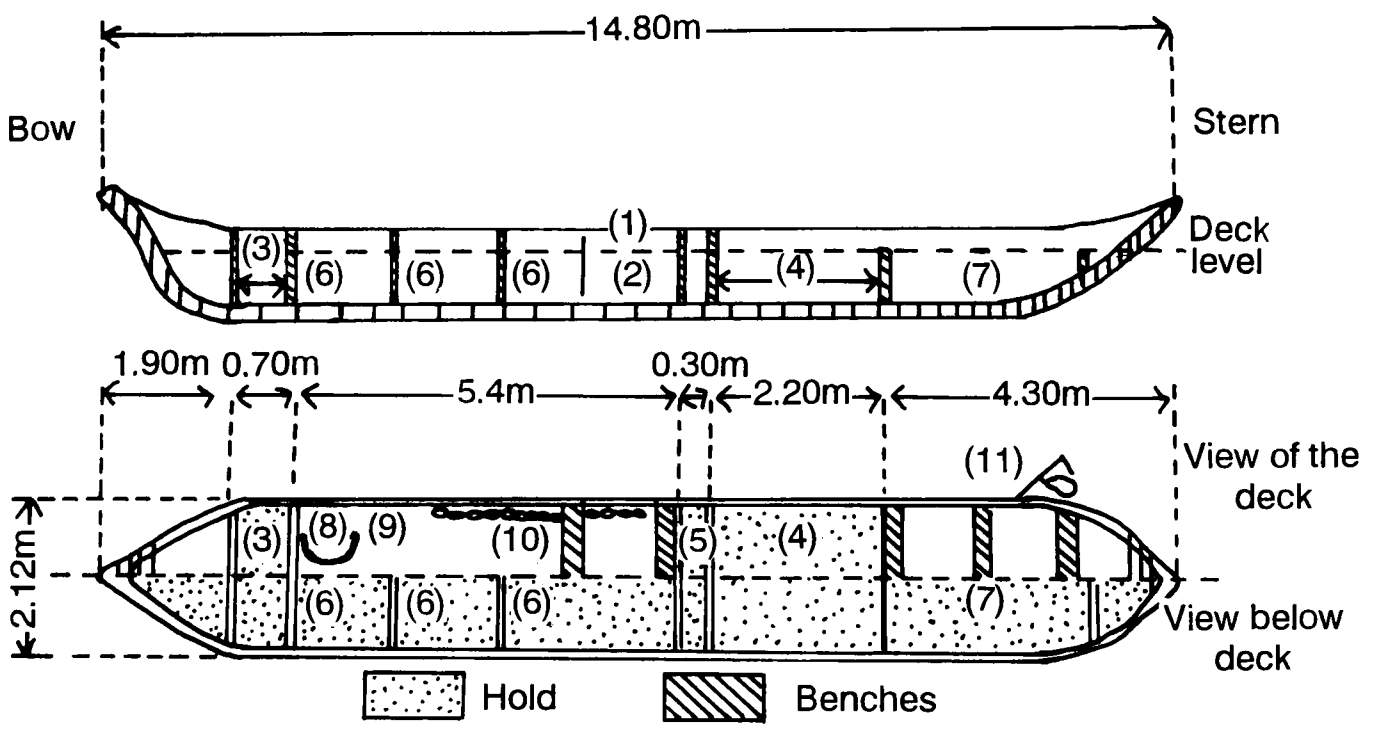


Fig. 4. Driftnet (a) and pirogue (b) for swordfish and tuna fishery by Ghanaian fishermen in Ivory Coast and Ghana (Ecoutin and Delahaye, 1989).

Table 10

Fleets operating and catches in Ghana (1988). Coastline = 500km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	0
Artisanal	8,000		
Trawlers/seiners	230		
Trawlers	17		
Tuna seiners	27		
Tuna liners	6		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	236,000	61,000	7,900

Table 11

Fleets operating and catches in Togo (1988). Coastline = 100km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	0
Artisanal	320		
Commercial	1		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	10,000	330	1,000

Table 12

Fleets operating and catches in Benin (1986-1988). Coastline = 900km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	0
Artisanal	300		
Trawlers	6		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	4,200	3,600	700

Togo (Table 11)

Togo fisheries (Fig. 5) are not large due to the narrow continental shelf. The artisanal fishery is concentrated around the main town, Lome. About 80% of the fishermen are Ghanaian. The pirogues use two types of nets (Weigel, 1984):

(1) *awli* nets that resemble a ring-net without rope and are 400–1,000m long by 30–50m deep, with 25mm mesh; and
(2) gillnets or *tonga*, made with 2–5 panels of about 3m in length with mesh sizes varying from 25mm at the top to 100mm at the bottom.

Benin (Table 12)

Fishermen from Benin fish in several other neighbouring countries. The fishery in Benin itself is limited to lagoons because the continental shelf is too narrow for the development of artisanal activities. The gear types used are the same as in other countries: lines, palangres, seines and gillnets. A small fishery for *Sardinella* with driftnets (mesh 40mm), similar to those described for Nigeria below, was reported by Prado and Smith (1990).

Nigeria (Table 13)

Given that Nigeria is the largest and most heavily populated (over 100,000,000) country in West Africa, its marine fisheries are not well developed. The artisanal fishery operates principally in the estuaries and lagoons. Of

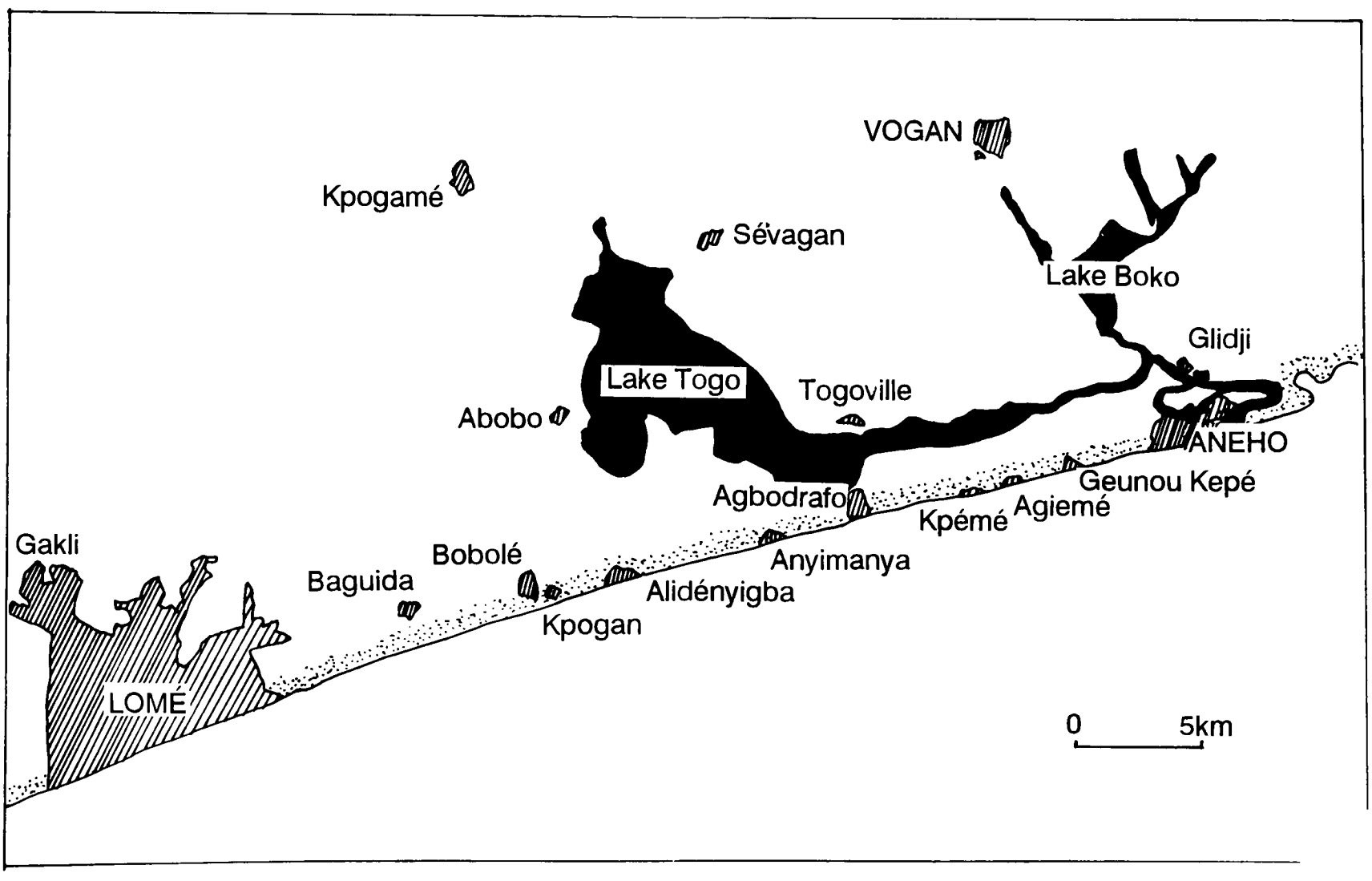


Fig. 5. Coast of Togo and artisanal fishery centres (Weigel, 1984).

Table 13

Fleets operating and catches in Nigeria (estimated 1988). Coastline = 900km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	A few
Artisanal	110,000		
Trawlers	70		
Shrimp trawlers	40		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	48,300	135,000	700

the 110,000 pirogues, only 20,000 are fitted with outboard engines. A mixed driftnet/surrounding-net fishery exists along the coast of Nigeria (P.E.K. Udolisa, pers. comm.). The pirogues are 7–11m and use monofilament nets 45–75m long, 10–17m deep and with mesh sizes of 50–63mm. The target species are small pelagic fish (*Sardinella* and *Ethmalosa*) for the domestic market. Little is known of the activities of this fleet which is widely spread along the coast. Although some cetaceans are incidentally caught, the number is not known.

Fishing occurs in the area where both the hump-backed dolphin and the manatee live and both are probably caught in the nets. Manatee meat is highly prized and manatees might be hunted in the mangrove channels to be sold on the market as in several other West African countries (cf. Senegal).

Cameroon (Table 14)

Typically for this part of the Gulf of Guinea, Cameroon's continental shelf fishery is small and the productivity of the waters is limited. The artisanal fishery exploits the richer estuaries and lagoons. Fishing is a domestic activity and the catches are unloaded at more than 120 centres along the coast, particularly around the capital Douala.

Table 14

Fleets operating and catches in the Cameroons (1988). Coastline = 360km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	0
Artisanal	2,000		
Trawlers	15		
Shrimp trawlers	16		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	1,800	700	10,400

Equatorial Guinea (Table 15)

The artisanal fishery uses principally lines, palangres (on the rocks of the continental shelf) and also some setnets and beach-seines on the shore. No additional information is available.

Sao Tome and Principe (Table 16)

Five fishery centres employ 3,000 fishermen, but only 1,000 of these work full time. In addition to the three main ports (Sao Tome, Principe and Neves) there are many small

Table 15

Fleets operating and catches in Equatorial Guinea (1988). Coastline = 200km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	700	Trawlers	10
Liners	Some	Tuna seiners	48
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	1,800	700	10,400

Table 16

Fleets operating in Sao Tome and Principe Islands (1988).

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	1,500 [1]	Tuna seiners	48/50
Liners	6		
Trawlers	2		
Traps	1		

[1] Only 300 with engines.

centres which are used for unloading the fish. The artisanal fishery uses gillnets and sweepnets to catch small pelagic fish, and lines and palangres for bottom fish. Tuna is caught with driftnets. The fisheries are potentially dangerous for cetaceans, but it is not known if any are incidentally caught.

Gabon (Table 17)

The artisanal fishery comprises only foreign fishermen (from Ghana, Nigeria and Benin) and operates in estuaries and lagoons. There is a small driftnet fishery on the continental shelf taking bottom species and small pelagic fishes (mesh size 60mm) and as in Nigeria (Prado and Smith, 1990) it is developing rapidly. The industrial fishery exploits bottom fishes with lines and palangres, and shrimps with trawls. There is no information on fishery/marine mammal interactions.

Table 17

Fleets operating and catches in Gabon (1988). Coastline = 800km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	700/800	Trawlers	3
Trawlers	9	Tuna seiners	No agreements
Shrimp trawlers	18		
Liners	7		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	3,000	7,200	13,800

Congo (Table 18)

The artisanal fishery comprises 200 pirogues (Fig. 6) and some 16 unloading centres. Lines and gillnets are both used. There is no maritime tradition in the Congo and the fishermen principally come from Benin.

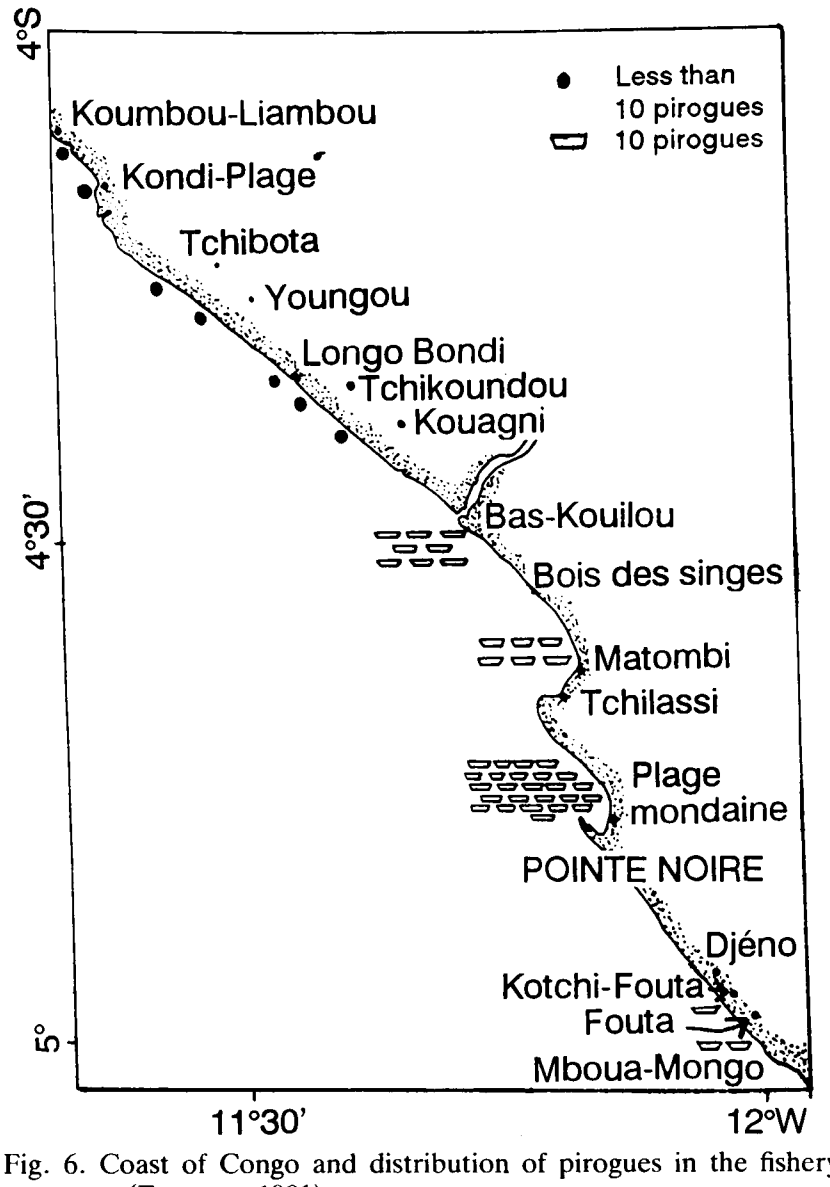


Fig. 6. Coast of Congo and distribution of pirogues in the fishery centres (Fontana, 1981).

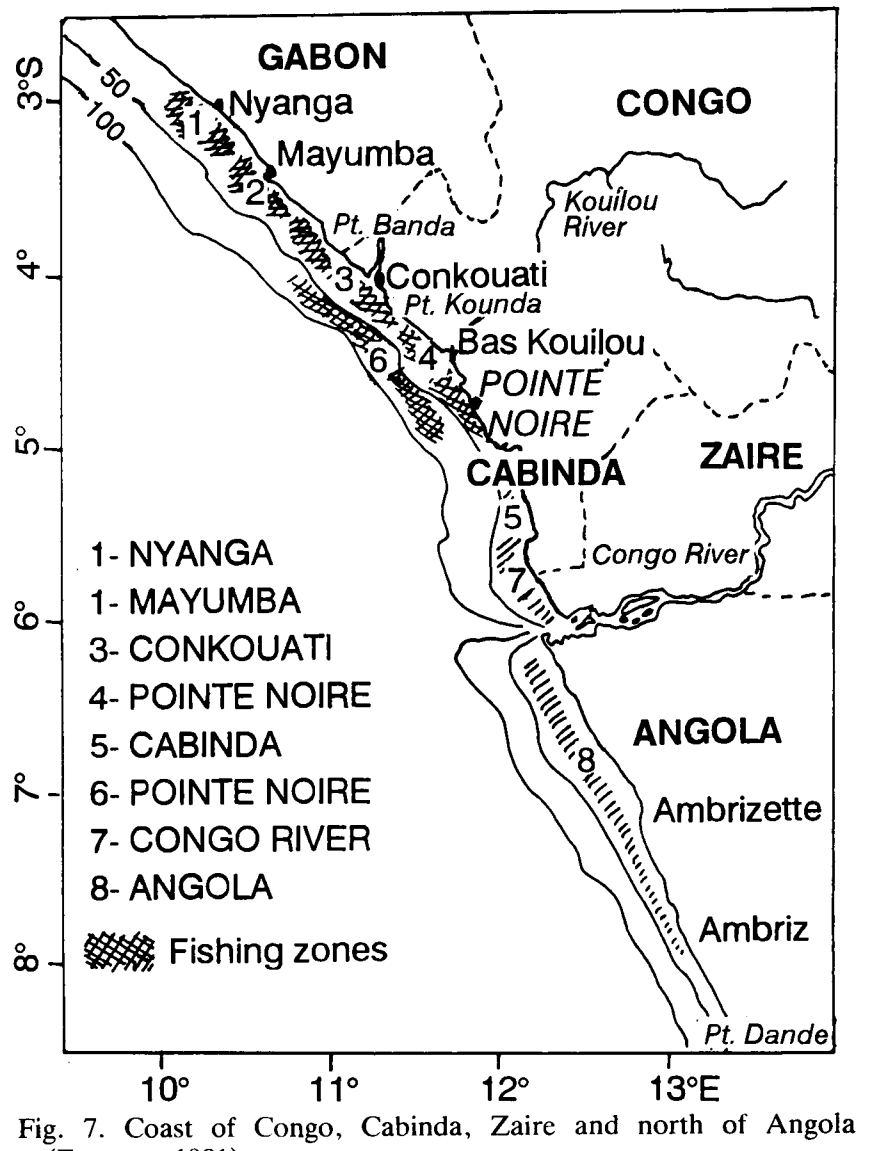


Fig. 7. Coast of Congo, Cabinda, Zaire and north of Angola (Fontana, 1981).

Table 18

Fleets operating and catches in the Congo (1988). Coastline = 180km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	150/200	Shrimp trawlers	-
Seiners	5	Tuna seiners	-
Trawlers	13		
Tuna seiners	3		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	8,500	5,200	300

Table 19

Fleets operating and catches in Angola (estimated 1988). The fleet of East European countries is not included in this Table. Coastline = 1,600km.

Vessel type	No.	Vessel type	No.
National		*Foreign*	
Artisanal	Unknown	Shrimp trawlers	37
Seiners	120	Tuna seiners	23
Trawlers	33		
Tuna liners	43		
Nets	12		
Liners	7		
Catches:	Pelagic fish	Demersal fish	Tuna
Tonnes:	565,000	65,000	7,000

Cabinda and Zaire

I was unable to obtain information on fisheries in either of these countries.

Angola (Table 19)

Angola (Fig. 7) is in a similar situation to Mauritania, with high fish production and a strong foreign fleet, particularly from east European countries (USSR, Poland and Romania). There is little information on these fisheries but the problems for marine mammals are probably similar to those for Mauritania.

I have no information on artisanal fisheries but, as there is no maritime tradition, fishing activity is probably slight.

CONCLUSIONS

There is no traditional fishery for marine mammals in West Africa. Incidental catches appear to be rare in local fisheries. Catching cetaceans will often result in the loss or destruction of the net and a heavy financial loss for the fishermen, who are often poor. Some coastal populations have a high regard for marine mammals and in some cases their religious belief prohibits their capture (e.g. the Imraguen of Mauritania).

Similar fishing techniques are used throughout the region and are often employed by the same people (Oualofs of Senegal, Beninois and Ghanaians) who migrate temporarily or permanently to other coastal areas bringing their techniques and fishing gear. Pirogues, lines and palangres, sweepnets and setnets probably have no effect on marine mammals. Seines and gillnets may result in entanglement of cetaceans but such catches are rare; the former are used to catch small pelagic fish such as *Sardinella* and *Ethmalosa*. The mesh sizes (between 30 and

100mm) can entangle dolphins but the fishing technique used allows them to swim out of the net before the net is closed. Cetacean catches are so destructive to the nets that the fishermen prefer to catch nothing at all.

Dolphins are occasionally entangled in set nets used to catch bottom fish while anchored in rocks and channels (e.g. South Moroccan lobster fishery). The panels are made up of several pieces of net, none longer than 100m. With the introduction of nylon monofilament nets in the 1980s there has been an increase in the catches of marine mammals in such nets. I was unable to determine the extent to which this kind of net is used. They are more difficult to maintain and repair and under the conditions of African fisheries they do not last long. Their use should be monitored and discouraged given their more harmful effect on marine mammals.

It seems that only the new tuna fishery in Morocco and the driftnet swordfish fishery by Ghanaians are likely to catch large numbers of cetaceans. Although I did not obtain information on the use of driftnets in other countries, they are probably employed elsewhere.

I obtained little information on direct hunting for manatees and there is little information on its status. Where information does exist (e.g. Senegal), manatees appear to be rapidly decreasing.

It appears from this survey that the artisanal fisheries of West Africa are in general not sophisticated or intense enough to have a large direct effect on marine mammals. However, foreign industrial fisheries are more likely to be able to deplete cetacean populations (e.g. mid-water trawlers from eastern Europe and the tuna-clippers from east Asia). Monitoring of such fleets is necessary but their mode of operation makes this difficult.

RECOMMENDATIONS

Fundamental research (distribution, ecology and status) on marine mammal populations along the West African coast is required, particularly on endemic and possibly endangered species such as the Atlantic hump-backed dolphin, the manatee and the monk seal.

Although it is necessary to determine the structure of the fisheries along the African coast, in the long term, such studies are only useful if the countries and their fishermen understand why they should protect marine mammals, despite the apparent increasing demand for food for their populations. Consequently, a training programme for scientists should be implemented in order to facilitate the formation of a local network to study the problem of incidental catches in this area.

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Passive Gear Fisheries of the Southwestern Indian and Southeastern Atlantic Oceans: An Assessment of their Possible Impact on Cetaceans

V.G. Cockcroft and R. Krohn[1]

Centre for Dolphin Studies, Port Elizabeth Museum, P.O. Box 13147, Humewood 6013, South Africa

ABSTRACT

The majority of coastal states in the southwestern Indian and southeastern Atlantic oceans are under-developed, with poor infrastructure and limited harbour facilities. Consequently, there are few data on the extent and distribution of passive gear fisheries in this area. Nevertheless, there is evidence of substantial use of drift or set gillnets in some areas, which may result in the depletion of local stocks of coastal cetaceans. Because most passive gear fisheries are artisanal and probably for subsistence, they are difficult to monitor and regulate. High seas fisheries in the southern African region of the Atlantic and Indian Oceans have traditionally used either trawls, long lines or purse-seines. The incidental entrapment of cetaceans during these operations is unknown, but seems minimal. However, there is a growing driftnet fishery in both the Indian and Atlantic Oceans and the few data available suggest that there is probably an extensive cetacean bycatch. Recommendations for the monitoring and regulation of both artisanal and industrial passive gear fisheries of this region are presented, with particular recognition of the developmental status of the nations in this area.

KEYWORDS: INCIDENTAL CAPTURE; SOUTH ATLANTIC; INDIAN OCEAN; BOTTLENOSE DOLPHIN; COMMON DOLPHIN; HUMP-BACKED DOLPHIN; SPOTTED DOLPHIN; SPINNER DOLPHIN; KILLER WHALE; RISSO'S DOLPHIN; HUMPBACK WHALE; MINKE WHALE; BEAKED WHALE; PINNIPEDS; FISHERIES

INTRODUCTION

The islands of the southern Atlantic are British territory and consist of St. Helena and its dependencies. All are either sparsely or unpopulated, with little development and few harbour facilities. Although the islands of the southern Indian Ocean are well populated, their infrastructure and harbour facilities are generally poor and, in many instances, primitive. Similarly, after decades of political instability and war, the infrastructure and harbour facilities of Mozambique are basic. Almost 90% of all domestic fish catches in this region are made by fleets from Namibia and South Africa, the tonnage landed by the latter country accounting for almost 70% of all catches.

South Africa, with the most robust economy in the region, has a fishing industry more than double the tonnage of that of all the other countries and territories combined. The South African harbour and industrial infrastructure is the most modern in the area and a significant amount of trans-shipping of catches from both the southern Indian and Atlantic Oceans occurs.

Consequent to the economic development status of most of these states, little is known of the extent of passive fishing gear use within either their exclusive economic zones (EEZ), or the oceanic waters surrounding them. In general, domestic harvesting of the major fish resources has used trawls, purse-seines, small-scale gillnets and baited lines, with foreign fleets participating in many of these activities, particularly the harvesting of pelagic tuna resources through long lines and purse-seines. Interaction between these latter fisheries and marine mammals has not been recorded, because of difficulties in accurate monitoring.

There is evidence that Japanese, Taiwanese and Korean driftnetting vessels, some probably displaced from the Pacific Ocean, are relocating to the southern areas of the Indian and Atlantic Oceans. Many of the vessels which hitherto used long lines may now also use driftnets to supplement catches. This expansion in the use of driftnets is likely to increase fisheries/marine mammal interactions.

Unfortunately, the occurrence and distribution of cetaceans in this area are also little known, although Northridge (1984) has provided a comprehensive list of those that may be present in the southern areas of the western Indian and eastern Atlantic Oceans. A number of papers review the available information on cetaceans found in the International Whaling Commission's Indian Ocean Sanctuary (Chantrapornsyl *et al.*, 1991; Kasuya and Wada, 1991; Kruse *et al.*, 1991; Leatherwood *et al.*, 1991).

Coastal passive net fisheries in this area are described on a regional basis. Subsequently, the expanding pelagic driftnet fishery in the southern portions of the western Indian and eastern Atlantic Oceans is examined. The area covered by this report includes the southeastern Atlantic Ocean eastwards of 0° and the southwestern Indian Ocean westwards of 80°, between the equator and 45° south (Fig. 1). Since this report was completed, large-scale pelagic driftnet fishing has been prohibited by UN Resolution 46/215 (e.g. Nagao, 1994).

LITERATURE REVIEW

A review of the possible interactions of marine mammals and fisheries on a regional basis is furnished by Northridge (1984). An overview of the geographic, political and economic structure of all states, including domestic fish tonnages landed, is provided by Europa Yearbook (Anonymous, 1990a). More specific and detailed summaries of the fisheries of each of the Indian Ocean nations within this region, except South Africa, are given in Sanders *et al.* (1988). Information on the domestic fisheries of South Africa and Namibia were obtained from the relevant fisheries departments and individuals involved within the industry. Details of the number, type and gear of vessels fishing in the southern Atlantic and Indian Oceans were garnered from various FAO Fisheries Reports and

[1] *Zoology Department, University of Cape Town, P. Bag Rondebosch 7700, South Africa*

data kept by the Port Captain in Cape Town. Incidental information from organisations such as the Dolphin Action and Protection Society, concerned scientists and press cuttings provided alternative details of the likely expansion of driftnetting activities in this area.

SYNOPSIS BY COUNTRY

South Africa (Fig. 2)

The total recorded marine fish catch by South African registered vessels in 1989 was in excess of 700,000 tonnes. Almost all of the fishing within South Africa's EEZ uses active fishing gear. Nevertheless, there are several small artisanal fisheries using set gillnets, for which little or no information is available. Also, nets set off the southern half of Natal, to catch and deplete the population of sharks and reduce shark and bather interaction, are a special case and are discussed as a fishery. The characteristics of this latter fishery and its incidental take of dolphins has been reviewed by Cockcroft (1990) and Cockcroft and Ross (1991).

South Africa has comprehensive legal protection for cetaceans and the harassment, killing or capture of these animals is expressly prohibited.

(A) Natal anti-shark net fishery

LOCATION OF PORTS

The nets are shore based and cover the southern half of the Natal coast, centred on Durban (Cockcroft, 1990).

TARGET SPECIES

Sharks are the target species.

AREA OF OPERATION

The affected area in the southern half of Natal stretches from Mzamba to Richards Bay (Cockcroft, 1990).

VESSELS AND CREW

Surf launched small boats with outboard motors are used to check and clear the nets.

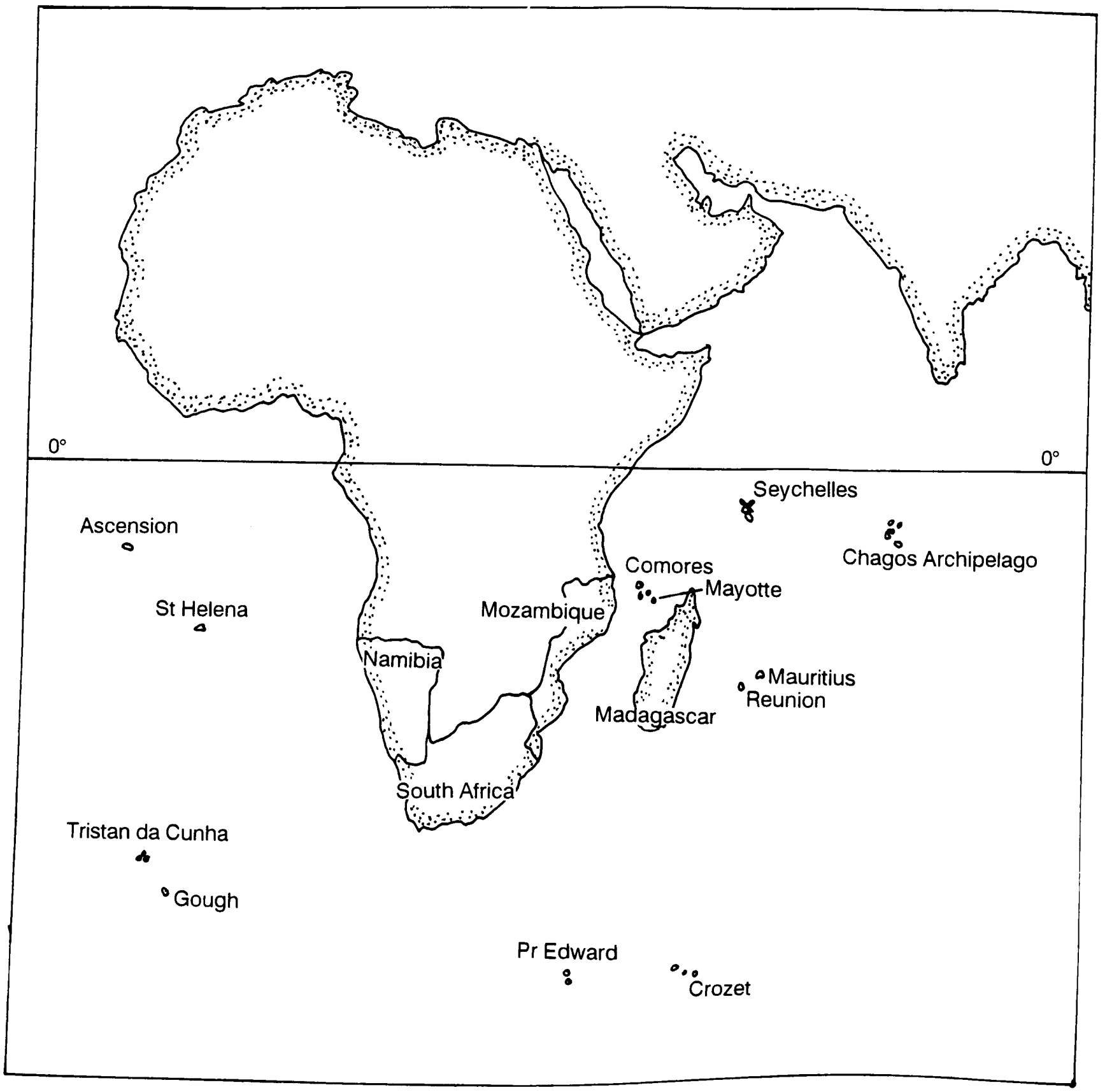

Fig. 1. States and islands of the southwestern Indian and southeastern Atlantic oceans.

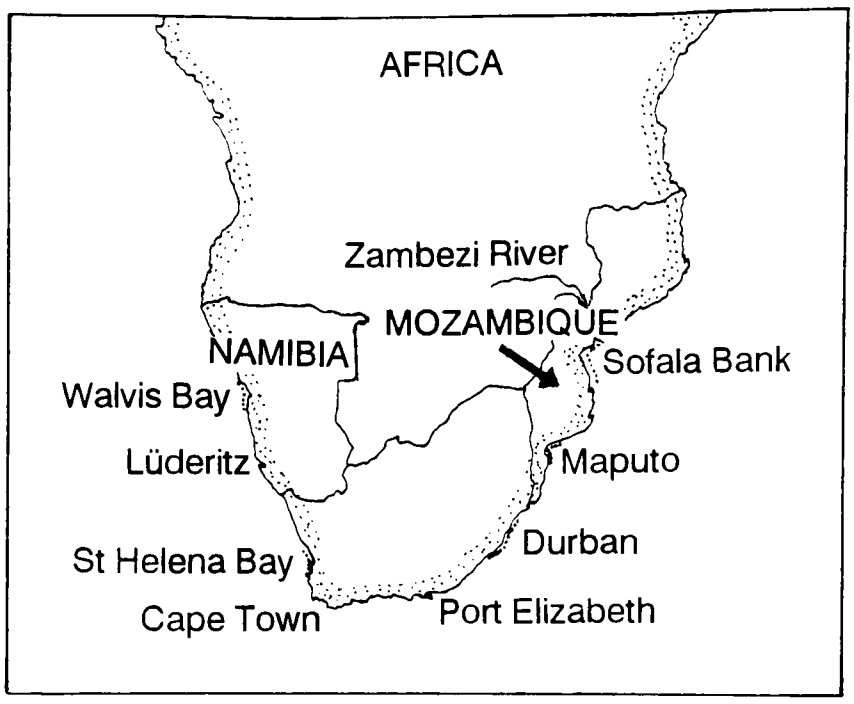

Fig. 2. The three southern African coastal states (cf. Fig. 1), their major ports and principal areas of passive gear fishing (....).

GEAR

Braided nylon (3.5mm diameter) multifilament nets, with a 25cm mesh size are used. Single nets are 110m in length by 10m in depth, with elliptical floats every 3m. Nets are set in a constant, fixed position and all operations are carried out by hand. If multiple nets are set, they are set discontinuously, in a staggered fashion, some 500m offshore. The number of nets set at any beach is dependant upon the extent of its use by bathers. A total of 416 nets (46km) are set at irregular intervals along 270km of coastline (Cockcroft, 1990).

OPERATIONS

Other than during periods of storm seas, nets are always in place and are hung from the surface, in water less than 20m in depth. Nets are examined daily, excluding weekends or during bad weather (an average of 18 days per month). Any catch is returned to shore bases for freezing.

ECONOMICS AND HISTORY

Nets were first set off Durban in 1952, subsequent to a number of horrendous and well publicised shark attacks on local and tourist bathers. Following several shark attacks at other beaches along the coast, with disastrous consequences for the tourist industry, other cities and towns followed Durban's successful lead in setting gillnets, the number of nets set reaching its present extent by 1981. Currently, the tourist industry along the Natal coast is worth several tens of millions of dollars annually and relies on the apparent safety provided by shark nets. Other than this, the fishery has little commercial value and all catches are used primarily for research purposes. In view of the apparent effect of these nets on the inshore ecology of this region, it is unlikely that any expansion will be contemplated and it is possible that the number of nets in certain areas may be reduced.

TOTAL LANDINGS

An average of about 1,400 sharks, some 90 tonnes, of various species are captured annually (Cliff *et al.*, 1988). Incidental captures include batoids, teleost fish and marine mammals. The latter includes an average of 31 bottlenose (*Tursiops truncatus*), 34 common (*Delphinus delphis*) and eight hump-backed dolphins (*Sousa chinensis*) annually (Cockcroft, 1990).

EFFORT DATA

In general, most nets are set for 360 days per year.

INTERACTIONS WITH CETACEANS

Although the capture or harassment of cetaceans in South African waters is illegal, this fishery is run by a state funded organisation and the incidental take of cetaceans in these nets is therefore permitted. The catch of small cetaceans in these nets between 1980 and 1988 is reviewed by Cockcroft (1990). Less than 1% of small cetaceans captured are released alive. In addition, minke and southern right whales (*Balaenoptera acutorostrata* and *Eubalaena glacialis*) are captured on occasion, although most escape.

PINNIPED BYCATCHES

No incidental catches of pinnipeds occur.

DISCUSSION

The effects and consequences of this fishery on the inshore ecology of Natal are controversial and are subject to ongoing research. The continued mortality of inshore bottlenose and hump-backed dolphins in these nets is of concern and the majority of evidence suggests that the Natal stocks of these two species may be unable to sustain this depletion (Cockcroft, 1990).

(B) St. Helena mullet and elephant fish fishery

LOCATION OF PORTS

This is an artisanal fishery on the South African west coast, primarily in St. Helena Bay and Lamberts Bay.

TARGET SPECIES

Although mullet (*Mugilidae*) and elephant fish (*Callorhinchus capensis*) are the main target species, the entire catch is apparently utilised.

AREA OF OPERATION

The fishery is localised to St. Helena Bay and Lamberts Bay.

VESSELS AND CREW

Because this fishery is shore based and mostly at a subsistence level, only small, 1–2 person vessels are used.

GEAR

Although the specifications of the nets used are highly variable, the primary type is nylon monofilament with a 5–10cm mesh.

OPERATIONS

Fishing occurs in shallow water, close to shore. Nets for mullet are set at the surface, while those for elephant fish are set on the bottom.

ECONOMICS AND HISTORY

There is little historical information on this fishery and it appears to be mainly at a subsistence level. Consequently, no rapid expansion is envisaged.

TOTAL LANDINGS AND EFFORT DATA

There is no system of data collection for this fishery.

INTERACTIONS WITH CETACEANS

Only two catches, both of dusky dolphins (*Lagenorhynchus obscurus*), are known from this fishery (P. Best, pers. comm., 6 June 1990). All fishermen require licences to set these nets, which may not be left unattended.

PINNIPED BYCATCHES

There is no information on pinniped interaction with this fishery, although given the large numbers of Cape fur seals resident on the west coast, a considerable interaction seems highly likely.

DISCUSSION

This is a small artisanal fishery and although all cetacean bycatches are supposedly reported to local officials, this is not well monitored and records are unreliable. Despite this, it is unlikely that this fishery poses any serious problem to local cetacean populations, although better recording of catch and bycatch would be beneficial.

There are other small, artisanal set net fisheries off the South African coast for which no information is available.

A new development (March 1991) is the industrial exploitation of inshore reef resources between Port Elizabeth and Durban. Nets, 300m in length and with a mesh between 15 and 30cm, are set in shallow water above inshore reefs to exploit resident fish stocks. Timely action by the South African authorities resulted in the prosecution of the Master of the *Captain George* (registered in Panama) and has probably excluded this fishing method from further use in the South African EEZ. However, it is possible that this or other fleets may use or attempt to use this method to exploit reef resources within the EEZs of other southwestern Indian Ocean states.

The impact of 'ghost nets' (portions of netting lost from vessels trawling within the EEZ) on cetacean populations in this area is unknown, but given the number of vessels in the trawl fleet, there is a possibility of some interaction.

Namibia (Fig. 2)

Although Namibia has potentially one of the richest fisheries in the world, the Namibian-registered fleet landed only 17% (>200,000 tonnes) of the estimated total catch within its EEZ in 1986. As far as is known, almost all of the fish resource exploitation within the EEZ involves the use of active gear, either by locally registered, South African or foreign vessels. Despite sporadic reports of stranded dolphins displaying apparent net marks (Rice, F.H. and Saayman, 1984), little is known of Namibian passive gear fisheries which may impact on cetaceans. Best and Abernathy (1994) provide some details of the incidental capture of Heaviside's dolphin (*Cephalorhynchus heavisidii*) in a set net fishery for inshore line fish near Walvis Bay. Although this fishery has apparently been terminated, rumours suggest that it may be either still in operation or about to be reintroduced. In either instance, any incidental catch of Heaviside's dolphin is of concern. Other inshore cetaceans which may entangle in these nets include bottlenose dolphins and southern right whales.

Apparently, a set net fishery for mullet was recently initiated off the southern Namibian coast. Although no data are available for this fishery, it is likely that some cetacean bycatch occurs, as it does for other set net mullet fisheries in South African waters.

As for South Africa, the incidence of gear loss from trawlers, resulting in 'ghostnetting', and the impact on cetaceans is unknown.

Mozambique (Fig. 2)

Recorded Mozambique fisheries catch landings for 1986 totalled 79,212 tonnes. As with South Africa and Namibia, most known passive gear fisheries off Mozambique are artisanal and most are probably only at subsistence level (Silva and Sousa, 1988). Mozambique does not have a system of statistical data collection for all its fisheries, particularly artisanal fisheries for which few data are available. However, a number of fisheries use passive gear which may impact on cetaceans.

(A) Mozambique shallow water shrimp fishery

LOCATION OF PORTS

The fishery is shore based throughout the coastal waters of Mozambique, particularly in shallow bays and estuaries. The main centres are the Sofala Bank at the mouth of the Zambezi River and Maputo Bay.

TARGET SPECIES

The target species is the shrimp *Panaeus* sp.

VESSELS AND CREW

Various types of small boat are used in this fishery. The number and specification of the boats used along most of the coast are unknown. In 1986, 196 boats were operating in Maputo Bay.

GEAR

The standard way of fishing for shrimp is the use of small hand drawn bottom trawls or beach seines. However, fine mesh 'mosquito' nets are also used and are normally drawn through the water, but may be left to drift and entangle the shrimp. The proportion of boats using 'mosquito' net and the drift method is unknown.

OPERATIONS

Operations are normally carried out in waters less than 10m in depth.

FISHERY DETAILS

There is no information on the economics and history of the fishery. Annual catches are probably over 5,000 tonnes. No effort data are available.

INTERACTIONS WITH CETACEANS

There are no reported interactions with cetaceans.

DISCUSSION

The likelihood of the incidental catch of cetaceans is small, given the small mesh of this gear. However, in view of the extensive fisheries elsewhere on the Mozambique coast, any additional incidental catches may be significant. Although little is known of the occurrence and distribution of cetaceans in Mozambique, this shallow water fishery is likely only to affect bottlenose (*Tursiops truncatus*), hump-backed (*Sousa chinensis*) and perhaps spotted (*Stenella attenuata*) dolphins.

(B) Maputo Bay kelee shad fishery

GENERAL

This fishery operates out of Maputo and targets kelee shad (*Hilsa kelee*) in Maputo Bay (682km^2).

VESSELS AND CREW

The exact type and construction of vessels used in this fishery are unknown. However,[2] four motorised boats (6.5–8.5m in length) and 434 sailing boats (3 – 7m long), some of which have auxiliary motors, are used throughout the bay. The catch is stored on ice, probably in the open on the smaller sailing boats and within holds on the motorised boats.

GEAR

The net material is nylon monofilament. Both the industrial and artisanal fleets use nets of 5cm mesh, of variable length up to 200m and 5m deep. Between three and five panels are carried per vessel and these are deployed and retrieved by hand.

OPERATIONS

Vessels apparently deploy and retrieve nets daily (early morning and late evening, respectively), although this is presumably restricted by bad weather. Between three and five nets are set, at the surface, to drift in water less than 20m deep, but mostly less than 10m in depth.

ECONOMICS AND HISTORY

The catch is sold fresh and dried to the domestic (Maputo) market. Because of the lack of data collection, the history of this fishery is unknown, although some data are available from 1972. The stock appears over-exploited, although the number of artisanal boats fishing per year seems to be increasing. Fisheries biologists recommend an increase in mesh size (Silva and Sousa, 1988). Total landings and effort for the years 1984–6 are given in Table 1.

Table 1

Landings and effort for the Maputo Bay kelee shad fishery.

	Semi-industrial fishery		Artisanal fishery	
Year	Catch (t)	Effort (boats)	Catch (t)	Effort (boats)
1984	407	21	2,600	303
1985	128	6	3,730	434
1986	43	2	3,015	449

INTERACTIONS WITH MARINE

Bycatches are not monitored or reported and there is no known bycatch of marine mammals. It is illegal to catch or kill marine mammals in Mozambique waters.

DISCUSSION

Bottlenose and hump-backed dolphins inhabit Maputo Bay (VGC, pers. obs.), as they do other coastal areas of Mozambique (P. Dutton, pers. comm., 8 November 1990). Presently, however, both species appear only to occur on the seaward edge of the Bay, where fishing operations are absent or much reduced. These observations and the fact that both species are known to prey on kelee shad further south in Natal waters (Cockcroft and Ross, 1990), imply that some interaction with this fishery is probable. With the deployment of some 300km of driftnets daily in an area of almost 700km^2, it seems highly likely that captures of these two species occur and that there is or has been a substantial impact on local stocks.

[2] Semi-industrial fishery.

Dugongs were also once apparently commonly sighted in the outer reaches of the Bay, particularly in the Saco da Inhaca (Bay of Inhaca Island), where there are extensive tidally exposed mud flats and sea grass beds and small outcrops of coral reef. For several years, however, there have been no sightings of these animals. The mud flats and sea grass beds are extensively fished with short (30m), small-mesh (8cm) gillnets, which are anchored either to mangrove trees or stakes and left to drift with the tides. Although the capture of dugongs is illegal, fishermen like the taste and are known to eat any dugongs incidentally captured. There is some evidence that this has resulted in a directed fishery for dugongs in Maputo Bay (R. de Paula E Silva, pers. comm., 29 March 1991).

Other cetacean species which may interact with this fishery, especially just outside Maputo Bay, include humpback whales (*Megaptera novaeangliae*) during the austral spring and summer and spinner (*Stenella longirostris*) and common dolphins, both of which occur close inshore (VGC, pers. obs.). In view of the extensive use of gillnets in and around Maputo Bay and the mortality of bottlenose and hump-backed dolphins in shark nets off Natal (400km south), monitoring of the catch and bycatch in Maputo Bay and environs is imperative. An increase in the mesh size used in this fishery should be discouraged, as this would almost certainly increase marine mammal mortality.

There is little information on other passive gear fisheries in Mozambique waters. The recent establishment of a fish canning factory in Maputo (R. de Paula E Silva, pers. comm., 29 March 1991) suggests that fisheries within the area are set for expansion. A set gillnet fishery for sharks, in which some dolphin and dugong catches were made, operated north of Maputo until the mid 1980s. Although this fishery has apparently ceased (R. van der Elst, pers. comm., 29 March 1990), an industrial fishery for sharks was recently established within Maputo Bay and environs, but there is no information on marine mammal interactions with this operation (R. de Paula E Silva, pers. comm., 29 March 1991). There is a shark net fishery in the region of Vilankulos (central Mozambique), with sporadic reports of dugong catches in these nets (P. Dutton, pers. comm., 8 November 1990). In view of the scale of these and other coastal fisheries operations in the waters of Mozambique, some form of assessment and monitoring of cetacean bycatches is imperative.

Madagascar (Fig. 3)

Although there is great potential for the development of marine fisheries within Madagascar's EEZ, estimated existing total catches are relatively small, less than 20,000 tonnes in 1986. Of this total, artisanal fisheries contribute some 13,000 tonnes, most, possibly, on a subsistence basis. Fishery statistics are poor and little is known of fishing extent, distribution or target species. Consequently, there are no data for specific artisanal fisheries.

In 1981 it was estimated that some 10,651 full and part-time fishermen, using about 7,000 dugout canoes, were engaged in the artisanal fishery along the entire 4,500km of coast out to the 100m isobath (117,000 km^2) (Ralison, 1988). The most common gear of these fishermen is either hand line or gillnet, the latter suggesting that cetacean incidental capture is highly likely.

Although no accurate data are available, there are reports of incidental entanglements. Entanglement of bottlenose and hump-backed dolphins, and dugongs is reported for Antongil Bay, near Maroantsetra and

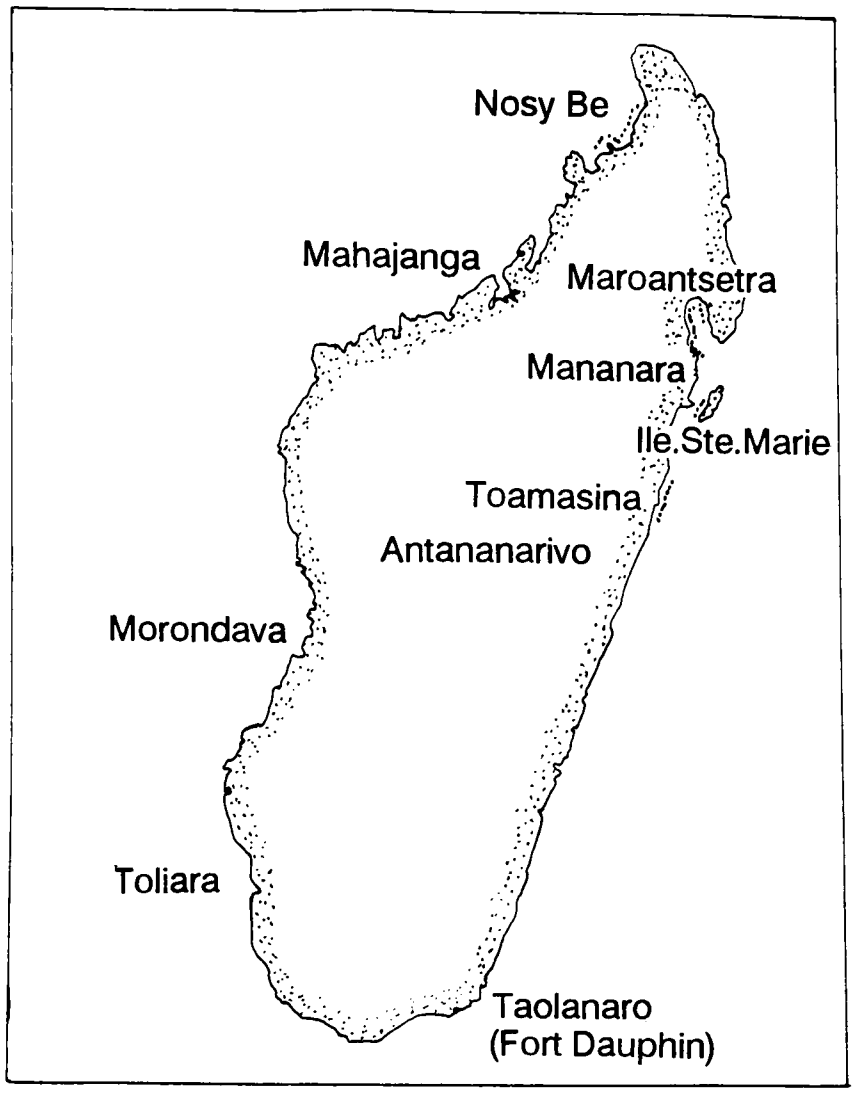

Fig. 3. Madagascar, off the southeast coast of southern Africa, its major coastal cities and towns and known principal areas of passive gear fishing (....).

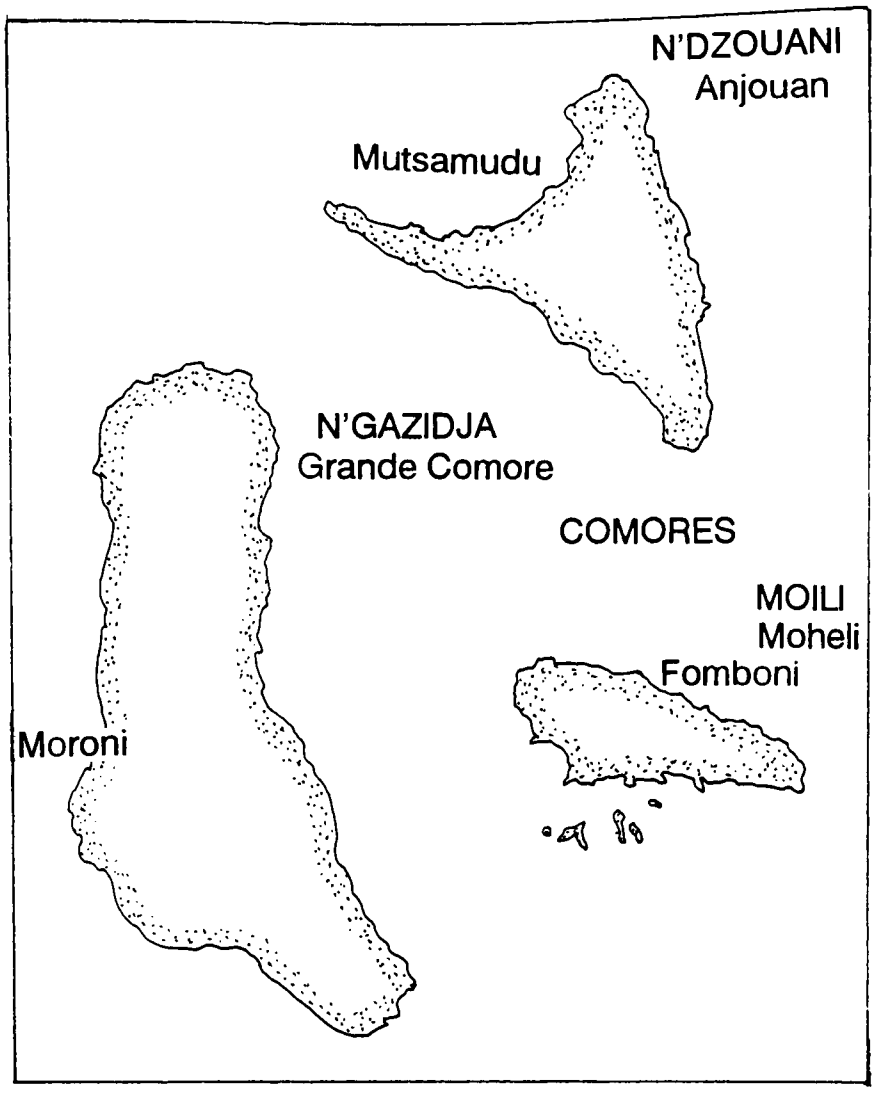

Fig. 4. The Comores Islands situated in the Indian Ocean between Africa (Mozambique) and Madagascar.

Mananara, at the south end of Ile. Ste. Marie and near Nosey Be (P. Folkens, pers. comm., 5 May 1990). Humpback whales in shallow bays during the austral spring may also be at risk in these nets. For the past five years, killer whales (*Orcinus orca*) have been netted in the nearshore waters north of Toamasina (P. Folkens, pers. comm., 5 May 1990). Some monitoring of and data for these fisheries is required, especially in view of the possible capture of bottlenose and hump-backed dolphins, which are probably subject to capture throughout this region.

The recent signing of a general fisheries agreement between Japan and Madagascar indicates that fishing effort, possibly in the nearshore zone, may be substantially increased in the near future. Although it is unknown what form this may take, in view of the impact of coastal gillnetting on marine mammals in other areas, this development should be closely monitored.

Comores Islands (Fig. 4)

There has been no collection of systematic statistical fisheries data in the Comores and documentation of fisheries and catches is non-existent. Estimated total catch for 1986 was 5,300 tonnes, the major portion of which was in artisanal fisheries. Fishing occurs around all three of the major islands, principally using 'Pirogues', which are either 4m in length with two outriggers (1,500 boats based mainly on Grande Comore), or 7m in length with one outrigger (1,200 boats based at Anjouan and a further 300 at Moheli) (William James, 1988). Although hand lines are the primary gear, gillnets are also used. These include, 15 locally manufactured gillnets (100m x 1.5m, mesh size 14cm and probably monofilament) and 100 nets, provided through Japanese aid, which are probably of similar size to the locally made nets. All three major islands have relatively narrow shallow water areas (<100m in depth; Moheli = 721km^2, Anjouan = 64km^2 and Grande Comore = 300km^2) suggesting that most fishing occurs close inshore.

The incidence of interactions between these artisanal fisheries and cetaceans is unknown, although the use of gillnets, whether set or drift, suggests that some cetacean mortality is likely, particularly for coastal species. Any increased aid involving gillnets would exacerbate this interaction. However, the neritic fish resources of the Comores appear to be at maximum exploitation levels (William James, 1988) and any expansion of artisanal fishing effort within existing fishing grounds seems unlikely.

Mauritius and Chagos Archipelago (Fig. 5)

With foreign aid to set up harbours and fish canning factories the fish catch in Mauritian waters almost doubled from an estimated 7,000 tonnes in 1981 to 13,000 tonnes in 1986. Of this total, artisanal fisheries account for some 28%, while industrial (oceanic tuna) and semi-industrial fisheries (hand lines for reef species on the Malha Bank and the bank surrounding the Chagos Archipelago) constitute the remainder (Samboo and Mauree, 1988). Statistics are only kept for the Mauritius Island fishery, although some information for the two other islands is available.

(A) Mauritian shallow water artisanal fishery

LOCATION OF PORTS

This fishery is shore based and does not require port facilities.

TARGET SPECIES

Various species are targeted by this fishery; these include Serranidae, Siganidae, Lethrinidae, Scaridae, Mullidae, percoids and octopus.

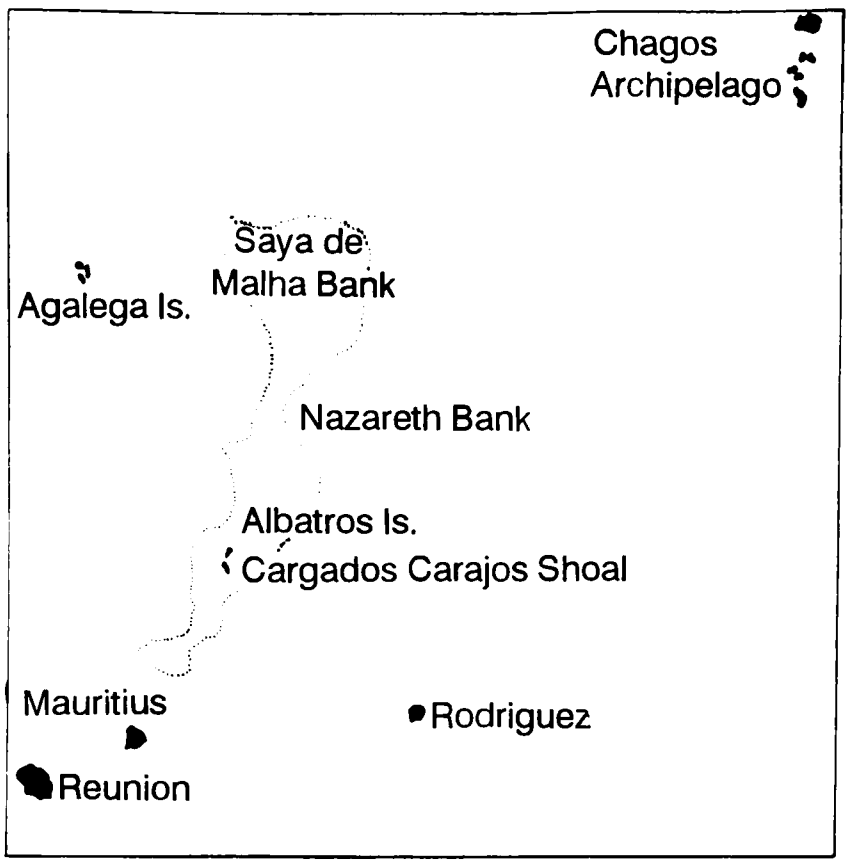

Fig. 5. The major islands of Mauritius and the Chagos Archipelago (shaded) in the southwestern Indian Ocean.

AREA OF OPERATION
The areas fished are primarily the lagoon areas of all three main islands, Mauritius, Rodrigues and Agalega, and the off-lagoon areas of the former two islands (Mauritius Island lagoon = 376 km^2; Mauritius Island off-lagoon = 832 km^2; Rodrigues Island = 1688 km^2 ; Agalega Island = 15 km^2; all areas to 100m depth).

VESSELS AND CREW
The specifications of the fishing craft used are unknown but all are between 7 and 10m in length. One thousand and nineteen (1,019) boats are based on Mauritius Island, with a further 215 on Rodrigues Island. The catch is apparently either landed and sold fresh or is dried before sale.

GEAR
Various gears are used, including seines and gillnets. A total of 201 fishermen use gillnets of unknown specification (69 in Mauritius Island lagoon and 132 off Rodrigues) and all gillnets are deployed primarily within lagoons.

OPERATIONS
Fishing is probably carried out on a daily basis, weather permitting, and in shallow water, because most is within lagoons.

ECONOMICS AND HISTORY
This type of fishing activity possibly began with the first settlements of the three main islands (c. mid 19th Century) as a food supply, fresh or dried fish, for domestic consumption. The total catches of the artisanal fishery are believed to be at or near maximum sustainable yield (MSY) levels and, consequently, no further expansion is envisaged.

TOTAL LANDINGS
The artisanal fishery is believed to catch about 3,500 tonnes annually. Some 65,000 part-time (subsistence) fishermen are also believed to fish the lagoons using hand lines and each is believed to take an average of 0.5kg of fish per day (almost 12,000 tonnes annually). About 15kg of fish per set are landed.

INTERACTION WITH CETACEANS
There is little information on any interaction with cetaceans, with only one known instance of incidental capture (sei whale – P. La Hausse de Lelouviere, pers. comm. 10 May 1991). However, with the regular use of gillnets by about 200 fishermen, it seems likely that more incidental cetacean mortality occurs. Species of at least two of the fish families targeted are known prey of bottlenose dolphins off Natal. Recently Corbett (1994) reported on a survey to assess the occurrence of cetaceans off the west coast of Mauritius. The most common species encountered were sperm whales (*Physeter macrocephalus*) and spinner dolphins. Other species seen included spotted, bottlenose and Risso's dolphins, two unidentified beaked whales (one probably *Mesoplodon layardii*) short-finned pilot whales (*Globicephalus macrorhynchus*) and humpback whales during the austral summer. Several of these species may be at risk of capture. Depletion of fish resources by part-time fisherman could also have an impact on local cetaceans. Mauritian law specifically protects marine mammals, but in common with all countries of the region, the authorities have little ability to enforce or implement these regulations.

PINNIPED BYCATCHES
Unknown, but unlikely.

DISCUSSION
With so little information on the fisheries or marine mammals of this area it seems prudent to attempt to promote, through the relevant authorities, a monitoring programme on the use of gillnets and any incidental bycatch.

Seychelles (Fig. 6)
Apart from the industrial tuna fishery in Seychelloise waters, some 4,630 tonnes of fish were taken by between 1,100 and 1,200 artisanal fishermen in 1986. Most artisanal fishing effort is centred on the three main islands of Mahé, Praslin and La Digue, although the Seychelles consists of a total of about 100 islands (Lablache *et al.*, 1988).

(A) Artisanal net fisheries (encircling gillnet and bottom shark gillnet fisheries)

LOCATION OF PORTS
This fishery is shore based and does not require port facilities.

TARGET SPECIES
For the encircling gillnet fishery, the main target species are Indian mackerel (*Rastrelliger kanagurta*) and big eye scad (*Selar crumenophthalmus*), while the bottom set shark gillnet fishery targets sharks of several species.

AREA OF OPERATION
This fishery operates in the nearshore region of the three main islands, an area of some 200km^2.

VESSELS AND CREW
Some 36 vessels, 28 motorised and 8 hand propelled, are in use by this fishery. These (Pirogues) are of unknown specification, but are probably similar to the small open boats used by Mauritian fishermen.

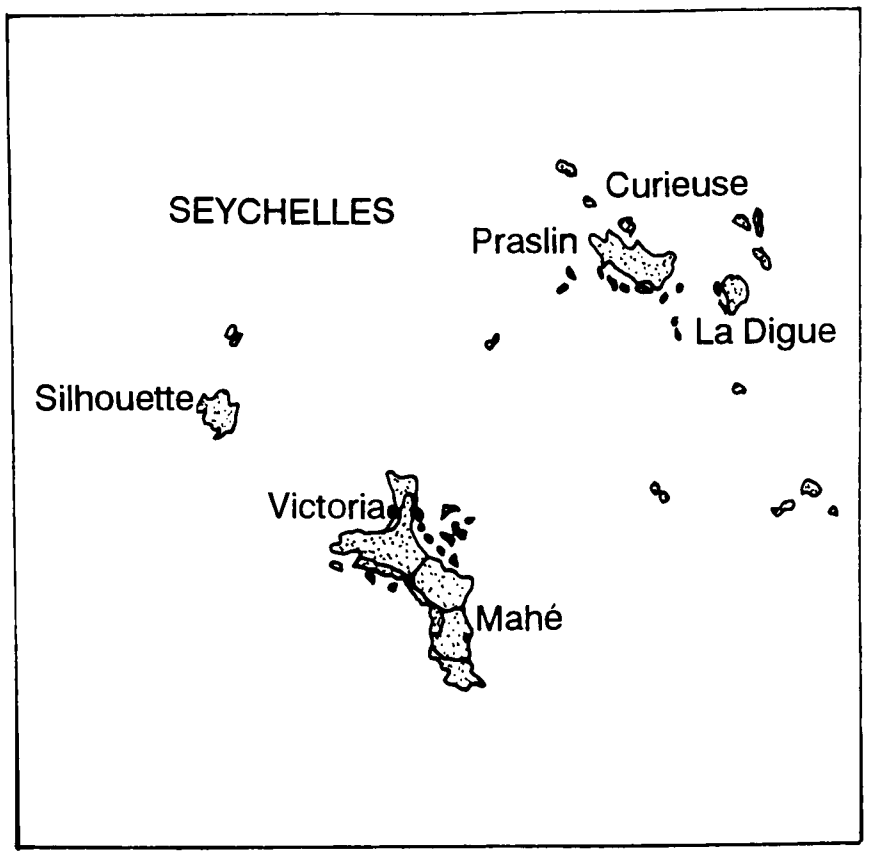

Fig. 6. The Seychelles group of islands in the south western Indian Ocean.

GEAR

Nets used in the encircling gillnet fishery are manufactured from polyester/cotton and have a mesh of about 6cm. Net panels are approximately 50m in length, but of unknown depth. Lengths of net are commonly strung together up to a maximum length of about 300m. Nets used in the bottom shark set gillnet fishery have a mesh of 15cm and range in length from 100 to 200m and a depth of between 4 and 5m.

OPERATIONS

Nothing is known of the operations of this fishery, although it is likely that it operates daily, weather permitting.

ECONOMICS AND HISTORY

The history of this fishery is unknown, but presumably it grew from local demand for either fresh or dried fish. The total landings in the fishery for 1985 and 1986 are given in Table 2.

Table 2

Catches for 1985 and 1986 for Seychelles artisanal net fisheries.

	Catch (t)			Catch (t)	
	1985	1986		1985	1986
Species			**Fishery**		
Jacks	1.9	2.4	Encircling gillnets	241	145
Mackerels	206	159	Set gillnets	31	50
Barracudas	7	5			
Trap fish	1	6	Total landings	375	272
Sharks/rays	38	27			
Others	124	71			

EFFORT DATA

In 1985 there were 4,900 sets of encircling gillnets and 600 sets of shark gillnets. The respective values for 1986 were 2,400 and 1,500.

INTERACTIONS WITH CETACEANS

There are no reported interactions between cetacean or indeed any marine mammals and the fisheries of Seychelles, including the offshore industrial tuna purse-seine and long line fisheries. Nevertheless, it is possible that some interaction occurs, probably involving the same species implicated in Mauritius. Marine mammals are comprehensively protected under Seychelles law.

DISCUSSION

Catches appear to fluctuate annually and the resource appears under-exploited (Lablache *et al.*, 1988), consequently fishing effort may have expanded since 1986, particularly that using bottom set nets, as these may be part of aid packages from industrialised nations.

Mayotte and La Reunion (Fig. I)

These two islands sustain small artisanal fisheries of which little is known. Fisheries statistics are not collected on Mayotte, but are routinely collected for La Reunion. On both islands, the most common gear used is various types of hand line, although both set and drift gillnets are used occasionally (Biais, 1988b; Biais, 1988a). No information is available on the number of these nets deployed, the number of fishermen using these nets, or any cetacean involvement. Given the fairly extensive shallow water banks in the vicinity of both islands, however, it seems probable that some cetacean and fisheries interaction takes place and is likely to increase if fishing expands.

Kerguelen

The only known fisheries within Kerguelen's EEZ are commercial bottom and mid-water trawling operations by French and Russian vessels. No cetacean bycatch has been reported for either these or other fisheries in the area (G. Duhamel, pers. comm., 1 August 1990).

St. Helena and Dependencies (Fig. 1)

With only some 6,500 people resident on St Helena and its dependencies of Ascension and Tristan da Cunha, there appears to be little or no artisanal fishery. Total fish landings for 1987 approached 335 tonnes, mostly from tuna long lines.

The industrial fisheries of the southwestern Indian and southeastern Atlantic Oceans (Figs. 1 and 7)*

There is increasing evidence of an expansion of industrial fishing effort in the southwestern Indian and southeastern Atlantic oceans. Specifically, there has been a recent significant increase in the industrial and artisanal catch of tuna in the Indian Ocean (Anonymous, 1989a). Traditionally, tuna fisheries in the western Indian Ocean (Fig. 7) have used either long line or purse-seine methods. There is conflicting evidence of tuna and dolphin association for this area and although fishing authorities throughout the region deny any cetacean interaction with tuna purse-seining, there is circumstantial evidence of incidental captures. The extent of this interaction is unknown and is not reviewed in this paper.

In 1990 there were apparently only 44 driftnet vessels (20 Japanese and 24 Taiwanese) in operation in the South Pacific, whereas the Taiwanese fleet consisted of more than

* Since completion of this report, the following developments occurred (Nagao, 1994): (1) Japan banned large-mesh driftnet fishing from 15 August 1990 in all waters outside the Pacific Ocean; (2) UN Resolution 46/215 banning such fisheries came into effect on 1 January 1993.

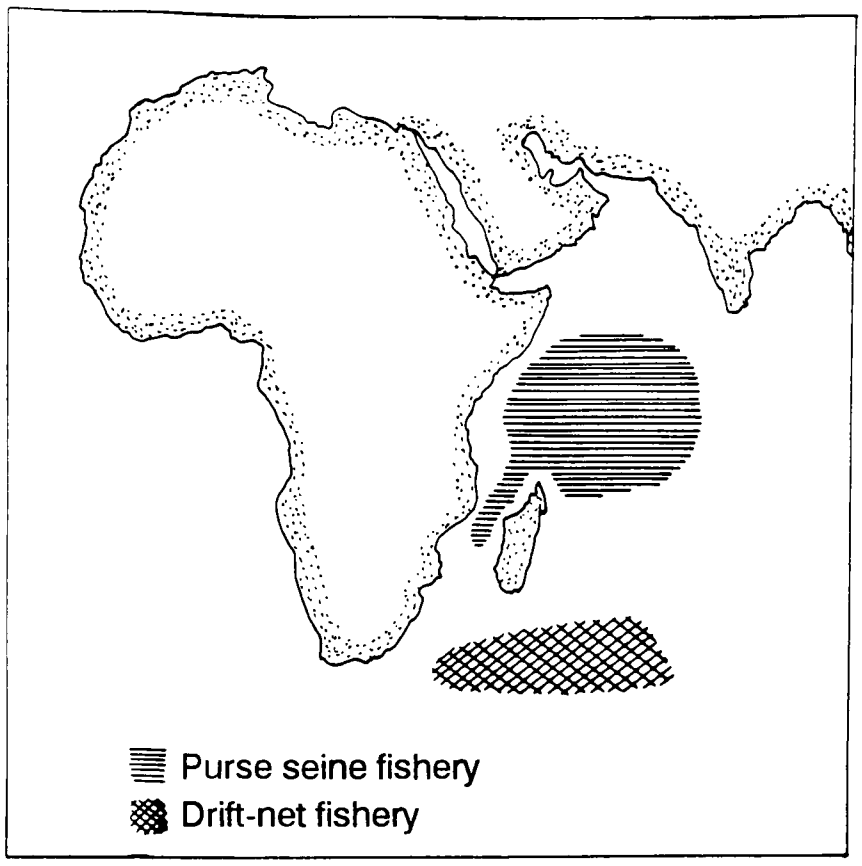

Fig. 7. The southwestern Indian Ocean. The position and extent of the tuna purse-seine and Taiwanese large-mesh driftnet fisheries are shown.

150 vessels in the recent past (Anonymous, 1990b). There is concern that many of these vessels may have relocated to the Indian Ocean (Anonymous, 1989a), with evidence also of the presence of the use of drift gillnets in the southern Atlantic Ocean. Little information is currently available for this fishery in the southwestern Indian and southeastern Atlantic oceans, although some evidence for this expansion is available.

(A) Taiwanese Indian Ocean industrial large mesh drift gillnet fishery (Fig. 7)

LOCATION OF PORTS

Kaohsiung is the major domestic port and there are a number of foreign ports used: Bangkok; Port Louis (Mauritius); Singapore; Penang and Cape Town (South Africa).

TARGET SPECIES

The target species of this fishery are the various tuna fishes. Historically albacore (*Thunnus alalunga*) tuna was the primary target, but latterly yellowfin (*T. albacares*) and bigeye (*T. abesus*) tuna are increasingly targeted. Although blue fin (*T. thynnus thynnus*) is not specifically targeted, catches of this species are retrieved and sold.

AREA OF OPERATION

The northwestern Indian Ocean and the south central to southwestern Indian Ocean (Fig. 7) are the main areas in which this fishery is concentrated.

VESSELS AND CREW

Many of the vessels used in this fishery are converted trawlers or long liners and, consequently, the specification of vessels used is highly variable. In the 1987/88 fishing season, 149 vessels were in operation. The officers are normally Taiwanese nationals, whereas the crew may consist of individuals of a number of nationalities, including South Africans. Captured tuna are stored refrigerated until trans-shipment either at a home or foreign port or at sea to a 'mothership'.

GEAR AND OPERATIONS

Nylon monofilament nets appear to be the standard gear used by these vessels. Net mesh is between 20 and 22cm, with each panel being about 45m in length and between 20 and 24m in depth. Vessels carry between 700 and 900 panels each, all of which may be joined and set during one operation (on average 37 to 47km per set). Nets are set to drift at the surface in the late afternoon (from one report). Soak time is apparently about 12hrs, with recovery beginning at about midnight. Floats are spaced at 20m intervals and the use of radio transponders at the ends of each net probably facilitates recovery. The main fishing season within the Indian Ocean is apparently five to six months, between January and May.

ECONOMICS AND HISTORY

This fishery was initiated in 1983 and the number of vessels engaged in the Indian Ocean has steadily increased since (cf. below). This indicates that the fishery may still be expanding, particularly as grounds in the southern Atlantic are explored and exploited subsequent to fishing in the Indian Ocean. Fish are sold both fresh, if landed at the home port, and canned to both foreign and domestic markets. Processing may occur at some of the foreign ports listed above (not Cape Town) although this is not known with certainty. There is one record of a vessel off-loading fish for processing in Puerto Rico.

TOTAL LANDINGS AND EFFORT DATA

Catches and available effort data are given in Table 3. The average weight of albacore netted was 9kg and that for bigeye tuna 26kg, for both 1986/87 and 1987/88.

INTERACTIONS WITH CETACEANS

Bycatches of non– marketable resources are not recorded and there is no information on the extent of any cetacean involvement with this fishery, or indeed any marine mammals.

DISCUSSION

Cetacean bycatch in this fishery is highly probable and may be considerable. A wide variety of cetacean species (38 listed for area 51 (Northridge, 1984) may occur in this area and could be captured during operations. To obtain some idea of the potential bycatch, if we assume an average vessel deployment of 42km of nets per day, for each of 149 vessels, and a cetacean catch rate of 0.54/10km of net/day [the mean of driftnet catches in the Arafura/Timor Sea, Tasman Sea, North Pacific tuna and flying squid fisheries (Anonymous, 1990b)], this could result in up to 350 cetacean captures per day, or over an assumed five month fishing season, in excess of 50,000 cetaceans for this Taiwanese fleet alone. The extent of this bycatch may be doubled by other Taiwanese vessels which appear to fish with driftnets in the Indian Ocean while in transit to the southeastern Atlantic (cf. below).

Interestingly, South African law prohibits the landing of any gillnetted fish at South African ports, even though Hsu and Liu (1990) report that only tuna caught using driftnets is off-loaded in Cape Town. This indicates that the origins of fish caught in this fishery and probably also those from the Southern Atlantic fishery, may purposely be kept concealed for fear of the problems arising from the use of driftnets.

Table 3

Catch and effort data for the Taiwanese Indian Ocean drift gillnet fishery.

Season	Effort (vessels)	Catch (tonnes)	Season	Effort (vessels)	Catch (tonnes)
1983/84	1	24	1986/87	123	18,281
1984/85	36	3,941	1987/88	130	18,486
1985/86	74	13,777	1988/89	149	

Landings (tonnes) by Port 1987/1988:
Kaohsiung = 13,162.4 tonnes (9,732.7 t. *albacore*)
Bangkok = 3,643.4 tonnes (2,829.4 t. *albacore*)
Port Louis = 37.7 tonnes (37.7 t. *albacore*)
Singapore = 461.9 tonnes (446.8 t. *albacore*)
Penang = 362.6 tonnes (357.7 t. *albacore*)
Cape Town = 817.5 tonnes (773 t. *albacore*)

No information is available for South Korean or Japanese vessels fishing in the southwestern Indian Ocean area, although it seems likely that, with the reduction of vessels in the South Pacific, substantial numbers of these vessels may operate in this area (1 South Korean and 13 Japanese vessels were due to dock in Cape Town in 1990 after transiting the Indian Ocean). The entire fleet should be encouraged to report on their fishing operations in the southwestern Indian Ocean. Monitoring of this fishery and any cetacean bycatch, similar to that recommended for the North and South Pacific fleets, is urgently needed.

Driftnet fisheries in the southeastern Atlantic

There is little documentary evidence for driftnet fishing in the southeastern Atlantic Ocean (Anonymous, 1990b), although there are increasing signs of a substantial fishery in pelagic waters and also, possibly, within the EEZ of some states. There were 4,658 'line-boat' (tuna long liners) dockings at Cape Town during 1989. Additionally, the discharges and trans-shipments of frozen tuna in Cape Town harbour have increased from an average of 87,165 fish in the years 1982 to 1986 to 131,632 fish for 1987 to 1989 (Portnet, unpublished harbour statistics). This increase (51%) has not been matched by comparative long line discharge figures issued by the International Commission for the Conservation of Atlantic Tunas (ICCAT), but was coincident with a very large increase in landings of angelfish (*Brama brama*), a known bycatch of driftnet fishing. This may roughly indicate when large scale driftnetting in the South Atlantic started.

During the 1989/90 season, South African authorities granted 167 driftnet vessels (153 Taiwanese, 13 Japanese and 1 South Korean) permission to call at South African ports *en route* to the South Atlantic. Only 14 of these vessels had permission to fish within the Falklands 150 mile Fishery Conservation Zone (FCZ) in 1989 and five in 1990. Another 123 vessels were licensed to fish within the Falklands FCZ during 1990. Some of these ships may have engaged in driftnet fishing in transit to the Falklands, implying a substantial potential fishing effort in the Southern Atlantic.

It is unclear whether the Taiwanese vessels issued South African permits were from the large mesh Indian Ocean gillnet fishery, although the dates of their call in Cape Town infer they were not. The Indian Ocean gillnet season begins in December/January, between 70° and 100°E, but moves westwards to 30°E by March/April (Hsu and Liu, 1990). In contrast, Taiwanese vessels bound for the Falklands called at Cape Town between November and January. This disparity implies that a large number of vessels, apart from the 149 driftnetters in the Taiwanese Indian Ocean fleet, may fish while in transit from Taiwan to Cape Town. After off-loading the catch and refuelling, most of this fleet proceeds to the Southern Atlantic to fish, before moving to the Falklands to jig for squid (Anonymous, 1989b). This may not be a typical pattern, however, as the movements of at least one driftnet vessel show that Ponce, Puerto Rico, was the next port of call after Cape Town (Rice, N., 1990).

Unequivocal evidence for driftnetting off Tristan da Cunha and Gough Island is provided by Ryan and Cooper (1991), who document the presence of Taiwanese vessels driftnetting within the EEZ of the islands. In an interview before an attorney, a South African crew member from a Taiwanese ship that docked in Cape Town, indicated that during approximately one month of driftnet fishing (probably off Tristan or Gough), 15 - 20 'dolphins', three to four 'small whales' and many penguins were incidentally captured. The cetaceans were discarded and the fish caught during this time were trans-shipped at sea before the fleet proceeded to the Falklands. This was one of five vessels fishing in the area.

South African authorities have found and confiscated driftnets from several Taiwanese and South Korean fishing boats. A Taiwanese vessel returning from the Falklands, the *An-Hung 1*, recently ran aground on the Southern Cape (South Africa) coast carrying 145km of gillnet, more than triple the length of net that these vessels are reported to carry. Besides carrying a full load of tuna in its holds, several rockhopper penguins and two sub-Antarctic fur seals (*Arctocephalus tropicalis*) were found, which indicate that this vessel was probably driftnetting off Tristan da Cunha (Ryan and Cooper, 1991). The gear used on these vessels is apparently different from that used by those in the Indian Ocean and consists of mesh of 30 to 40cm, 20m deep panels, with a total set of about 35km (Anonymous, 1989b). Soak time is approximately three hours, but hauling takes some five hours, so sections laid last remain in the water for considerably longer.

Fishing interests in South Africa believe that this fishery takes more than the MSY and is decimating stocks of tuna in the Southern Oceans (Anonymous, 1989b). Its impact on cetaceans is unknown and quantitative estimates of the extent and identity of bycatch are urgently required. Judging from catch rates in the Pacific, the extent of pelagic marine mammal bycatch could be substantial, probably of the order of several tens of thousands, and the spectrum of species captured may be wide (Northridge, 1984).

The fact that driftnetting takes place within the EEZ of Tristan and its dependencies, and probably South Africa, indicates that it could be used elsewhere within the EEZs of the other states in this area. This has clear implications for neritic species of cetaceans, some of which may also be subject to incidental captures in the inshore region.

GENERAL DISCUSSION

Generally, coastal set and drift gillnet fisheries in the Southern African Atlantic and Indian Ocean region are artisanal and most are at subsistence level. There are indications that stocks of some cetacean species, particularly bottlenose and hump-backed dolphins from adjoining areas such as South Africa and Mozambique, may be subject to heavy depletion pressure, raising concern for the continued survival of these stocks. Available data for bottlenose and hump-backed dolphins off Natal, South Africa, indicate that geographically separated groups are distinct (Cockcroft *et al.*, 1989), which suggests that depletion of individual groups may lead to local extinctions. If a similar depletion is occurring off Mozambique and Madagascar, the prognosis for these and other coastal species in south western Indian Ocean waters is cause for concern.

Recently, there has been an increase in aid to the developing countries of this region, especially aid involving the expansion of fishing operations and the deployment of gillnets. Consequently, it seems likely that artisanal gillnet fisheries will expand and that the probability of cetacean bycatch in coastal fisheries will increase concurrently. The majority of states in this area are undeveloped and their financial and manpower resources are limited. Therefore, any regulation or monitoring of their artisanal fisheries is difficult. Consequently, it would seem logical to encourage the donors of aid, particularly aid in the form of gillnets, to require or promote the documentation of catch and bycatch and also to provide instruction on how best to use this gear to minimise entrapment of cetaceans and other non-target species. Given that most of the states specifically protect marine mammals, the best course of action would seem to be liaison with existing regulatory bodies and the promotion of monitoring and research through these bodies.

In many of the states dealt with here, the killing of marine mammals and possession of their remains is illegal. To some degree this mitigates against the adequate monitoring of any bycatch as fishermen would rather discard and disclaim any knowledge of bycatches for fear of the law. This suggests that efforts should be made to formulate model legislation and encourage its use in all countries. This legislation should, obviously, fulfil the main requirement of protecting marine mammals, but encourage the reporting of those captured incidentally and facilitate their retention for examination.

In contrast to coastal artisanal fisheries, the probable effects of the massive pelagic driftnet fishery in the southwestern Indian and southeastern Atlantic Oceans is likely to have a significant impact on a broad spectrum of cetacean species. Although estimates of cetacean mortality in these fisheries is speculative, they indicate that tens of thousands may perish annually. Given this and in view of the fact that to wait for quantitative data may be disastrous, a number of courses of action are recommended.

High seas driftnet fisheries have a number of disadvantages. These include; the bycatch of non-commercial but possibly ecologically important species; the size non-selectivity of the gear, which may lead to overexploitation of the resource; damage to the target species, leading to a high discard proportion; death and loss of commercially important species, which are then subsequently not available. These deficiencies have clear socio-economic implications for the undeveloped coastal states of this region. States with vested interests in the ecology of their coastal and bordering pelagic seas, including investments in fisheries, should be encouraged to immediately protect their natural resources.

Communication of concern for the proper management of non-target species resources to the management bodies of regulated regional fisheries is imperative. For those regions where there are no regulatory bodies, the formation of co-operative regional organisations with management function should be encouraged. Given co-operation between adjacent coastal states and their fisheries management bodies, the regional assessment and management of non-target species is possible. In this context, the promotion of on-board observers and vessel surveillance, whatever the shortcomings of these, should be immediately recommended.

The coastal states of the southwestern Indian and southeastern Atlantic Ocean areas should be encouraged to amend their legislation in accordance with and to take advantage of the United Nations General Assembly international moratorium on the use of high seas driftnets.

Given the equivocal findings of past research on the effectiveness of size and species selectivity of gillnets and the bycatch reduction of sub-surface positioning of driftnets, further research aimed at bycatch reduction is urgently required.

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SC/O90/G22

Review of Gillnet Fisheries and Cetacean Bycatches in the Northeastern Indian Ocean

R. S. Lal Mohan

Research Centre, Central Marine Fisheries Research Institute, West Hill, Calicut 673–005, India[1]

ABSTRACT

Small cetaceans and some great whales become entangled and die in gillnets in a variety of fisheries in the northeastern Indian Ocean. Information on operational details, present status and future plans for development of fisheries was compiled from published literature, widely-distributed questionnaires the author's own research. The study concentrated on fisheries for 14 fish species or groups of species (seerfish, tunas, pomfrets, sharks, skates and rays, catfish, polynemids, oil sardines, mackerels, lesser sardines, whitebait, hilsas, riverine catfish and prawns) and cetaceans entangled and killed during their operations. In general, documentation of the extent of cetacean mortality is poor but sufficient to suggest that mortality is high in at least some fisheries (e.g. driftnet fisheries) and in some countries (e.g. Sri Lanka and India). Apparently low levels of mortality noted for Bangladesh and Burma may be due to low fishing effort. It is suspected that the primarily hook-and-line methods employed in the Maldives minimise the chance of serious levels of cetacean entanglement. Virtually all cetacean species known to inhabit the areas of operation become entangled at some time, and rates of mortality for some species in some areas appear high. This fishery-related mortality occurs at a time when national programmes are encouraging further expansion and development of fisheries to feed burgeoning human populations. Recommendations are made to increase programmes of cetacean research, public awareness and monitoring of cetacean mortality and its impact on cetacean populations.

KEYWORDS: INCIDENTAL CAPTURE; INDIAN OCEAN; SPINNER DOLPHINS; HUMP-BACKED DOLPHINS; BOTTLENOSE DOLPHINS; FINLESS PORPOISE; COMMON DOLPHINS; STRIPED DOLPHINS; RISSO'S DOLPHINS; SPOTTED DOLPHINS; FRASER'S DOLPHINS; SPINNER DOLPHINS; ROUGH-TOOTHED DOLPHINS; PYGMY KILLER WHALES; PYGMY SPERM WHALE; DWARF SPERM WHALE; GANGES RIVER DOLPHINS; IRRAWADDY DOLPHINS

INTRODUCTION AND METHODS

The aim of this study was to obtain information on gillnet fisheries in the northeastern Indian Ocean that take marine mammals incidental to their operations and, when possible, to assess the magnitude and impact of that take. The approach was twofold: (1) relevant published literature was reviewed; (2) a questionnaire was distributed to scientists and resource managers within the five countries bordering the northeastern Indian Ocean (Fig. 1) and to specialists outside the region who were known or believed to have information on gillnet fisheries within this region that affect marine mammals.

India, Bangladesh, Burma, Sri Lanka and the Maldives have a combined coastline of 11,000km and it is not surprising that fishing is dominant in the economy of the region. However, the coasts of these countries are substantially different from one another and therefore support different combinations of marine, estuarine and even riverine fisheries. The traditional fishing vessels and methods which have developed within each region, and the current economic conditions as they affect use of more modern fishing equipment and techniques, also differ. Although fishing is important in all the studied countries, the levels of information available on the fisheries in general, and the involvement of cetaceans in fisheries in particular, vary within and among countries. There is good information, for example, from India and Sri Lanka, but virtually no information for Burma. This report is thus preliminary and is intended to stimulate further research in this region.

[1] Present address: *Conservation of Nature Trust, B/24, Gandhinager, Calicut 673005, Kerala, India*

REVIEW OF LITERATURE ON THE FISHERIES

Scientific investigations into gillnetting were initiated early in this century when Nayudu (1920) and Hornell (1924; 1938) began studies on the vessels and gear of the Malabar coast of India and such studies have continued (e.g. Chopra, 1951; Nagaraja Rao, 1958; Jhingran, 1985; Bal and Virabhadra, 1984). Recent Indian studies include Gulbrandsen's (1984) review of the fishing vessels of Kerala and Kalavathy and Tietze's (1984) investigation of artisanal vessels and fishing gear of Orissa. Considerable attention has also focussed on small-scale fisheries (e.g. Roy, 1981; Silas *et al.*, 1980; Williams, 1981; BOBP, 1985). Balachandran (1983) and Leatherwood and Reeves (1989) studied the fishing vessels and gear of Sri Lanka. Fishing gear used in Bangladesh was investigated by Ali and Haq (1980), Bergstrom (1982), Pajot and Das (1981, 1984), Kashem (1985) and BOBP (1985). Preliminary investigations on the fisheries of Burma were made by Drushinin (1970), Naumov (1971), Pauly (1984) and Sivasubramanian (1985).

Sten (1978) examined the fisheries of the Maldives and found the pole-and-line method to predominate there. About 95% of the tuna landed are taken by motorised *thonies* using this technique (Jonklass, 1962). As cetacean entanglement is not thought to be a problem in this area it is not considered further in this report.

A detailed comprehensive study of the development and structural and operational details of vessels and gillnets of northeastern Indian Ocean countries is still needed to determine the impact of, and to predict the future for, gillnet fisheries. The Bay of Bengal Project (BOBP) and the efforts of the Central Marine Fisheries Research Institute (CMFRI) in India have helped in this assessment. Details of the vessels and fishing gear of India are given in Table 1.

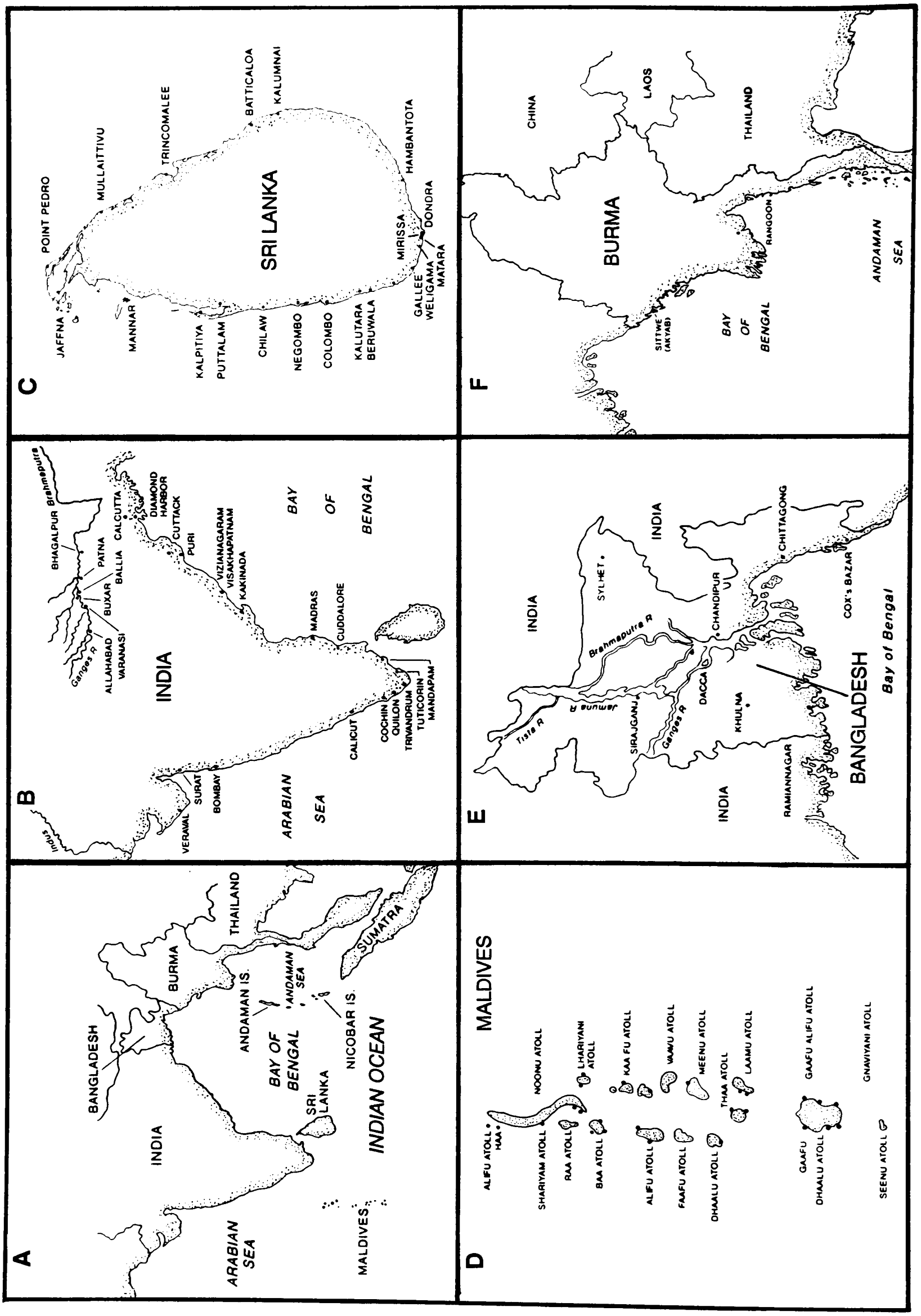

Fig. 1. The northeastern Indian Ocean (A) with some of the important fish-landing and/or trading centers in the countries treated: India (B), Sri Lanka (C), the Maldives (D), Bangladesh (E), and Burma (F).

Large-scale pelagic driftnet fisheries and their impacts on the living marine resources of the oceans were addressed recently by the Indian Ocean Fisheries Commission (IOFC, 1990) and in December 1989, the United Nations passed a resolution recommending a moratorium on all large-scale pelagic driftnet fishing by June 1992. This review however deals primarily with national fisheries, i.e., within the Exclusive Economic Zones (EEZs) of the countries named. It builds on a FAO-sponsored review by Northridge (1984) on the interactions of cetaceans with gillnet fisheries worldwide.

SYNOPSES OF THE FISHERIES

To simplify presentation, countries have been abbreviated as follows: India (**I**), Sri Lanka (**SL**), Bangladesh (**Ba**) and Burma (**Bu**). The first such appearance, after the name(s) of the target species, indicates the presence of a fishery for the target species in that country. If a fishery exists but there is no entry under a given subheading, that signifies that no information was available to the author. All landings are given in metric tonnes.

Seerfish

References
I: CMFRI (1992–1993); Yohannan and Balasubramanian (1989); Silas *et al.* (1984). **Ba**: Bergstrom (1982); Mohiuddin *et al.* (1980). **Bu**: Sivasubramanian (1985); Anon. (1982). **SL**: Leatherwood and Reeves (1989); Fernando (1980); BOBP (1984); Alling (1985); IWC (1986); Kasim and Hansa (1989).

Primary ports
I: multiple but unlisted. **Ba**: Khulna, Sylhet, Cox's Bazar and Chittagong.

Target species
I: *Scomberomorus commersoni* and *S. guttatus*. **Ba**: *S. commersoni* and *S. guttatus*; (**Bu**) Indian round scads and *Dendrophysa russelli*. **SL**: *S. commersoni* and *S. guttatus*.

Vessels
I: northwest coast – dugout canoes (*satpati* and *machuva*); southwest coast – dugouts (*thonies, vanchi* and *odum*) and plank boats (*kettuvallam*); east coast – *catamaram*, Tuticorin-type boats, fibreglass outboard and *pablo* (8–10m) inboard. **Ba**: *dinghi, chhandi, balam* and motorised traditional vessels. **Bu**: motorised and non-motorised vessels. **SL**: *theppam, catamaram, oru, thonies, vallam* and motorised vessels.

Nets
I: drift- and gillnet (setnet) – 500–1,000m length multifilament synthetic twine (0.5–0.9mm), 25–200mm mesh size, 8–10m depth. **Ba**: drift- and gillnet – 10–17cm mesh multifilament nylon twine (5–8mm), 500-1,500m length. **Bu**: gillnet. **SL**: drift- and gillnet – 10–15cm mesh multifilament twine (0.5–0.8mm), 100–600m length, 8–10m depth.

Operations
I: 10–30m depth; 45–60min set time; 4–6hr soak time. **Ba**: 5–60m depth; 9–13+ or 5–9 day trips. **SL**: 1–6 day trips, 15–16 miles from shore, 5–40m depth, 4–5hr soak time.

Total landings
I: 1,200–8,900t (1956–1960); 18,897–29,547t (1975–1979); 33,611–35,820t (1982-1985); 29,841–42,894 (1990–1992). **Bu**: 430,800t (1982). **SL**: 174,462t (1981).

Table 1

Number and type of marine fishing craft and gear in India by state in 1980 (from CMFRI, 1981).

	West Bengal	Orissa	Andhra Pradesh	Tamil Nadu	Pondi, Karai Maheo,Yenam	Kerala	Karna-taka	Goa Daman	Gujarat	Total	%
I. Fishing crafts											
A. *Mechanised*											
Trawlers	-	-	447	2,295	176	745	808	407	1,410	6,288	67
Gillnetters	247	106	9	324	-	215	23	213	1,225	2,362	25
Dol netters	-	-	-	-	-	-	-	-	241	241	2
Purse seiners	-	-	-	-	-	9	173	39	-	221	2
Others	63	-	-	8	-	14	74	-	18	177	1
Totals	310	106	456	2,627	176	983	1,078	659	2,894	9,289	100
B. *Non-mechanised*											
Plank-built	3,972	3,262	11,359	8,957	83	4,376	1,747	1,108	3,040	37,904	29
Dugout canoes	89	186	1,781	2,210	72	10,415	4,454	1,397	1,080	21,684	16
Catamaram	-	6,276	22,198	31,851	1,595	11,480	23	8	-	73,431	54
Others	-	4	675	325	-	-	718	-	-	1,722	1
Total	4,061	9,728	36,013	43,343	1,750	26,271	6,942	2,513	4,120	134,741	100
II. Fishing gear											
Trawl nets	-	-	823	6,219	437	1,454	1,788	772	2,672	14,165	2
Purse seines	-	-	-	-	-	9	188	41	-	238	0
Drift/gillnets	2,467	10,427	42,385	118,300	1,851	23,307	6,571	3,346	7,383	216,037	36
Boat seines	-	2,676	9,738	7,220	375	9,779	23	165	-	29,976	5
Fixed bag net	6,200	2,778	14,617	1,842	152	-	941	430	21,857	48,817	8
Hook and line	869	15,265	10,752	22,111	720	2,949	1,507	127	2,376	56,676	9
Rampans	-	-	-	-	-	-	86	101	-	187	0
Shore seines	436	2,893	3,042	4,549	84	2,926	3,924	987	-	18,841	3
Traps	61	515	130	8,919	9	2,239	-	-	86,952	98,825	16
Scoop nets	345	37	2,925	1,040	362	1,371	-	-	-	6,080	1
Others	2,433	5,201	37,199	6,339	120	2,761	10,925	2,813	28,013	95,804	16

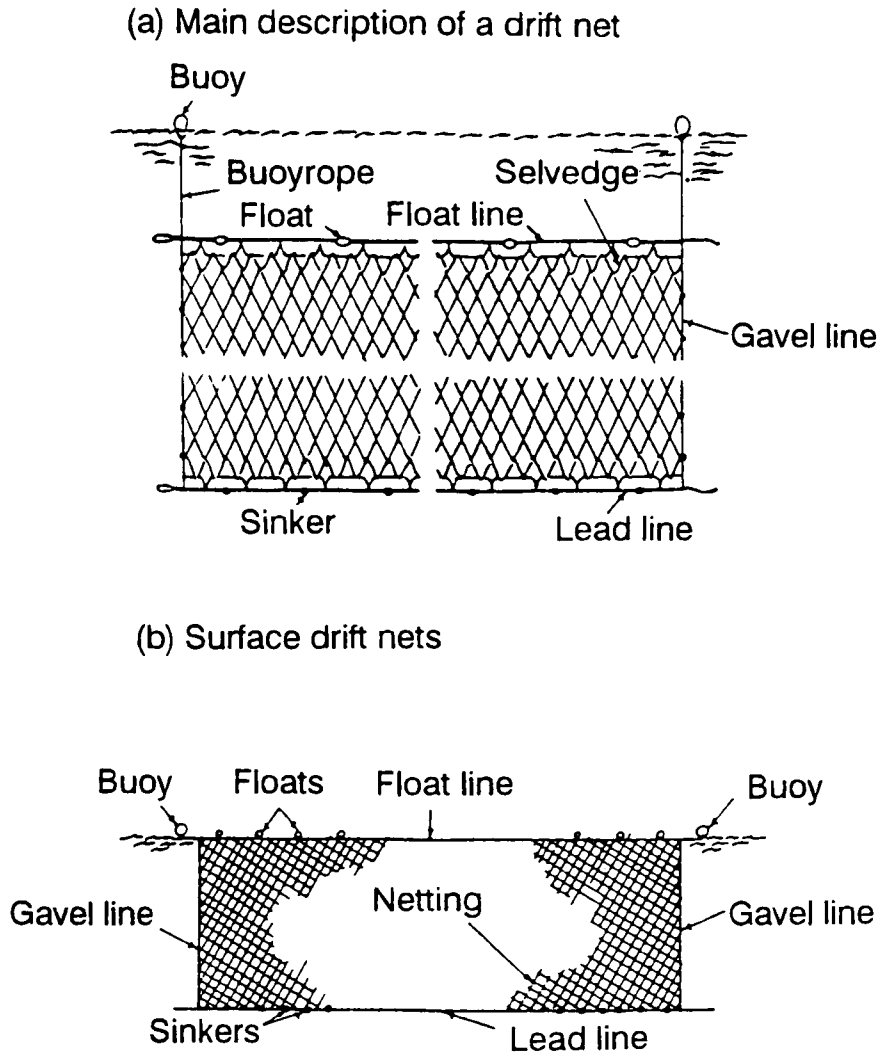

Fig. 2. Configurations and deployments of driftnets (a-c) used in portions of the northeastern Indian Ocean. (Modified from Nedleck and Prado.)

Cetacean bycatch
I: spinner dolphins (*Stenella longirostris*); Indo-Pacific hump-backed dolphins (*Sousa chinensis*); bottlenose dolphins (*Tursiops truncatus*); finless porpoises (*Neophocaena phocaenoides*); common dolphins (*Delphinus delphis*). **SL**: (in this and a variety of other fisheries) bottlenose dolphins, spinner dolphins (45% at Tricomalee in 1984–86), striped dolphins (*Stenella coeruleoalba*, 8%), Risso's dolphins (*Grampus griseus*, 15%), spotted dolphins (*Stenella attenuata*, 17%) and ten other species (totalling 15%).

Tuna

References
I: CMFRI (1989; 1993). **SL**: BOBP (1984); Joseph and Amarasiri (1988); Leatherwood and Reeves (1989).

Primary ports
I: Veraval, Mangalore, Calicut, Cochin, Vizhijam, Tuticorin. SL: Colombo, Galle, Trincomalee, Beruwala, Tangalle, Mirissa, Myliddy, Jaffnaa.

Target species
I: *Katsuwonus pelamis, Thunnus albacares, Auxis rochi, A. thazard, Euthynnus affinis, Kishoniella tonggol, Thunnus alalunga, T. orientalis.* **SL**: *T. albacares, Kishoniella tonggol, Katsuwonus pelamis, Auxus thazard, Euthynnus affinis.*

Vessels
I: northwest coast – *machwa, galbat*; Maharastra coast – *rampani, chemboke, thanga, vallam, patta, vala, thonies, pagar*; southwest coast – dugout canoes, *kettuvallam*; east coast – *catamaram*, Tuticorin-type boat, *masula*; Orissa and Coramandal coasts – bar boat, *padava, padagu*, fibreglass outboard, *pablo* inboard; **SL**: *vallam, catamaram*, fibreglass outboard, fibreglass inboard.

Nets
I: driftnet – 105–140mm mesh multifilament synthetic twine (0.2–1.0mm). **SL**: drift– and gillnet – 100–180mm mesh multifilament synthetic twine (0.5–1.0mm), 7–10m depth.

Operations
I: 15–18hr trip length, 15–30m depth, 5–6hr soak time. **SL**: 15–18hr or 2–3 day trip length, 15–35m depth, 5–6hr soak time.

Total landings
I: 3,201t (*Katsuwonus pelamis* 1985); 3,076t (*Auxis rochi, Auxus thazard* 1985); 16,625t (*Euthynnus affinis* 1985); 1,087t (*Kishoniella tonggol* 1985); 31,725–52,060t (all species, 1990–1993). *SL: 29,374t (1982).*

Cetacean bycatch
I: common dolphins; bottlenose dolphins; spinner dolphins. **SL**: (see **seerfish** above).

Pomfrets

References
I: Srinath *et al.* (1987). **Ba**: FAO (1980; 1981; 1982).

Primary ports
I: Veraval, Surat, Bombay, Mangalore, Calicut, Cochin, Vizhinjam, Puri. Ba: Khulna, Cox's Bazar, Chittagong. **SL**: Sylhatt, Chandipur, Mohipur, Nayahata, Bhagykal, Bheramara, Sirajgang, Bahadurpur, Tista.

Target species
I: *Pampus argenteus, P. chinensis, Formio niger.* **Ba**: *P. argenteus, P. chinensis.*

Vessels
I: northwest coast – *satpati, machwa*; South Kanara coast – *rampani, odam, vanchi, thonies, beputhoni,* and *pasta thoni*; southeast coast – *catamaram, masula.* **Ba**: *chhandi, balam*, Cox's Bazar type.

Nets
I: drift– and gillnet – 30–150mm mesh nylon multifilament (0.5–0.8mm). **Ba**: drift– and gillnet – 100mm mesh, 1750m length.

Operations
I: northwest coast – 3–4 day trip length; southwest coast – overnight trips, 4–5hr soak time, 20–60m depth. **Ba**: 15hr 4 day trip length, 4–5hr soak time.









Fig. 3. Some of the fishing vessels involved in gillnetting off India: (A) a motorised large dugout (*odam*) with an indigenous *chundanvallan*, used for purse seining, in the background, (B) a smaller dugout (*thoni*) of the Malabar coast, (C) a plank-built *kettuvallam* of the southwest coast, and (D) a typical fibreglass boat with two outboard motors at Calicut.

Bickham
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Total landings
I: 13,718t (1980); 23,427t (1984); 33,912–42,649t (1990–1992). **Ba**: 157,593t fish (1982–1983), 4,824t shrimp and 87,000–141,000t fish (1972–1982).

Cetacean bycatch
I: common dolphins, spinner dolphins, Indo-Pacific hump-backed dolphins, bottlenose dolphins.

Sharks

References
I: Devadoss *et al.* (1989); CMFRI (1993). **Ba**: Hussain, pers. comm. (1987). **SL**: Sivasubramanian (1985).

Primary ports
I: Veraval, Bombay, Mangalore, Calicut, Cochin, Tuticorin, Madras, Visakhapatnam. **Ba**: Khulna, Cox's Bazar, Chittagong. **SL**: Jaffna, Mannar, Kalpitiya, Puttalam, Chilaw, Negombo, Colombo, Kalutara, Beruwala, Ambalangoda, Gallee, Weligama, Matara, Mirissa, Dondra, Hambantota, Kalumanai, Batticaloa, Trincomalee, Mullaitivu, Point Pedro.

Target species
I: *Carcharhinus limbatus, C. melanopterus, Scoliodon laticaudus, Rhizoprionodon acutus, Galeocerdo cuvier.* **SL**: *C. melanopterus, C. falciformis, C. longimanus, C. limbatus, Sphyrna blochii.*

Vessels
I: same as for tuna and pomfret fisheries. **Ba**: *dinghi, chhandi, balam,* motorised non-traditional boats. **SL**: same as for tuna fishery.

Nets
I: drift– or gillnet – 70–150mm mesh or 140–185mm mesh multifilament twine (0.7–1.0mm). SL: 100–150mm mesh size nylon with filament (1–1.2mm), 900–1400m length.

Operations
I: same as for tuna fishery.

Total landings
I: 56,145t; 25,013–44,303t (1993). **Bu**: 430,800t (1982). **SL**: 18,739t (1982).

Cetacean bycatch
I: common dolphins; spinner dolphins; bottlenose dolphins; Indo-Pacific hump-backed dolphins; finless porpoises. **Ba**: kills known to occur, but no details known. SL: bottlenose dolphins; spinner dolphins; Fraser's dolphins (*Lagenodelphis hosei*); Risso's dolphins.

Skates and rays

References
I: Devadoss *et al.* (1989); CMFRI (1989;1993). **SL**: Joseph and Amarasiri (1988); Anon. (1982); Leatherwood and Reeves (1989).

Primary ports
I: Veraval, Bombay, Mangalore, Cochin, Vizhinjam, Tuticorin, Cuddalore, Madras, Kakinada, Visakhapatnam. SL: Puttalam, Chilaw, Negambo, Colombo, Kalutara, Galle, Matara, Hambantota, Kalmani, Batticola, Tricomalee, Mullaitivu, Jaffna, Mannar.

Target species
I: *Pristis cuspidatus, P. microdon, Rhynchobatus djiddensis, R. granulatus, Gymnura poeilura, Himanutura uarnak, Aetobatus narinari, Rhinoptera javanica.* **SL**: *P. cuspidatus, R. sephens, A. narinari, Himanutura uarnak.*

Vessels
I: northwest coast – *machwa*; southwest coast – *vanchi, vallam, kettuvallam*; east coast – *catamaram*, Tuticorin-type boat, *masula*, bar boat, fibreglass outboard, *pablo* inboard. **Ba**: *chhandi*, Cox's Bazar type. **SL**: *catamaram*, dugout canoe, fibreglass inboard, fibreglass outboard.

Nets
I: drift– and gillnet – 500–800m length, 6–8m depth, 150–300mm mesh multifilament twine (0.8–1.0mm). **Ba**: gillnet – 150–200mm mesh, 50 mesh deep. SL: Bottom driftnet – 100–250mm mesh, 700–1000m length; 6–7m depth, synthetic fibres.

Operations
I: up to 40m depth, 12–15hr trip length; 5–7hr soak time. **SL**: up to 40m depth, fishing at night, 5–6hr soak time; 15–40m depth.

Total landings
I: west coast – 3,472t (skates and rays, 1985-1986); east coast – 16,148t (skates and rays, 1985-1986); 17,941–28,644t (1992–1993). **Ba**: 7,014t (1982).

Cetacean bycatch
I: **SL**: spinner dolphins (*Stenella attenuata*), striped dolphins, rough-toothed dolphins (*Steno bredanensis*), pygmy killer whales (*Feresa attenuata*), pygmy sperm whales (*Kogia breviceps*), dwarf sperm whales (*Kogia simus*).

Catfish

References
I: Silas *et al.* (1980); James *et al.* (1989); CMFRI (1993). **Ba**: Hussain, pers. comm. (1987); Sivasubramanian (1985).

Primary ports
I: Veraval, Bombay, Karwar, Mangalore, Calicut, Cochin, Kakinada, Tuticorin, Visakhapatanam. Ba: Khulna, Chittagong, Cox's Bazar.

Target species
I: *Tachysurus sona, T. platystomus, T. malabaricus, T. tenuispinis, T. thalassinus.* **Ba**: *T. gagora, T. thalassinus.*

Vessels
I: *machwa, padu, ratnagiri, hodi, odam, thoni, kettuvallam, catamaram*, Tuticorin-type. **Ba**: *dinghi, chhandi, balam*, Cox's Bazar-type.

Nets
I: drift– and gillnet – 100–180mm mesh nylon monofilament (7–10mm), 5–8m depth.

Operations
I: northwest coast – 2–3 day trip length; southern coast – 15–18hr trip length, 10–60m depth.

Total landings
I: 45,450t (1985–1986), 52,290t (1984–1985); 34,110–39,374t (1990–1992).



Fig. 4. Mortality of cetaceans in gillnets in the northeastern Indian Ocean. (A) Indo-Pacific hump-backed dolphin, in Calicut fish market, brought alive to market and killed; (B) live Indo-Pacific hump-backed dolphins caught in gillnets off Calicut; (C) Indo-Pacific hump-backed dolphin kept in captivity in a polythene film-lined pond at Calicut for public display; (D) finless porpoises entangled in a gillnet off Calicut; (E) bottlenose dolphins (3.2 m) entangled in a drift gillnet off Calicut; and (F) spinner dolphins for sale in the Calicut fish market.



Fig. 5. Indo-Pacific hump-backed dolphin meat for sale (head in the foreground) at Quilandy (near Calicut) fish market.

Cetacean bycatch
I: common dolphins; bottlenose dolphins; spinner dolphins.

Polynemids

References
I: Kagwade (1970); Bal and Rao (1984); CMFRI (1993); **BA**: BOBP (1985). **Bu**: no gillnet fishery. **SL**: larger polynemids not fished.

Primary ports
I: Veraval, Bombay. Ba: Khulna, Cox's Bazar, Chittagong.

Target species
I: Polynemus indicus, P. eleutheronema, P. tetradactylum.

Vessels
I: *valion, matada, hodi, galbat, dinghi.* **Ba**: *balam, chhandi,* motorised vessels.

Nets
I: drift- and gillnet - 1200–5000m length, 180–210mm mesh. Ba: 1400m length.

Operations
I: 20–40m depth, 4–5 days or 10–15 day trip length, 15–60m depth, 5–6hr soak time. Ba: 5–6hr or 15–18hr soak time.

Total landings
I: 9,059t (1985); 6,837–7,849t (1990–1992).

Cetacean bycatch
I: entanglements known. **Ba**: entanglements known.

Oil sardines

References
I: CMFRI (1989; 1993). SL: Anon (1977); Nevill (1887); Lantz and Gunasekera (1955). No fishery in **Ba** and **Bu**.

Primary ports
I: Karwar, Mangalore, Calicut, Cochin, Vizhinjam. **SL**: Jaffna, Mannar, Kalpitiya, Puttalam, Chilaw, Negombo, Colombo, Kalutara, Beruwala, Ambalangoda, Gallee, Weligama, Matara, Mirissa, Dondra, Hambantota, Kalumanai, Batticaloa, Trincomalee, Mullaitivu, Point Pedro.

Target species
I: *Sardinella longiceps.* **SL**: *S. longiceps.*

Vessels
I: *odam, thoni, vanchi, kettuvalam, pandi, hondi.* **SL**: *oru, kulla, thoni, vallam, log rafts, catamaram, theppam.*

Nets
I: drift- and gillnet - nylon monofilament/multifilament (0.5–0.7mm), 20–25mm mesh, 5–6m depth, 200–300m length. **SL**: gillnet - 25–35mm mesh.

Operations
I: 30 min - 1hr soak time.

Total landings
I: 34,420t (1950); 189,016t (1960); 301,446t (1968); 168,078t (1978); 128,724t (1985–1986); 104,062 - 260,995t (1990–1992).

Cetacean by catch
I: no mortality in nets. **SL**: no mortality in nets.

Mackerel

References
Sources: **I**: CMFRI (1993); Srinath *et al.* (1987); Yohannan and Balasubramanian (1989); Jhingran (1989); Bal and Virabhadra Rao (1984). **SL**: BOBP (1984).

Primary ports
I: Mangalore, Calicut, Cochin. Ba: Khulna, Sylhet, Cox's Bazar, Chittagong.

Target species
I: *Rastrelliger kanagurta.* **Bu**: *R. brachysoma.*

Vessels
I: northwest coast - *machwa*; southwest coast - *vanchi, vallam, kettuvallam*; east coast - *catamaram,* Tuticorin-type, *masula*, bar boat, fibreglass outboard-type, *pablo* inboard. **Ba**: *dinghi, chhandi, balam*, Cox's Bazar-type. **SL**: *catamaram, theppam, vallam, oru, kulla, thoni*, fibreglass reinforced plywood (FRP).

Nets
I: gillnet - 25–55 mm, 6–8m mesh, 10m depth. **Ba**: driftnet - synthetic nets, 50–100mm mesh, 1700m length, 6–7m depth. **Bu**: drift- and gillnet. **SL**: gillnet: 50–60mm mesh, 500–1000m length, 5–6m depth.

Operations
I: up to 25m depth, 3–6hr trip length, 1–2hr soak time. **Ba**: in water from 10–30m deep with net fishing at 5–15m depth, trip length averages about 15 hours, soak time is about 4–5hr.

Table 2

Common fishing craft of Bangladesh.

Name	Length (m)	Breadth (m)	Depth (m)	Crew	Propulsion	Fishing gear
Plank built (traditional):						
Dinghi	5-7	10-1.2	0.9	2-3	oar/sail	gillnet/long
Chhandi	10-15	3	1.0	7-15	oar/sail	gillnet/Hilsa
Dugout						
Balam (medium)	10-15	1.5-2.0	1.2	10-15	oar/sail	gillnet
Balam (large)	15-20	1.5-2.0	1.2-1.5	20-30	oar/sail	gillnet/Behundi
Motorized (traditional):						
Cox's-Bazar type	12-14	3.0-3.2	1.2-1.5	8	22-33 hp	gillnet/Behundi
Modified Cox's-Bazar	12	3	1.2	6	22hp	gillnet/Behundi
Chhandi	12-13	1.6-1.8	1.0	10	9hp	gillnet
Longliner	6-7	1.0-1.2	10.9	6	10-15hp	longline

Total landings
I: 204,575t (1971); 23,863t (1967); 65,152t (1985–1986); 113,658–184,380t (1990–1992). **SL**: 751,000t (1983–1984).

Cetacean bycatch
I: not entangled. **SL**: probably not entangled.

Lesser sardines

References
I: Bennet and Arumugham (1989). **Ba**: no major gillnet fishery. Bu: no gillnet fishery. **SL**: Leatherwood and Reeves (1989).

Primary ports
I: Vizhinjam, Tuticorin, Madras, Visakhapatanam. **SL**: Jaffna, Mannar, Kalpitiya, Puttalam, Chilaw, Negombo, Colombo, Kalutara, Beruwala, Ambalangoda, Gallee, Weligama, Matara, Mirissa, Dondra, Hambantota, Kalumanai, Batticaloa, Trincomalee, Mullaitivu, Point Pedro.

Target species
I: *S. fimbriata, S. albella, S. gibbosa, S. sirm, S. dayi, Tenualosa toli, Dussumieri acuta*. **SL**: *S. gibbosa, S. albella, S. sirm, S. dayi, S. clupeoides, Thrissocles* spp.

Vessels
I: *masula, catamaram*, Tuticorin-type, dugout canoe, *odam, thoni, kettuvallam*. **SL**: *theppam, catamaram, vallam, oru, thoni, pathia*.

Nets
I: multifilament/monofilament synthetic twine (0.3–0.5mm), 25–40mm mesh. **SL**: drift- and gillnet – 20–40mm mesh, 500–700m length, synthetic twine (0.4–0.6mm).

Operations
I: (**SL**) 1–3hr soak time, up to 10m depth.

Total landings
I: 52,467t (1969); 68,351t (1979); 60,828t (1985–1988).

Cetacean bycatch
I: probably not entangled. **SL**: not usually entangled.

Whitebait

References
Sources: **I**: Luther *et al.* (1982); Bennet and Arumugham (1989); CMFRI (1989; 1993). **Ba**: no whitebait fishery. **Bu**: no information from Burma coast. **SL**: Leatherwood and Reeves (1989).

Primary ports
I: Mangalore, Calicut, Cochin, Vizhinjam, Tuticorin; Vizhinjam, Tuticorin, Madras, Visakhapatanam. **SL**: Jaffna, Mannar, Kalpitiya, Puttalam, Chilaw, Negombo, Colombo, Kalutara, Beruwala, Ambalangoda, Gallee, Weligama, Matara, Mirissa, Dondra, Hambantota, Kalumanai, Batticaloa, Trincomalee, Mullaitivu, Point Pedro.

Target species
I: *Stolephorus indicus, S. bataviensis, S. buccaneeri, S. devisi, S. commersoni*. **SL**: *S.* spp., *Thrissocles* spp.

Table 3
Distribution of traditional fishing vessels in Bangladesh (from BOBP, 1985)

Districts	Plank built	Dugout	Total
Chittagong	4,055	1,871	5,926
Nokhali	780	185	965
Barisal	1,025	-	1,025
Patuakhali	1,077	11	1,088
Kulna	445	3	448
Jessore	11	3	14
Total	7,393	2,170	9,563

Vessels
I: dugout canoe, *thoni, odam, vanchi, kettuvallam, catamaram*, Tuticorin-type, *vallam, Masula*. **SL**: *catamaran, theppam, oru, thoni, vallam,* fibreglass reinforced plywood (FRP).

Nets
I: 25–30mm mesh, monofilament/multifilament twine (0.3–0.4mm), 70–100m length, 6–8m depth. SL: drift- and gillnet – 20–25mm mesh, 60–70m length, 6–7m depth, synthetic fibre.

Operations
I: 4–8hr trip length, 5–8m depth, 2–3hr soak time. SL: 4–6hr trip length, up to 15m depth, 1–3hr soak time.

Total landings
I: 63,692t (1985–1986); 77,447–93,300t (1990–1992).

Cetacean bycatch
I: not entangled. SL: probably not entangled.

Hilsa

References
I: Pillay (1958); Sharma and Grover (1982); (CMFRI) (1980, 1989); Jhingran (1989). **Ba**: Ali and Haq (1980); Karim (1977); Hossain *et al.* (1987); Sivasubramaniam (1985); Shahidullah (1986). **Bu**: Sivasubramaniam (1985). **SL**: no hilsa gillnet fishery.

Primary ports
I: Varanasi, Buxar, Ballia, Patna, Allahabad, Bhagalpur, Diamond Harbour. **Ba**: Khulna, Sylhet, Chittagong, Cox's Bazar, Chandipur, Mohipur, Nayahata.

Target species
I: *Hilsa ilisha, Tenualosa toli*. **Ba**: *H. ilisha*.

Vessels
I: *donga, ekhta, jalia dinghi, chhandi, bachari, chhot*. **Ba**: *dinghi, chhandi, balam*, Cox's Bazar-type, motorised boats.

Nets
I: nylon twine driftnets, 1500m long, 3m wide, mesh sizes from 50–110mm. **Ba**: surface driftnets – 75–120mm mesh monofilament or multifilament synthetic fibre (0.4–0.8mm), 360–600m long in coastal fishery, and 400–1500m long in the offshore fishery. Bu: gillnet, little other information available.

Operations
I: 5–12m depth. **Ba**: 5–6hr (river) or 2–3 day (offshore) trip length, 5–30m depth, 1–4hr soak time.

Total landings
I: marine sector only: 404–1,769t/yr (1964–1974); 4,189–12,068t/yr (1975–1979); 1,909t (1984–1985); 5,543t (1985–1986); 14,243–28,895t (1990–1992). **Ba**: 132,000t/yr (1980–1982); 234,000t (1985). **Bu**: 322,895t (1972–1973); 442,920t (1982–1983).

Cetacean bycatch
I: Ba: Ganges river dolphins (*Platanista gangetica*); Irrawaddy dolphins (*Orcaella brevirostris*).

Riverine catfishes

References
I: Jhingran (1985); Mohan (1989a; 1989b); Sharan and Sinha (1989). **Ba**: Mohan (1989b); Shahidullah (1986). **Bu**: Hershkowitz (1966). **SL**: no riverine catfisheries.

Primary ports
I: Agra, Allahabad, Kanpur, Varanasi, Buzar, Ballia, Patna, Bhagalpur, Dhubri, Guhathi, Tezpur, Dibrugarh. **Ba**: Chandpur, Bhagykal, Bheramara, Sirajgang, Bahadurpur, Tista.

Target species
I: *Mystus aor, M. seenghala, Wallago attu, Notopterus chitala, Pangasius pangasius, Eutropichthys vacha*. **Ba**: *M. aor, M. seenghala, Clupisoma garua, Bagarius bagarius, Clarius batrachus*.

Vessels
I: *donga, ekhta, jalia dinghi, chhandi, bachari*. **Ba**: *chhandi, dinghi*.

Nets
I: drift- and gillnet – 300m length, 3m width, 76–102mm or 12–250mm mesh cotton, nylon or Assam silk nets. **Ba**: 300m length, 5–8m depth, 100–150mm mesh.

Operations
I: 3–30m depth; 3–8hrs trip length; 4–5hrs soak time.

Total landings
I: **Ba**: 580,000t (inland only).

Cetacean bycatch
I: Ganges river dolphins. **Ba**: Ganges river dolphins.

Prawns

References
I: CMFRI (1993); **SL**: Sivasubramaniam (1985); FAO (1986).

Primary ports
I: Veravel, Bombay, Goa, Mangalore, Calicut, Cochin, Quilon, Mandapam camp, Tuticorin, Madras, Kakinada, Vishakapatnam, Puri, Calcutta.

Target species
I: *Penaeus indicus, P. monodon, P. semisulcatus, Metapenaeus dobsoni*.

Vessels
I: northwest coast – *machwa, satpati*; southwest coast – *odam, thoni, vanchi, kettuvallam*; east coast – *catamaram*, Tuticorin-type, *masula, chhandi*, fibreglass outboard, *pablo* inboard.

Table 4

Names of set- or drift-gillnets deployed for mackerel from various fishing craft along the Indian coast (Srinath *et al.*, 1987; Jhingram, 1989; Bal and Rao, 1984; Yohannan and Balasubramanian, 1989).

State	Craft	Local name(s) of set- or drift-gillnet(s) operated
1. Maharastra	Dugout canoes	Bangdajal
	Pagar & Thoni	Petite bale
2. Karnataka	Dugout canoes	Kandadi bale
	Thoni	Patta bale, Chala bale
	Canoe boat	Kantha bale
	Pandi	Ida bale
3. Kerala	Dugout canoes	Ozhuku vala, Noo vala
	Odam & Thoni	Vengadu vala
	Canoe boat	Ayilachala vala
	Vallams	
	Catamaram	
	Kattaumaram	
4. Tailnadu	Plank-built boat	Vazhi valai
	Vallam, Padagu	Vala valai
	Catamaram	
	Kattumaram	
	Periamaram	
	Chinna maram	Podi valai
5. Andhra pradesh	Plank built boat	
	Padava	Gillnet
	Masulas	
	Catamaran	
	Theppalu	
6. Orissa	Plank-built boat	
	Ber	
	Masula	
	Chhoat	Phasi Jalo
	Palia	Ilishi Jalo
	Dhingy	Behendi Jalo
	Danga	Bhasani Jalo
	Salti	Jagawala (Bottomset net)
	Catamaraan	Kilumala (Bottomset net)
		Katlala (Surface driftnet)

Nets
I: drift- and gillnet – 15–30mm mesh nylon twine (0.5–0.7mm), 100–500m length, 8–10m width.

Operations
I: 5–30m depth, 12–15hr trip length, 3–5hr soak time.

Total landings
I: 132,198t (1985); 29,204t (1985) (Penaeid prawns alone); 164,580–190,434t (1993). **Ba**: 4,824t (1982–1983). **SL**: 7,493t (1982).

Cetacean bycatch
No evidence of cetacean involvement in **I** or **SL**.

RECENT DEVELOPMENTS IN THE FISHERIES

Gillnets are one of the most important types of fishing gear in small-scale traditional fisheries. Mechanised vessels also have taken up gillnetting because of the advantages they offer. The relatively recent introduction of synthetic twines made of polyamide (PA), polyester (ES), polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC) in the place of cotton and hemp has increased the efficiency of gillnets, while the use of outboard engines on traditional vessels and the introduction of fibre glass boats has increased operational efficiency. Fishermen can thus remain on the fishing ground for more time and still bring catches to shore in better condition than in earlier days.

In India, there were 18,169 driftnets and gillnets in 1950 (Chopra, 1951). By 1980 that number had risen to 216,037 (CMFRI, 1980). There are about 35 such gillnets per kilometre of Indian coast. About 150,000 indigenous vessels and 6,000–8,000 small, mechanised boats operate the gear. The usual gillnet panels are 25–75m in length, with a total net length of less than 1.8km. These are multi-meshed, multi-species nets and operate mostly within 50m depth.

In Bangladesh, Burma and Sri Lanka, driftnets and gillnets are also used extensively in small-scale coastal marine fisheries. Increases in landings in such coastal fisheries as those for seerfish, tuna and pomfret are mainly due to the introduction of synthetic driftnets and gillnets (Bal and Virabhadra, 1984). Increases in effort in the hilsa fishery in Bangladesh (BOBP, 1985) and the tuna fishery in Sri Lanka are a direct result of deployment of more gillnets. Synthetic gillnets of various mesh sizes were introduced in 1962 and since then have become very popular. The fish landings of the coastal fisheries increased from 103,636t in 1966 to 180,816t in 1980. In 1982, gillnets contributed some 42.4% of total fish production; during a period of increasing gillnet use, tuna production went up from 23,159t in 1977 to 32,307t in 1982 (BOBP, 1984). There are about 2,000 boats of 3.5–4.0t and 70 boats of 11t operating gillnets, in addition to other traditional vessels. The nets are made of small panels of 100 units with mesh sizes of 90–180mm (the most commonly used mesh size is 140–150mm). The total length of the net is about 3.0–4.5km. About 90% of the offshore catches come from driftnets. Skipjack and yellowfin tuna, along with small tuna, form 70% of the driftnet catches.

Gillnets contributed about 97% of the 100,000t of hilsa landed in Bangladesh. Mechanised vessels operating large-mesh nets averaged 1,340kg/trip, 190kg/fishing day, while those operating small-mesh nets averaged 2,060kg/trip, and 280kg/fishing day (Sivasubramanian, 1985).

The Taiwanese fished for tunas on the high seas of the Indian Ocean, deploying 200–220mm mesh nets with a depth of 100–120mm mesh (vertical depth of 20–24m). The total number of nets deployed is 700–900, and the length of the nets is 37–47km. They captured about 111,480t of tuna in 1988 with yellowfin tuna (*Thunnus albacares*) forming about 106,969t (IOFC, 1990).

The total catch of tuna and other large pelagic fish by gillnets in the Indian Ocean was about 105,577t in 1988 (IOFC, 1990). Most came from Sri Lanka (25,551t, 24.2%), followed by India (20,935t, 19.8%), Iran (19,420t, 18.3%), Pakistan (19,402t, 18.3%), Malaysia (5,603t, 5.3%), Indonesia (2,950t, 2.7%), Thailand (522t, 0.5%) and Bangladesh (16t, 0.01%). The total catch of Taiwanese vessels operating drift gillnets in the Indian Ocean increased from about 24t in 1983–1984 to 18,486t in 1987–1988. The number of boats operating also has increased from 1 to 39. *Thunnus albacares* contributed 91 to 95% of the catch during 1987–1988 (IOFC, 1990).

CETACEAN BYCATCHES

Dolphins are known to become entangled in gillnets along the Indian coast (Jones, 1976; Lal Mohan, 1985; Lal Mohan, 1989a; Lal Mohan, 1989b; CMFRI, 1988; IOFC, 1990). The introduction of synthetic gillnets and driftnets has increased dolphin mortality. An estimated 1,000–1,500 dolphins may be killed by gillnets annually along the Indian coasts. The southwest coast has been found to be the core area for entanglement of dolphins in gillnets, accounting for about 90% of the known entanglements (CMFRI, 1988). A total of 202 dolphins were observed entangled in coastal gillnet fisheries during 1986–1987; the southwest coast accounted for 197 of them. Spinner dolphins comprised 61.6% of the total followed by common dolphins (23.6%) and bottlenose dolphins (12.1%). Gillnets from Cochin landed 123 dolphins, while 27 were landed at Calicut. Almost all (92%) of the landed spinner dolphins were in the length group 100–199cm, the rest being larger (200–249cm). A similar pattern was seen for common dolphins where 84% were from 100–199cm in length and 16% from 200–299cm. However, the reverse was true for the largest of the three species, 88.8% of bottlenose dolphins were in the 200–299cm length group, while 11.2% were in the range 100–199cm. It has been estimated that about 350 Ganges river dolphins are killed annually throughout its range (Lal Mohan, 1992; Reeves *et al.*, 1993). Lal Mohan *et al.* (1993) counted 268 Ganges river dolphins in the River Brahmaputra from Dhubri to Shaikwaghat, a distance of about 600km in Assam. They estimated that the total population of the river dolphins in the river may not be more than 400 and about 50 dolphins are killed in the gillnets annually.

Sri Lanka

Leatherwood and Reeves (1989) have recently reviewed the history, current status and immediate future plans of Sri Lankan fisheries and the involvement of marine mammals in those fisheries. Marine mammal fishery interactions in Sri Lanka have been known since the last century (Nevill, 1887). Blegvad (1951) and Medcof (1963) stated that dolphins caused considerable financial loss to fishermen both by damaging nets and feeding on the fish caught in them. They advocated measures to kill the dolphins and suggested developing a dolphin fishery in Sri Lanka, a view supported by Lantz and Gunasekera (1955). However, it was not until 1983 that the problem of cetacean mortality in Sri Lankan gillnet fisheries was confirmed to be widespread and began to receive attention (Alling, 1983; Joseph *et al.*, 1983).

With increased fish production in Sri Lanka, the mortality of dolphins has also increased. For example, nearly 13,000 dolphins, mainly spinner dolphins, were killed by gillnet fishing in 1988 (IOFC, 1990). Small cetaceans are killed directly and indirectly and are used for human consumption and for bait in longline fisheries. Until recently, the dolphin mortality was not monitored and its effect on the populations was not studied. There have been various attempts to monitor cetacean landings along the coast of Sri Lanka and estimates of total mortality have ranged from around 10,000 (e.g. Alling, 1983; Joseph and Siddeek, 1985) to as many as over 40,000 (Alling, 1985). Leatherwood and Reeves (1989) carefully reviewed the numerous problems associated with any estimates of total cetacean mortality in the Sri Lankan fishery.

More recently the Sri Lankan National Aquatic Resources Agency (NARA) estimated that approximately 13,000 small cetaceans are caught in gillnets annually (Dayaratne and de Silva, 1990) but the methods used were not presented in sufficient detail to warrant critical evaluation. Joseph and Dayaratne (1993) estimated that 5,181 dolphins were caught off the Sri Lankan coast during 1992 and suggested that 'the number of dolphins caught in Sri Lankan coast is too small to warrant drastic management action at present'. Most recently, Leatherwood (1994) re-examined data originally presented in Leatherwood and Reeves (1989) on fishing effort and

dolphin catches in Sri Lanka from 1984–86 and estimated that at least 8,042–11,821 small cetaceans and a few great whales were taken annually, the estimate depending on the assumptions used. The conclusion that 'All attempts to estimate mortality of cetaceans in Sri Lankan fisheries ... are compromised in significant ways' (Leatherwood and Reeves, 1989), remains valid.

Bangladesh and Burma

Data on the interaction of gillnets and cetaceans in Bangladesh and Burma are too fragmentary for any estimates of bycatches.

DISCUSSION

The designation of the Indian Ocean as a whale sanctuary by the International Whaling Commission in 1980 also served to focus attention on the status of marine mammals in general in that region. A series of cetacean reviews and research projects were subsequently conducted and reported on, mainly in meetings and symposia in the region (e.g., see the summary in Leatherwood and Donovan, 1991). Many of those reports showed that marine mammal mortality in gillnets was extensive in the region and, in at least a few well-documented cases, (e.g., Sri Lanka) was, and remains, cause for concern. Although conservation laws related to cetaceans exist for most of the countries bordering the northeastern Indian Ocean, enforcement is generally poor. Furthermore, notwithstanding evidence of overfishing of many target resources, there is continuing pressure to expand and develop marine fisheries within the area to keep pace with burgeoning human populations (James, 1988); increased effort will lead to increased cetacean mortality. Finally, increasing tendencies to use cetaceans caught incidental to fishing operations may ultimately result in the development of directed fisheries for cetaceans, as it has in Sri Lanka (Leatherwood and Reeves, 1989). These factors make it especially difficult for managers to implement methods to prevent unintended entanglements and deaths of cetaceans in gillnet fisheries. Gillnet operations are responsible for the livelihoods of thousands of people and proposals to ban this type of fishing to protect cetaceans will be difficult, if not impossible, to introduce and enforce.

Cetacean mortality in gillnets is a global phenomenon (e.g. International Whaling Commission, 1994) and experience has shown that resident coastal populations may be particularly at risk. In this region this includes species such as the Indo-Pacific hump-backed dolphin and the Ganges river dolphin, that are subjected not only to heavy fishing pressure but also to the effects of pollution and other human interference leading to habitat degradation.

RECOMMENDATIONS

Data collection

(1) Comprehensive surveys should be made of cetacean entanglement in the coastal gillnet fisheries of Bangladesh, Burma, Sri Lanka and India, with special attention being paid to coastal dolphins, such as Indo-Pacific hump-backed dolphins, finless porpoises and Irrawaddy dolphins, especially populations inhabiting shallow lagoons such as Chilka Lake in India and those ascending the estuaries of large rivers.

(2) Effort should also be made to collect information on the gillnet fisheries of the Ganges and Brahmaputra Rivers and other riverine fisheries in Bangladesh and Burma and their associated dolphin entanglement.

(3) Stock identity studies should be initiated on those species vulnerable to gillnetting.

(4) The population status of the various species subjected to gillnet mortality should be determined.

Legislation

(5) National cetacean protection agencies should be formed in India, Bangladesh, Burma, Sri Lanka and the Maldives to monitor and to take follow-up action on the conservation of cetaceans. Periodic national and regional reviews of progress should occur. The national agencies should be linked to international agencies (e.g. IUCN, IWC) to ensure coordinated distribution and analysis of the collected information.

(6) The preservation of natural habitats of cetaceans should be given importance and monitored on a continuous basis. For example, the pollution of the River Ganges and the habitat degradation of Chilka Lake should be studied in relation to the Ganges river dolphin and the Irawaddy dolphin and the effect of large dams on dolphin populations should also be monitored. In particular, areas where dolphins are highly vulnerable to driftnets and gillnets should be declared protected areas. Initially, the areas from Puttalam to Trincomalee in Sri Lanka (all species), Cochin to Goa in India (all species); Patna to Bhagalpur in the River Ganges (Susu) and Tezpur to Dibrugarh in the Bramahputra (Susu), should be considered for designation as protected.

Alternative technology/methods

(7) As dolphins are killed for bait in longline fisheries in Sri Lanka and the catfish fishery of the Ganges and Bramahputra, efforts should be made to find alternatives to the use of dolphin meat as bait.

(8) Studies should be initiated to find ways to make gillnets less dangerous to dolphins, as discussed in IWC (International Whaling Commission, 1994), with emphasis on co-operation with local fishermen and fishermen's societies.

Awareness programmes

(9) Public awareness programmes should be initiated to explain the nature of the threats to cetaceans from fishery interactions. Attention must be directed particularly at the fishermen themselves, local communities (e.g. schools and colleges) and local fisheries scientists who should also be involved in attempts to improve the situation. The use of whale/dolphin watching, as a way to raise public awareness and perhaps as a supplementary or alternative economic proposition, should be encouraged.

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Asia and North Pacific Pelagic

SC/O90/G21

Brief Review of Passive Fishing Gear and Incidental Catches of Small Cetaceans in Chinese Waters

Zhou Kaiya

Department of Biology, Nanjing Normal University, Nanjing, PR China

and

Wang Xiaoyan

Bureau of Fisheries, Ministry of Agriculture, Beijing, PR China

ABSTRACT

A total of 139 types of passive fishing gear are used in Chinese marine fisheries. Finless porpoises, false killer whales, bottlenose dolphins and common dolphins are known to be caught incidentally in the fisheries. Finless porpoises are probably killed in considerable numbers; recorded incidental catches suggest that dozens or perhaps hundreds have been caught annually in gillnets, drifting trammels, stow nets and pound nets along the coast of Liaoning, Hebei, Shandong, Jiangsu and Fujian Provinces. Individuals of the Yangtze River finless porpoise population are caught incidentally in rolling hook longlines and encircling gillnets. Attention has been focused on the kill of the baiji, *Lipotes vexillifer*, by rolling hook longlines and fyke nets in the same river. The rolling hook longlines have accounted for 53% and 23% of the known deaths of the dolphin in the middle and lower reaches of the Yangtze, respectively, and fyke nets accounted for 16% of the deaths in the lower Yangtze.

KEYWORDS: FISHERIES; INCIDENTAL CAPTURE; BAIJI; NORTH PACIFIC; FINLESS PORPOISE; BOTTLENOSE DOLPHIN; COMMON DOLPHIN; KILLER WHALE; PACIFIC WHITE-SIDED DOLPHIN; INDO-PACIFIC HUMP-BACKED DOLPHIN

INTRODUCTION

In 1988, the total fish production of Chinese marine and freshwater fisheries was about 4,630,000 tons and 650,000 tons respectively. Numerous fishing methods are used in Chinese coastal, distant and fresh waters. Some 250 different types of fishing gear used at sea in Chinese fisheries have been described (Feng *et al.*, 1989). In terms of total marine fisheries production, trawling is the most important fishing method in China, taking cutlassfish (*Trichurus haumela*), jack (*Decapterus maruadsi*), needlefish (*Ablennes anastomella*), mullets (*Liza haematocheila, Mugil cephalus*), filefish (*Navodon septentrionalis*), cowrie (*Amussium japonica*), cuttle fish (*Sepia esculenta*), prawn (*Penaeus japonicus*), swimming crab (*Portunus trituberculatus*) and some other species. It accounted for about 40% of the total fish production in 1988. Catches from stow netting and bottom set gillnetting comprised about 24% of the total while those from drift gillnetting and surround netting contributed about 15% and 13%, respectively. Other types of traps in addition to stow nets are used in coastal areas, as are longlines. In Chinese inland waters the main fishing methods used are trapping, longlining and gillnetting.

Dolphins and porpoises are killed incidentally in Chinese marine and freshwater fisheries. For instance, rolling hook longlines and traps in the Yangtze River have been implicated in the decline of the baiji, *Lipotes vexillifer* (Zhou, 1982; Chen and Hua, 1989; Zhou and Li, 1989). However, the incidental catches of small cetaceans in Chinese marine fisheries have not been monitored, nor have their effects on the cetacean populations been systematically addressed. The present paper is a brief review of passive fishing nets and traps used by Chinese fisheries and available records of incidental catch of small cetaceans. In addition to the literature review, brief accounts of previously unpublished data on incidental catches of small cetaceans in passive fishing gear are included.

PASSIVE FISHING GEAR IN THE SEA

Gillnets

There are more than 3,500,000 gillnets in use in China. They range in length up to 15,000–20,000m (Feng *et al.*, 1989). Most are used in coastal waters although some are used in distant waters by more powerful vessels.

Drift gillnets

Driftnet fisheries are distributed widely in Chinese coastal waters, catching species such as butterfish (*Pampus argenteus*), mackerels (*Scomberomorus niphonius, Pneumatophorus japonicus*), Chinese herring (*Ilisha elongata*), yellow croaker (*Pseudosciaena crocea*), common sea bass (*Lateolabrax japonicus*), anchovy (*Setipinna taty*), mullets, prawns, lobster (*Panulirus stimpson*), jellyfish (*Rhopilema esculenta*) and others. Mesh size varies from 30mm to 360mm according to the size and shape of the target species (Table 1). Motorised vessels fishing with driftnets are of various sizes: (1) 12 ton boats, 17m long, with 12–25HP inboard engines, 6–7 crew members and carrying 40–50 nets; (2) 17 ton boats, 19m long, with 40–60HP inboard engines, 9 crew members and carrying 60–100 nets; (3) 67 ton boats, 24m long, with 80–150HP engines, 10–12 crew members and carrying 150–300 nets (Zhou and Li, 1986).

Set gillnets

The target species of set gillnet fisheries include smooth dogfish (*Triakis scyllium*), spiny dogfish (*Squalus fernandinus*), gizzard shad (*Clupanodon punctatus*),

Chinese herring, maochang croaker (*Megalonibea fusca*), bummalo (*Harpadon nehereus*), common sea bass, sweetlips (*Plectorhynchus*), emperors (*Letherinus*), groupers (*Epinephelus*), javelinfish (*Pomadasys*), yellow porgy (*Taius tumifrons*), butterfish, bigcod croaker (*Nibea albiflora*), tonguefish (*Cynoglossus*), righteye flounder (*Pleuronichthys cornutus*), halibut (*Paralichthys olivaceus, P. orientalis*), lobster, mantis shrimps (*Squilla*), swimming crab, apus (*Tachypleus tridentatus*), cuttle fish and others. The set gillnet fisheries occur in shallow near shore waters. In the *chongyu* (butterfish) set gillnet fishery, the mesh size is 93mm. About 40 panels are carried by motorised junks equipped with 40–60HP engines and three rowboats are used in the net operation. These 15–18m junks carry a crew of 12. Data for various set gillnet fisheries are given in Table 2.

Table 1

Drift gillnets in Chinese marine fisheries.

Name	Mesh size (mm)	Panel length and height (m)	Target species	Locality
Taiyu driftnet	82	47.17 x 13.40	Common mackerel	Changhai, Liaoning
Duixia qua net	60	60.48 x 6.70	Prawn	Yingkou, Liaoning
Luyu santui driftnet	130	24.97 x 9.75	Common sea bass	Tanggu, Tianjin
E'zhenyu driftnet	43	45.65 x 0.60	Needlefish	Leting, Hebei
Qinglinyu driftnet	35	14.00 x 5.98	Common herring	Changli, Hebei
Bayu driftnet	90	54.00 x 8.60	Mackerel	Penglai, Shandong
Suoyu gillnet	72	30.68 x 0.90	Mullet	Rushan, Shandong
Yinchong driftnet	123	29.00 x 11.07	Butterfish	Qidong, Jiangsu
Leyu driftnet	84	33.26 x 12.6	Chinese herring	Guannan, Jiangsu
Huangji driftnet	40	24.20 x 8	Anchovy	Ganyu, Jiangsu
Hetunyu driftnet	100	41.40 x 1.65	Puffers	Ninghai, Zhejiang
Maochangyu driftnet	360	15.05 x 3.78	*Maochang* croaker	Dinghai, Zhejiang
Mianyu driftnet	160	18.72 x 4.72	Slate cod croaker	Dinghai, Zhejiang
Ziyu driftnet	85	72.00 x 1.28	Striped mullet	Ninghai, Zhejiang
Suozi driftnet	36	54.00 x 1.98	Mullet	Ninghai, Zhejiang
Meitongyu driftnet	43	18.00 x 3.40	Baby croaker	Yueqing, Zhejiang
Suozixie driftnet	160	18.00 x 3.52	Swimming crab	Daishan, Zhejiang
Jiali ling	210	38.84 x 2.94	Genuine porgy	Tong'an, Fujian
Qingling ling	30	32.24 x 3.30	Common herring	Xiamen, Fujian
Damu ling	173	26.00 x 17.39	Mackerel, etc.	Dongshan, Fujian
Bazhi lian	150	46.00 x 9.90	Butterfish, Mackerel	Xiapu, Fujian
Shayu lian	170	22.68 x 25.50	Sharks, Mackerel	Jinjiang, Fujian
Menshan net	135	43.72 x 3.44	Pike conger	Yangjiang, Guangdong
Bai lian	57	44.90 x 1.45	Threadfin bream	Yangjiang, Guangdong
Feiyu net	36	33.48 x 1.46	Flying fish	Lingao, Hainan
Longli driftnet	80	32.11 x 4.84	Tonguefish, Pike conger	Beihai, Guangxi
Xia driftnet	47	96.33 x 1.60	Prawn	Hepu, Guangxi
Hongyu gillnet	185	30.02 x 8.42	Snapper	Ledong, Hainan
Erceng menshan gillnet	130	51.17 x 11.92	Pike conger, Sharks	Haikang, Guangdong
	110			
Shuangceng sanjiao lian	130	41.00 x 4.96	Sharks, Yellow croaker	Hui'an, Fujian
	105			
Lezi ling	98	40.00 x 4.90	Chinese herring	Xiamen, Fujian

Table 2

Set gillnets in Chinese marine fisheries.

Name	Mesh size (mm)	Panel length and height (m)	Target species	Locality
Mao net	56	57.19 x 5.39	Gizzard shad	Zhuanghe, Liaoning
Damu mao net	200	16.40 x 1.00	Tonguefish, etc.	Suizhong, Liaoning
Luyu mao gillnet	150	20.00 x 6.75	Common sea bass	Ginhuangdao, Hebei
Xiagu gillnet	73	59.95 x 0.80	Mantis shrimps	Qinhuangdao, Hebei
Huangguyu set gillnet	74	46.60 x 5.92	Bigcod croaker	Tanggu, Tianjin
Suozixie set gillnet	79	60.00 x 10.17	Swimming crab	Tanggu, Tianjin
Shayu gillnet	220	80.53 x 3.14	Smooth dogfish	Haiyang, Shandong
Bimuyu gillnet	133	25.80 x 3.63	Halibut	Haiyang, Shandong
Ludeng net	76.7	95.95 x 7.48	Chinese herring	Haiyang, Shandong
Chongyu set gillnet	93	18.58 x 8.93	Butterfish	Qidong, Jiangsu
Maochangyu set gillnet	245	15.25 x 2.33	*Maochang* croaker	Xiangshan, Zhejiang
Longtouyu set gillnet	33	26.61 x 2.84	Bummalo	Cangnan, Zhejiang
Hou ling	300	108.00 x 1.05	Apus	Dongshan, Fujian
Moyu gillnet	130	49.20 x 0.60	Cuttle fish	Wuchuan, Guangdong
Longxia gillnet	105	102.10 x 1.47	Lobster	Nan'ao, Guangdong
Bazhishi bottom gillnet	145	94.27 x 1.52	Sweetlips	Beihai, Guangxi
Xie gillnet	139	70.13 x 0.97	Swimming crab	Hepu, Guangxi
Hou gillnet	320	52.69 x 2.40	Apus	Qinzhou, Guangxi

Encircling gillnets and trammel nets

Fisheries using encircling gillnets are mainly distributed off the coast of Guangdong Province and Guangxi Zhuang Autonomous Region (Fig. 1), catching gizzard shad or yellow croaker. Set trammel nets and drifting trammel nets are used in coastal fisheries both in northern and southern China. The target species of the trammel net fisheries include mullets, hilsa herring (*Macrura reevesi*), mackerel, butterfish, yellow croaker, tonguefish and sharks (Table 3). Boats fishing with set trammel nets are powered by 4HP engines or propelled by oars. Those fishing with drifting trammel nets are powered by 7–20HP engines.

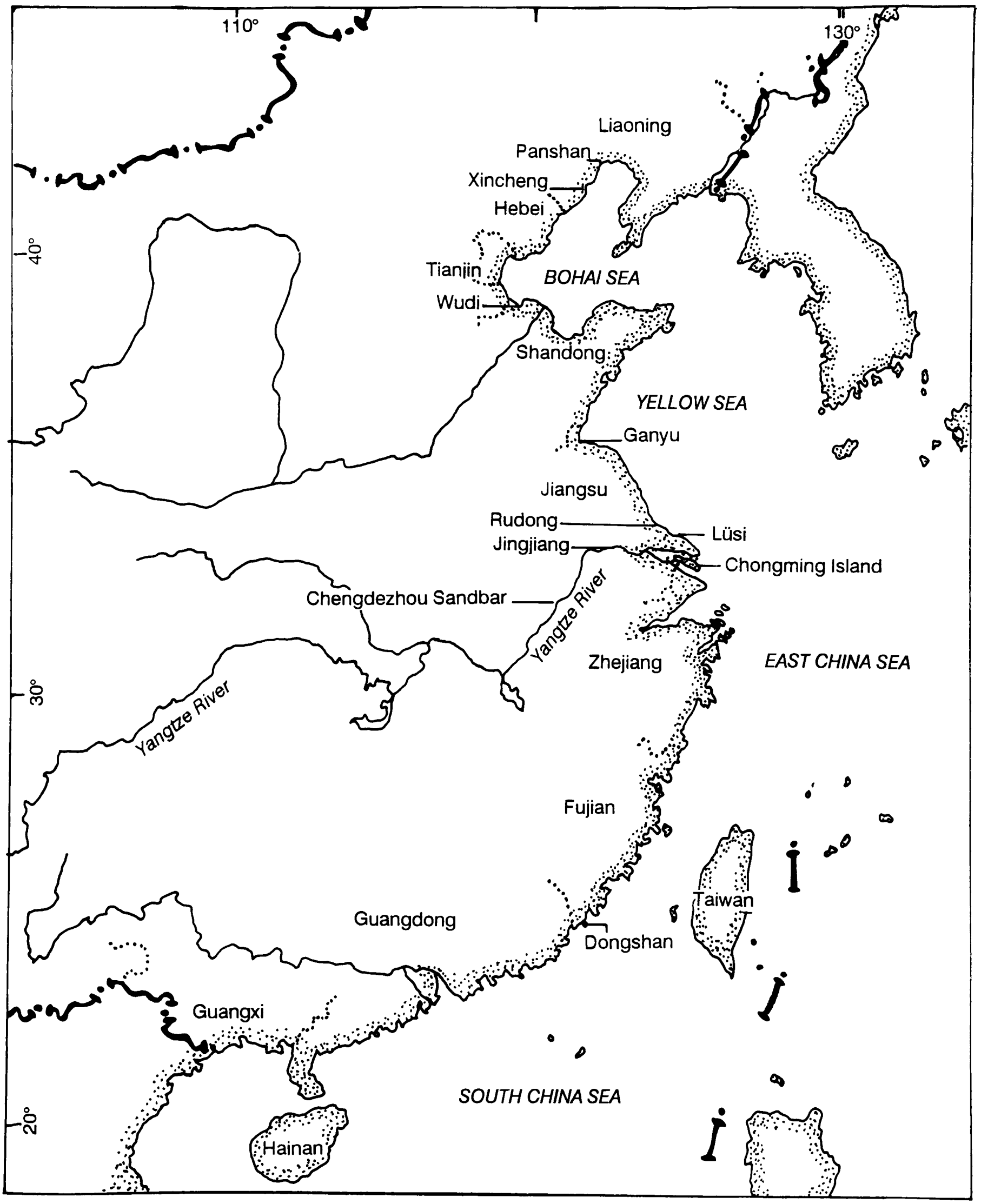

Fig. 1. Map of the area.

Table 3

Encircling gillnets and trammel nets in Chinese marine fisheries.

Name	Mesh size (mm)	Panel length and height (m)	Target species	Locality
Encircling gillnets				
Huanghuayu gillnet	120	63.75 x 20.50	Yellow croaker	Taishan, Guangdong
Huangyu gu	50	64.93 x 7.03	Gizzard shad	Qinzhou, Guangxi
Set trammel nets				
Sanchong gillnet	330 83	56.70 x 0.83	Mullet	Qinhuangdao, Hebei
Sanchong lian	565 46	39.34 x 1.56	Mullet, Tonguefish	Zhongshan, Guangdong
Drifting trammel nets				
Sanli net	600 100	37.66 x 3.30	Hilsa herring	Panyu, Guangdong
Sanchong ling	520 98	63.93 x 5.72	Butterfish, Mackerel	Zhangpu, Fujian
Zisuoyu sanchong driftnet	260 50	30.00 x 1.56	Mullet	Ganyu, Jiangsu

Table 4

Stow nets in Chinese marine fisheries.

Name	Type[1]	Mesh size (mm)	Dimension (m)	Target species	Locality
Fan stow net	1	400-33	180.00 x 124.97	Butterfish	Qidong, Jiangsu
Dabu net	1	147-21	116.32 x 78.77	Butterfish, Cuttle fish	Dinghai, Zhejiang
Yuguazi net	2	63.3-8.3	19.88 x 20.01	Bigcod croaker, etc.	Rongcheng, Shandong
Yangfang	2	87-20	19.50 x 9.31	Baby croaker, Anchovy	Qidong, Jiangsu
Xi net	2	133-50	18.86 x 12.35	Butterfish, Jellyfish	Dinghai, Zhejiang
Sangang net	2	70-2x2	17.40 x 11.74	Bummalo, Shrimps	Putuo, Zhejiang
Gaoxi net	2	147-73	11.00 x 5.57	Butterfish, Mackerel	Nanhui, Shanghai
Shumuchun stow net	2	100-5x3	16.00 x 13.00	Swimming crab, Butterfish	Luannan, Hebei
Haizhe net	2	330-95	17.80 x 11.77	Jellyfish	Chongming, Shanghai
Haizhe stow net	2	200-5x3	16.00 x 11.40	Jellyfish	Luannan, Hebei
Dongmeng	2	51-11.2	23.90 x 28.09	Shrimps	Changle, Fujian
Jiazi net	2	40-8	16.20 x 11.91	Shrimps	Tanggu, Tianjin
Kaikoushi xiaban net	2	100-2x2	16.00 x 11.50	Shrimps	Fengnan, Hebei
Maoxia guazi net	2	30-7.5	16.00 x 10.56	Shrimps, Palaemon, etc.	Zhanhua, Shandong
Dangenfang	3	167-20	39.00 x 39.71	Butterfish	Qidong, Jiangsu
Xiao net	3	33-10	20.40 x 19.09	Shrimps	Ganyu, Jiangsu
Sanjiaoleng net	3	33-9	10.05 x 10.96	Shrimps, Bummalo, etc.	Dongtou, Zhejiang
Danmao stow net	3	267-27	83.52 x 79.80	Butterfish	Qidong, Jiangsu
Ankang net	3	133-12	75.34 x 70.17	Common sea bass, etc.	Donggou, Liaoning
Paoding stow net	3	33-8	28.96 x 17.80	Shrimps	Cangnan, Zhejiang
Jie net	3	2x3-1x1	9.98 x 6.73	Shrimps, Icefishes, etc.	Haiyang, Shandong
Tanzi net	4	90-13.3	38.40 x 35.32	Cutlassfish, Octopus	Rizhao, Shandong
Shenshui stow net	4	110-15	35.10 x 22.18	Shrimps, Long-tailed herring, etc.	Baoshan, Shanghai
Fangang stow net	4	53-2x2	25.60 x 19.25	Bummalo, Shrimps	Yinxian, Zhejiang
Wangmen	4	80-4x4	35.84 x 36.52	Gizzard shad, Anchovies	Beihai, Guangxi
Qiheng	4	59-2x2	32.00 x 31.61	Shrimps, Anchovies, etc.	Pingtan, Fujian
Mao stow net	4	57-23	25.08 x 17.17	Baby croaker, Icefishes	Tanggu, Tianjin
Hu net	4	59-7.5	51.60 x 60.63	Anchovies, etc.	Longhai, Fujian
Yuchi net	4	70-10	23.00 x 24.54	Shrimps, Baby croaker	Sheyang, Jiangsu
Xiahu net	4	26-7	33.80 x 24.16	Baby croaker, etc.	Pingyang, Zhejiang
Chuang net	4	85-2x2	22.68 x 16.04	Shrimps, Cuttle fish, Prawns	Haiyang, Shandong
Qiang stow net	4	35-7.4	13.34 x 9.12	Shrimps, Miscellaneous fishes	Luannan, Hebei
Hemanmiao stow net	4	12-1x1	10.36 x 9.65	Elver	Cangnan, Zhejiang
Liubudai net	4	1x1	8.80 x 7.60	Chaff shrimps	Tanggu, Tianjin
Shanmen stow net	4	67-12.5	17.40 x 15.18	Bummalo, Shrimps, etc.	Linhai, Zhejiang
Daban zeng	5	270-12	91.80 x 59.63	Lanternfish, Cutlass fish, Cuttle fish	Xiapu, Fujian

[1] The type no. is explained in the text.

Traps

Stow nets

Stow nets are set mostly in the coastal areas of the East China Sea, Yellow Sea and Bohai Sea. They are fixed by stakes, anchors, masts or boats in shallow nearshore waters and catch shrimps, crabs and small fishes. The prey is driven into the net by water currents. Stow nets are next to trawls in importance in Chinese marine fish production.

There are five basic types of stow nets differing in the way the mouth of the net is kept open, and each type is subdivided into different sub-types (Table 4):

(1) *Zhanggang* (spreading rope) stow net – mouth held open by ropes;
(2) *Kuangjia* (frame) stow net – mouth stretched on frame;
(3) *Henggan* (beam) stow net – mouth kept open by upper and lower poles;
(4) *Shugan* (stake) stow net – mouth stretched on two vertical poles;
(5) *Youyi dannang* (winged single pocket) stow net – two wings set by two stakes, mouth kept open by floats and stones.

Other traps

Three other types of traps are used in Chinese fisheries. Fixed pound nets are usually constructed in tidal waters and fixed on bamboo poles or stakes. They are about 2–3m high and usually long, up to 3,000m. The prey is simply intercepted by the net or is guided into chambers or pockets. Anchored pound nets are shorter and higher than those of the fixed type, with various types of fish herding and retaining devices. Data for different kinds of pound nets are given in Table 5. Fish barriers are usually made of bamboo poles. The *yubo* (a kind of barrier used in Guangxi Province for mackerel and gizzard shad) has two guiding wings about 700m in length. Fyke nets are mostly used in freshwater fisheries and therefore are reviewed below.

Longlines

Several different types of lines are used in China: baited single-hook lines; artificially baited single-hook lines; baited multi-hook lines; hookless lines; etc. Baited single-hook set longlines are the most common. Rolling hook set longlines are similar to the former in structure, but have sharper, unbaited hooks and shorter interval between the branch lines. Data for different kinds of longlines in coastal fisheries are given in Table 6.

PASSIVE FISHING GEAR ON THE YANGTZE RIVER

Freshwater gillnets in China vary in structure, mesh size and operating period. *Daoyu* (long-tailed herring – *Coilia ectenes*) encircling gillnets in the lower reaches of the Yangtze operate from April-June. The term 'rolling hooks' is applied to set snagging longlines for silver carp (*Hypophthalmichthys molitrix*), puffers (*Fugu*), long-tailed herring, etc. They are operated by two fishermen in a small fishing boat. The lengths of the main line and branch lines are about 85m and 9cm, respectively. About 1,000 sharp, close-set unbaited hooks are carried by each longline. Both ends of the longline are anchored on the river bottom with stones. Drifting longlines, locally known as 'drifting hooks', are operated by two small fishing boats. Usually five longlines each with 100 unbaited hooks are lowered into the river during an operation. The lengths of the main line and branch lines are about 100m and 10cm, respectively. This gear can catch large fish such as black carp (*Mylopharyngodon piceus*) up to 50kg in weight and sturgeon (*Acipenser sinensis*) up to hundreds of kg in weight. Fyke nets, locally known as *mihunzhen* (brush weir) or *duanbo* (hedge), are set in shallow water along the river bank and consist of bamboo poles, panels and a pocket. The prey are guided into the pocket by wings constructed of panels.

Table 5

Pound nets in Chinese marine fisheries.

Name	Mesh size (mm)	Panel length and height (m)	Target species	Locality
Fixed pound nets				
Mi net	60-25	3000.00 x 2.85	Mullet, Prawn	Nantong, Jiangsu
Zhao net	35	2520.00 x 1.75	Mullets	Dafeng, Jiangsu
Cha net	33-16	2400 x 2.47-2.07	Mullet, Shrimps, Crabs	Fengnan, Hebei
Zu net	26.6	2000.00 x 1.33	Mullets	Dongtai, Jiangsu
Jiang net	97	1634.64 x 3.20	Butterfish, Mackerel, etc.	Dongtai, Jiangsu
Liang net	26-19	1404.54 x 1.66	Anchovies, Common herring	Zhuanghe, Liaoning
Diaoqian	25	1350.00 x 8.00	Mullet, Herrings, etc.	Nan'an, Fujian
Chuanyang net	130	1243.00 x 2.60	Hilsa herring	Nanhui, Shanghai
Qinqxia daolian net	11.1	321.30 x 2.33	Palaemon	Beidagang, Tianjin
Suoyu maodou net	50	8.35 x 0.17	Mullet	Jinxian, Liaoning
Dugu	35-12	2128.32 x 1.89	Baby croaker, Shrimp, Crab	Taishan, Guangdong
Suoyu tiao net	32-28	1148.00 x 1.30	Mullet	Shouguang, Shandong
Xuzi net	23-16.6	828.00 x 1.00	Common herring, Mackerel	Shouguang, Shandong
Chuan net	45-16	369.60 x 2.20	Mullet	Yueqing, Zhejiang
Chaxi net	32-6	200.00 x 2.35	Crab, Palaemon, etc.	Rui'an, Zhejiang
Liu net	39-36	184.86 x 1.50	Bigcod croaker, Crab	Shouguang, Shandong
Lanbo	70-30	22.40 x 3.15	Gizzard shad, Golden-lined spinefoot, etc.	Qiongshan, Hainan
Qiluo net	22	690 x 3.50-1.93	Mullet, Butterfish	Hangu, Tianjin
Anchored pound nets				
Luo net	120-40	397 x 34.22-23.6	Mackerel, Bigcod croaker	Weihai, Shandong
Dazhe net	500-60	377.84 x 24-16.7	Miscellaneous fishes	Jinxian, Liaoning
Liudai jian net	66.7-40	138.90 x 13.11	Mullet, Cuttle fish, etc.	Haiyang, Shandong
Sandai jian net	60-20	29.20 x 8.13	Flatfishes, Bigcod croaker	Laoshan, Shandong

Table 6

Longlines in Chinese marine fisheries. LML: length of the main line; IBL: interval between the branch lines, the total number of lines trolled is given in parentheses; TH: total number of hooks of a longline or that of the operating branch lines of troll lines.

Name	LML	IBL	TH	Target species	Locality
Baited single-hook set longlines					
Yaoyu longline	500.2	2.70	130	Rays	Changdao, Shandong
Shayu gang	419.2	9.02	20	Sharks, Groupers, Pike conger	Yangjiang, Guangdong
Dasha gun	470.2	7.76	18	Blue shark, Sharks	Hui'an, Fujian
Menshan gang	388.4	8.36	40	Pike conger, Sharks	Yangjiang, Guangdong
Manyu longline	227.2	3.60	30	Pike conger	Dongtou, Zhejiang
Manyu line	202.8	4.99	23	Pike conger	Lianjiang, Fujian
Hetunyu longline	326.7	0.08	60	Puffers	Putuo, Zhejiang
Heidiao longline	320.2	0.60	80	Porgy	Yinxian, Zhejiang
Huangheiyu longline	307.5	1.60	120	Greenlings, Jacopever	Dalian, Liaoning
Shibanyu longline	2007.3	1.70	600	Groupers	Fangcheng, Guangxi
Luyu longline	184.0	0.94	100	Common sea bass	Lianyungang, Jiangsu
Mianyu longline	170.0	1.30	70	Slate cod croaker, Common sea bass, etc.	Xiangshan, Zhejiang
Xiahuyu longline	127.0	0.20	250	Gobies	Leting, Hebei
Baited single-hook drifting longlines					
Majiao line	594.0	6.26	60	Mackerel	Haikang, Guangdong
Baiyu gun	456.0	1.95	126	Cutlassfish	Hui'an, Fujian
Baited single-hook troll lines					
Tuo line	26.4-130.4	(7)	7	Tunas	Wenchang, Hainan
Bienban line	100-202	(4)	460	Threadfin bream, Bigeye, etc.	Dianbai, Guangdong
Artificial bait single-hook troll lines					
Tuomao line	48.9-92.2	(8)	42	Tunas, Mackerel, etc.	Wenchang, Hainan
Majiao line	86.4	(3)	3	Mackerel	Pingtan, Fujian
Rolling hook set longlines					
Kong hook	105.0	0.11	1000	Mullet, Common sea bass	Haixin, Hebei
Ban hook	50.0	0.24	180	Rays, Flatfishes	Minhou, Fujian
Sha hook	36.0	0.14	249	Rays, Flathead	Rudong, Jiangsu

INCIDENTAL CATCHES OF SMALL CETACEANS

Baiji (*Lipotes vexillifer*)

Attention has been focused on the kill of the baiji in fisheries using rolling hook longlines and fyke nets in the Yangtze River (Zhou 1982; 1986; 1989; Lin *et al.*, 1985; Chen and Hua, 1989; Zhou and Li, 1989). Of 31 baiji found dead in the lower Yangtze between 1978 and 1985, seven were incidentally entangled by rolling hook longlines. In the middle reaches of the Yangtze, rolling hook longlines have accounted for 15 of 28 recorded deaths between 1973 and 1983. Fyke nets are another threat to the baiji. In the lower Yangtze these have accounted for five known deaths. Although the baiji is protected by the Law of Protection of Wildlife as one of the 'national protected animals' and regulations prohibiting the use of rolling hook longlines, fyke nets as well as bombing, poisoning and electric power in freshwater fishing exist, deaths and injuries caused by incidental entrapment in these gears continue to occur. For example, an injured baiji bearing dozens of hooks was seen floating near Chengdezhou Sandbar, Anhui Province, on 5 March 1990. Eight days later, an adult female baiji died because of hook injuries in the river section near Jingjiang, Jiangsu Province, about 370km downstream of Chengdezhou. It is not clear whether these were the same individual (Zhou, unpublished data). The baiji is one of the most endangered mammals of the world and is close to extinction (Perrin and Brownell, 1989). According to the census surveys and photo-identification studies conducted by researchers at Nanjing Normal University between 1989 and 1991, less than one hundred and fifty remain in over 1,700km of the Yangtze River. Incidental catches in passive fishing gears are one of the main factors that have caused the decline.

Finless porpoise (*Neophocaena phocaenoides*)

A total of 80 specimens of the Yangtze population of finless porpoise have been collected since 1974 by the Cetacean Research Laboratory of the Biology Department of Nanjing Normal University (NJNU). Most were caught incidentally by rolling hook longlines and encircling gillnets. Shi and Li (1986) reported the incidental catches of several finless porpoises at the east end of Chongming Island, located at the mouth of the Yangtze River. The finless porpoises were found in pound nets and driftnets; e.g. 11 were caught in fixed pound nets in March/April 1980. Killing of the finless porpoise in passive fishing gears (drift gillnets, stow nets and pound nets) has also occurred in the Yellow Sea off the coast of Jiangsu Province (Table 7). About 1,000 driftnetters, 700 set gillnetters and 2,000 boats using stow nets fish along the coast of Jiangsu, and thousands of other types of traps are set in the same area.

The target species of drift gillnet fisheries off the Jiangsu coast are primarily butterfish and anchovy. Usually the nets are set twice a day (in the morning and the afternoon) and retrieved 7–8 hrs later. Incidental catches of the finless porpoise in the drift gillnets have been reported on the Lüsi fishing ground off the Jiangsu coast; a net hauled on 11 April 1986 contained 2 males and 3 females.

No information on incidental catches of the finless porpoise in set gillnets has been reported so far.

Several kinds of stow nets are used in Jiangsu coastal fisheries including *tanzi, dangenfang* and *yangfang*. The number of *tanzi* netters counted in 1989 was 1,228, while that of *dangenfang* and *yangfang* netters was 496. About 40 nets are set by each of the boats during the fishing season from March through June. The fishermen haul up the pocket of the net and remove the catch every 24 hours. Sometimes a single finless porpoise is found in the pocket. Occasionally an adult female and a calf are caught in the same net.

Table 7

Incidental catches of the finless porpoise in passive fishing gear along Jiangsu coast.

Year	Date	Locality	Catch	Fishing gears
1983	Sept. 23	Ganyu	3	*Zhao* net
	Oct. 5-11	Rudong	3	*Zhao* net
	Nov. 7	Rudong	11	*Jiang* net
1984	May 15-31	Lüsi	11	Driftnet
1985	May 12	Lüsi	4	Driftnet
1986	Apr. 4-30	Lüsi	23	Stow net & Driftnet
1989	Apr. 21-May 10	Lüsi	19	Stow net & Driftnet

Most of the traps operated along the Jiangsu coast are of fixed pound net type. The *jiang* net is used primarily for butterfish and Chinese herring and is about 1,600m long. Eleven finless porpoises were caught in such a net in Nantong in November 1983. The *zhao* net is used primarily for mullets and is about 2,500m long. Incidental catches of the finless porpoise in this net were recorded in Ganyu County and Rudong County in the autumn of 1983.

Usually the carcasses of entangled porpoises are sold to local people for use as livestock feed. Therefore, while only 74 specimens have been collected from the coastal waters of Jiangsu since 1983 by NJNU, the recorded incidental catches suggest that dozens or perhaps hundreds of finless porpoises were drowned or caught in passive gear fishing in this Province annually over the past decade.

Incidental capture of the finless porpoise occurs also in the Bohai Sea and the East China Sea. Some were caught in gillnets in the Bohai Sea along the coast of the Hebei and Shandong Provinces in June and July (Wang, 1979; 1984). Ten specimens from the Bohai Sea were collected by the staff of NJNU at Xincheng, Liaoning Province in June and October 1990 (Zhou, unpublished data). Nine of these were taken in *sanceng* nets (a kind of drifting trammel net, not listed in Table 3).

Fifty-eight finless porpoises were caught in one fixed pound net set on the coast of Panshan, Liaoning Province, in June 1960, 48 in one fixed pound net set in the shallow waters of Wudi, Shandong Province in June 1959 (Wang, 1979; 1984), and another by a *liudai jian* net (a kind of anchored pound net, see Table 5) set near Xincheng, Liaoning in June 1990.

In the south part of the East China Sea, eight finless porpoises were taken by *sanchong ling* nets (a kind of drifting trammel net, see Table 3) in November 1987 near Dongshan, Fujian. Thirty individuals were caught in the same net in this region in December 1990 (Zhou, unpublished data).

Marine dolphins

One bottlenose dolphin (*Tursiops truncatus*) and one common dolphin (*Delphinus delphis*) were recorded killed in a drifting trammel net of *sanchong ling* type in December 1990 off Dongshan (unpublished data). False killer whales (*Pseudorca crassidens*) have been recorded captured in the Bohai Sea, Yellow Sea and East China Sea (Wang *et al.*, 1965; Wang, 1979; Wang, 1980; Zhou *et al.*, 1982). Some were caught in *liang* nets (a kind of fixed pound net, see Table 5) set along the coast of Liaoning Province in 1958 and 1961 (Wang, 1979) and September 1965 (Shi and Wang, 1983).

Other small cetaceans known to occur in the waters off the Chinese mainland include the spotted dolphin (*Stenella attenuata*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), rough-toothed dolphin (*Steno bredanensis*) and Indo-Pacific hump-backed dolphin (*Sousa chinensis*) (Huang *et al.*, 1978; Huang and Tang, 1979; Wang, 1979; 1982; Huang, 1980; Zhou *et al.*, 1980). No information concerning incidental catches of these species in passive fishing gear is available to date.

CONCLUSIONS

Very large numbers of gillnets, traps and longlines are set in Chinese coastal waters. Information concerning the incidental capture of small cetaceans in this gear is extremely limited. The best information available at this time indicates that large numbers of finless porpoises and a few individuals of three other cetacean species have been caught in gillnets, stow nets and other coastal traps in the Bohai Sea, Yellow Sea and East China Sea. A survey of coastal regions and fishing ports to determine the cetacean species present and document the incidental mortality of cetaceans is urgently needed.

The rolling hook longlines that are threatening the baiji in the Yangtze with extinction are illegal. The use of this gear in the middle and lower reaches of the Yangtze River must be stringently prevented. Information on fishing effort and kill rates for the Yangtze population of the finless porpoise is needed to evaluate the impact of the longline and gillnet fisheries in the river.

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Incidental Takes of Small Cetaceans in Fisheries in Palawan, Central Visayas and Northern Mindanao in the Philippines

Ma. Louella L. Dolar

Marine Laboratory, Silliman University, Dumaguete City, 6200, Philippines

ABSTRACT

Incidental takes of dolphins in fisheries in selected towns and villages in Palawan, Central Visayas and northern Mindanao are discussed. Dolphins are taken with the following types of fishing gear: troll lines, drivenets, bagnets, bottom setnets, driftnets and purse seines. The purse seines include those set by relatively small municipal boats around fish aggregating devices (FADs, locally known as *payaw*) within (and outside) 7km of shore and those set around free-swimming schools of fish by large commercial vessels operating seaward of 7km. Fishing methods are briefly described and total annual takes by each method are estimated. Dolphin species so far known to be involved are the spinner dolphin, *Stenella longirostris* (troll lines, bagnets, driftnets and purse seines); pantropical spotted dolphin, *S. attenuata* (purse seines and driftnets); bottlenose dolphin, *Tursiops truncatus* (bagnets and driftnets); Fraser's dolphin, *Lagenodelphis hosei* (driftnet and purse seines); Risso's dolphin, *Grampus griseus*, melon-headed whales, *Peponocephala electra* and pygmy killer whales, *Feresa attenuata* (driftnets). Additional species are probably taken. Only driftnet landings have been directly observed.

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; ASIA; BOTTLENOSE DOLPHIN; SPINNER DOLPHIN; SPOTTED DOLPHIN; FRASER'S DOLPHIN; RISSO'S DOLPHIN; PYGMY KILLER WHALE; MELON-HEADED WHALE

INTRODUCTION

Southeast Asia has been referred to as the 'sea of islands'. Fourteen thousand of these islands belong to Indonesia and 7,100 to the Philippines, while hundreds of others dot the Andaman and South China Seas. The countries of this region are dominated by coasts, making fishing an integral part of the industry and culture of their people (except perhaps for Singapore and Hong Kong). Indonesia, Thailand and the Philippines rank among the top ten fish producers of the world (Anon., 1986). For example, fishery products contributed $1.2 billion, or more than 5%, of the GNP of the Philippines in 1986 (Anon., 1986) and 8.75% of Thailand's total national output in 1982 (ICLARM, 1987). Given that fishery products from small scale fisheries are often not included in national statistics, the importance of fishing to these economies is underestimated even by these impressive figures.

Because of the region's heavy dependence on fishing, much research effort has focused on developing and improving fishing gear and methods to increase fish catches, often with little or no regard to the impact on either the target or non-target resources, including marine mammals. Interactions among cetaceans and fisheries are now well documented in many parts of the world (e.g. Northridge, 1984; Leatherwood and Reeves, 1989; Perrin, 1989). However, there has been no dedicated investigation of the interactions of cetaceans with fisheries anywhere in the Southeast Asian region. This paper presents some preliminary information on the types of fishing activity known to kill cetaceans in Palawan, the Central Visayas and northern Mindanao in the Philippines and estimates annual levels of mortality. Dolar *et al.* (1994) discuss directed takes of cetaceans in the Philippines.

METHODS

Information was obtained from trips on fishing vessels, visits to fish markets, and interviews with crew members and owners of commercial and municipal fishing vessels, local fishermen, market vendors and middlemen. Associates and I collected information directly in Basay and Malabuhan in Negros, Pamilacan Island in Bohol, Brooke's Point and Rio Tuba in Palawan, and Selinog and Aliguay Islands in Mindanao (Fig. 1) during the periods shown in Table 1. Information has been collected opportunistically on subsequent visits.

Table 1

Area	Dates information collected
Palawan	29-31 March 1991
Central and southern Visayan Islands	8 April 1990, 30 June 1990, 20 July 1990, January-April 1991, June 1991
Pamilacan, Bohol	30 April 1990, 1 May 1990, 10 July 1990, 5-6 April 1991
Selinog	14 February 1991, 7-8 April 1991
Aliguay	15 February 1991

During visits to fishing vessels and villages, fishermen and other knowledgeable local people were asked a series of questions.

(1) What are the different fishing methods used in this village?
(2) Which of these methods are known to catch dolphins?
(3) Please describe at least the size of the fishing vessel(s), the type and size of the net(s) used, the number of people employed and the procedures involved.
(4) May I see the boat and equipment you use in fishing.
(5) How many of these (boats, gear) operate in this village?
(6) Where do these boats fish?
(7) How long does one fishing operation take?
(8) How many operations do you conduct in one day, one month, one year?
(9) Is fishing seasonal? At what time of year does fishing peak?

(10) What is/are the target species?
(11) How many dolphins are accidentally caught in one fishing operation?
(12) What are the kinds of dolphins taken incidentally? (Determined by the interviewee's unprompted review of illustrations by Pieter Folkens in Reeves and Leatherwood (1987) and the poster 'Cetaceans of the World' by Pieter Folkens, and photographs in Reeves and Leatherwood (1987), Leatherwood and Reeves (1989) and Leatherwood *et al.* (1988)).
(13) Does the dolphin bycatch vary within the year? What time of year is the dolphin bycatch the highest? The lowest?
(14) What do you think influences the changes in dolphin bycatch?
(15) What do you do with the dolphins caught accidentally? Release them, catch and eat them, or sell them to markets?

For the driftnet fishery at Malabuhan, Siaton, Negros, data on number, length and sex of dolphins landed during the period February through June, 1991 were collected by a resident student trained by myself. I determined species of the dolphins by examining colour photographs taken by the student. The number of boats fishing each day and the number of dolphins taken by each boat were also monitored. Data for purse seiners fishing off southeastern Negros were collected during actual fishing trips.

RESULTS

There are five fishing methods/gear known to kill cetaceans in the studied areas of the Philippines: (in descending order of probable impact) purse seines, driftnets, bottom setnets, 'bagnets' and drive nets, longlines with multiple hooks and tuna troll lines.

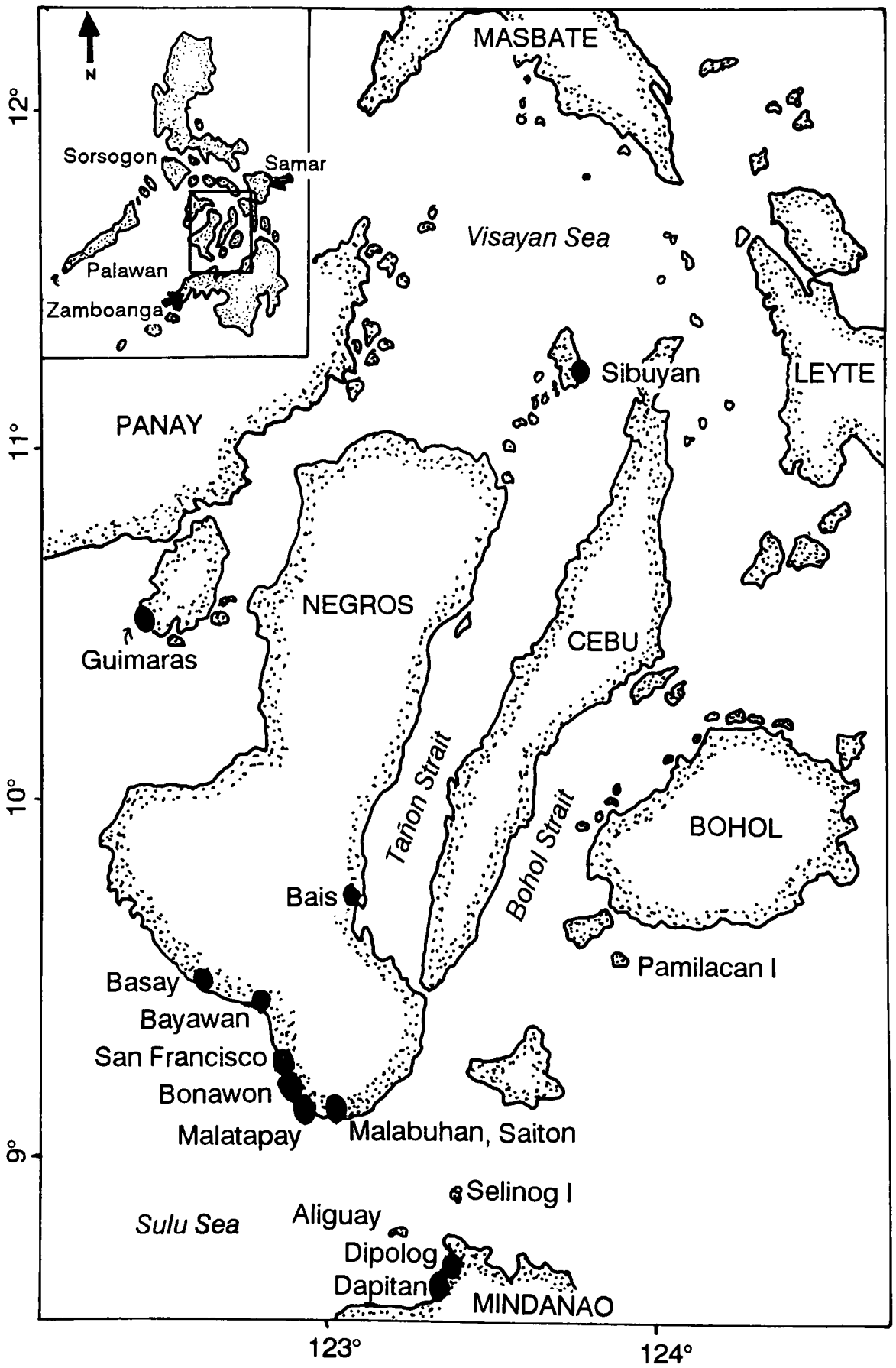


Fig. 1. Map of Central Visayas and northern Mindanao, Philippines. Palawan is the westernmost island shown in the inset.

Purse seines

There are both 'municipal' and 'commercial' purse seiners based in the Philippines. The municipal boats are generally smaller and lighter (<10 GRT), are widely based and may fish within 7km of the shore. The commercial boats are larger and heavier (>100 GRT) and fish largely around Palawan and in the Sulu Sea (Fig. 1). Cetacean bycatch in purse seines was investigated out of the small fishing town of Basay, located on the southwestern shore of Negros Island (Fig. 1). The region of the Sulu Sea off Basay has one of the country's many tuna fisheries and is visited annually by large numbers of purse seiners. The vessels fish in the Sulu Sea for six months each year during the northeast monsoon (November-April), when both coastal and offshore areas are shielded from strong winds by Negros Island. At other times of the year, they fish in various other areas (Fig. 1): Sibuyan (May), Samar (June-August), Masbate (August), Burias in Sorsogon (September-October), and Guimaras (May-October). During my eight days of observations in 1989–90 I saw five purse seiners and nine fish carriers operating in the area. The latter are vessels that collect catches from the seiners and ferry them to port for sale and processing, leaving the seiners to continue fishing.

Commercial purse seiners

The vessel whose operations I observed was *Catcher 1*, a 25m x 6m mechanised commercial purse seiner catching tuna for local markets. It is a steel hulled vessel of 142 GRT with a catch capacity of 80 metric tons, equipped with sonar for locating fish and a power block for hauling the net. It is manned by a crew of 32 (captain, masterfisherman, two assistant masterfishermen and 28 net handlers, swimmers and auxiliary boat handlers). There are four auxiliary motorised boats, two with outriggers and two without. One of the four (the light boat) has lights for attracting fish. The net is 400 fathoms long (about 740m), 60 fathoms deep (about 110m) and has a mesh size of 2.5cm near the bottom and 5cm near the top. It is made of no. 36 nylon twine. The floats are 11–13cm in diameter and attached at intervals of 5–10cm.

Both commercial and municipal purse seining in the Philippines may or may not involve the use of a fish shelter or aggregating device (FAD or *payaw*). Both techniques are practised in Basay, for example when the owner of a FAD requests that a purse seine captain catch the fish for an agreed share.

The traditional *payaw* consists of one or two layers of bamboo (approximately 5–10 poles, each about 10m long)

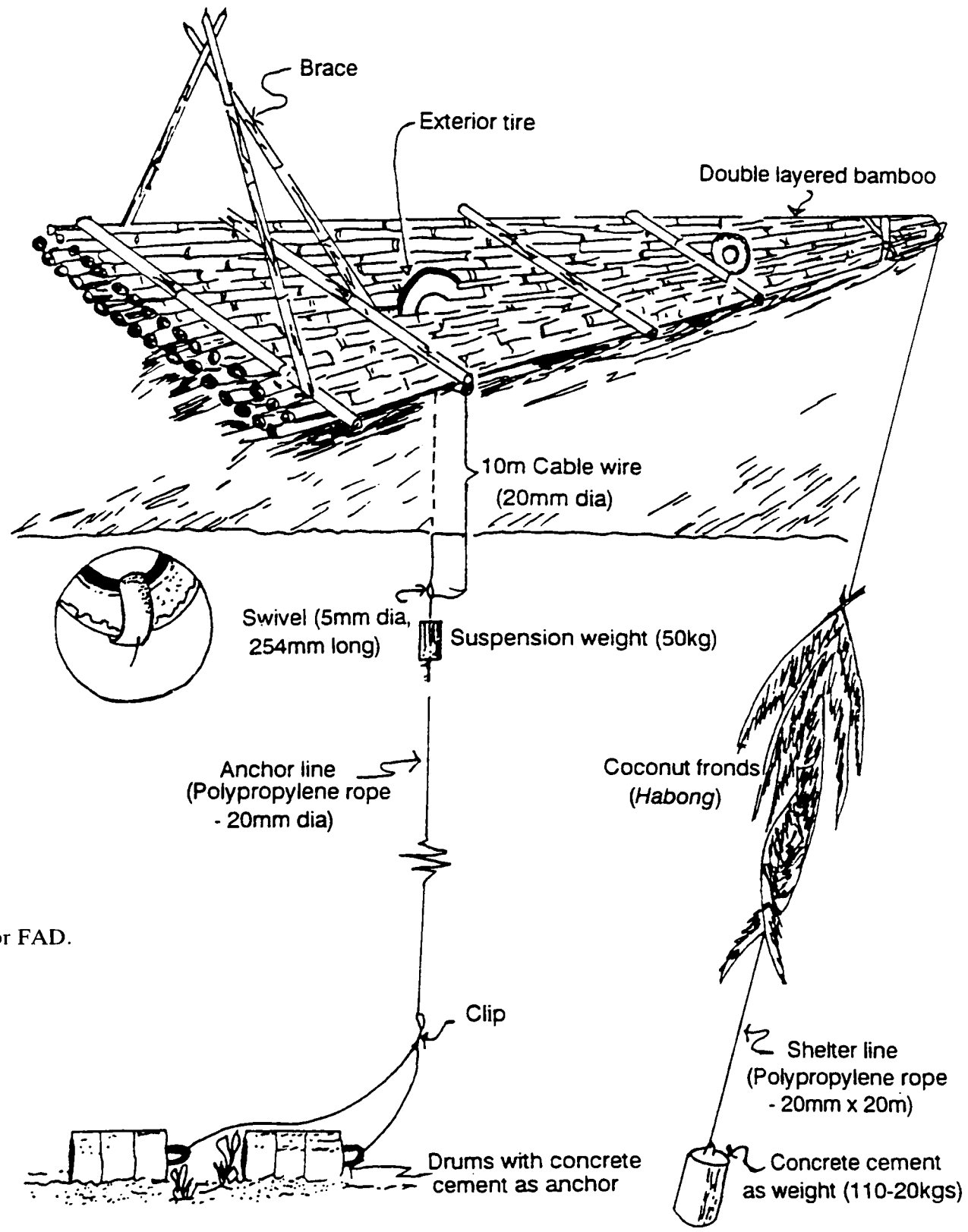


Fig. 2A. *Payaw* or FAD.

tied together as in a raft. It is rigged beneath with bundles of twigs and coconut fronds and is anchored with a steel barrel filled with concrete and rocks (Fig. 2A). A new modification uses a steel buoy 1.5m in diameter instead of bamboo poles. The *payaw* is set at a predetermined location, tagged with the owner's tag and periodically checked for the presence of tuna and other pelagic fishes. *Payaws* are anchored in 500 to 2,500 fathoms of water (900m-4,600m), a few hundred meters to several km offshore.

The seiners leave port at 1800hrs almost every day throughout the fishing season. When the *payaw* is reached, fish biomass is estimated with sonar or by a swimmer, who makes his estimate based on the amount of bioluminescence activated by the fish. If biomass is high, the fish are harvested. The light boat moves near the *payaw* to attract the fish and then moves slowly away, taking the fish with it. At the same time, the *payaw* is moved in the opposite direction by an auxiliary boat, until light boat and *payaw* are approximately 500m apart. With the FAD out of the way, the seiner, with the help of another auxiliary boat, surrounds the school of fish with the net. When the school is completely surrounded, the seiner retrieves the leadline to close the bottom of the net and hauls the net until the remaining bag is of manageable size. The catch is brailed using a scoop net and the *payaw* is put back into position. The FAD will be fished again after two or three months. The fishing operation lasts two to three hours. The total trip, including travel time, takes 10–14 hours. Catches are transferred to carrier boats near shore for distribution to various landing areas in Visayan cities and sometimes in Manila. Catches are sold in local markets.

The masterfisherman on *Catcher 1* roughly estimated (no record was available) that each of the five seiners caught 120 metric tons of fish per month. If correct, this means that the fleet catches 2,400 to 3,600 metric tons during the four to six months of the season.

Among the major fish species caught are: yellowfin tuna, *Thunnus albacares*; bigeye tuna, *T. obesus*; Indian mackerel, *Rastrelliger kanagurta*; bullet mackerel, *Auxis rochei*; frigate mackerel, *A. thazard*; eastern little tuna, *Euthynnus affinis*; narrow-barred Spanish mackerel, *Scomberomorus commerson*; pompano dolphinfish, *Coryphaena equiselis*; needlefish, *Belonia* sp.; and golden trevally, *Gnathanodon speciosus*.

Although I did not witness any cetacean kills during my trip on *Catcher 1*, interviews revealed that sizable numbers of dolphins are caught by purse seiners in this area. For example, *Catcher 1* caught 60 dolphins in a single set two days before I boarded the boat and another 20 in a set two weeks earlier. Seven interviews of crew members and the captains of other vessels confirmed these estimates. This suggests that one seiner catches an average of five dolphins per trip/day/set, or (assuming 15 days of fishing a month) 300–450 during the four to six month season. This extrapolates to 1,500–2,250 dolphins per season for the fleet of five seiners, or one dolphin for every two tons of fish caught. This is of necessity a very rough estimate because of the small sample of vessels and sets upon which it is based. Information on the total number of purse seiners in the Philippines or on the proportion of sets made on FADs is not available.

From descriptions and photographs, the dolphins caught appear to include pantropical spotted dolphins, *Stenella attenuata* (easily identified by the spots); spinner dolphins, *S. longirostris*; and Fraser's dolphins, *Lagenodelphis hosei*.

The dolphins are sometimes kept for sale. Only a small part of the dolphin catch of the Basay-based seiners is sold at the Basay market. A large proportion is transported to other ports, e.g. Bayawan and Bais (Fig. 1) where dolphin meat is more highly valued.

Municipal purse seiners

The 'municipal' purse seiners (locally called *kubkub* or 'ringnet') are similar in structure and mode of operation to the commercial seiners but are slightly smaller (15–20 x 6m) and often lack sonar. Some also lack a power block. They are usually constructed of wood, making them considerably lighter (≤8 GRT) than the steel commercial seiners. Each is manned by a crew of 26 (captain, masterfisherman and 24 hands) and can operate both in municipal (to 7km offshore) and oceanic waters. The net is 250 fathoms (about 460m) long (some 60% of the length of the commercial net) and 80 fathoms (150m) deep. It is made of no.7 twine, lighter than that used in the commercial nets. Mesh size is 2.5cm near the bottom and 5.0cm near the top. There are two corkline configurations: one using large 30cm floats placed 4m apart and another using 10cm floats at 11–20cm intervals. Ten of these vessels operate in the Basay area during the fishing season (November-May), fewer at other times of the year. From June to October, some vessels fish elsewhere, e.g. on the lee side of Negros, Bohol and Mindanao Islands.

Each fishing trip lasts about 10–12 hours. Roughly the same fish species are captured as by the commercial seiners. Although some *kubkubs* employ carrier boats to transport fish to distant cities where the demand is higher, most return to their home port to sell the catch.

Interviews with boat crews, owners and fish vendors revealed that each of the ten Basay-based *kubkub* caught about three dolphins a week (five fishing days). This extrapolates to an average of 48 dolphins killed per four-month fishing season per boat, or 72 in a six-month season. Thus the ten *kubkub* in the Basay area alone may account for the deaths of very roughly 480–720 dolphins during the principal fishing season. The ten boats catch about ten dolphins during the remaining six to eight months, raising the total to 490–730.

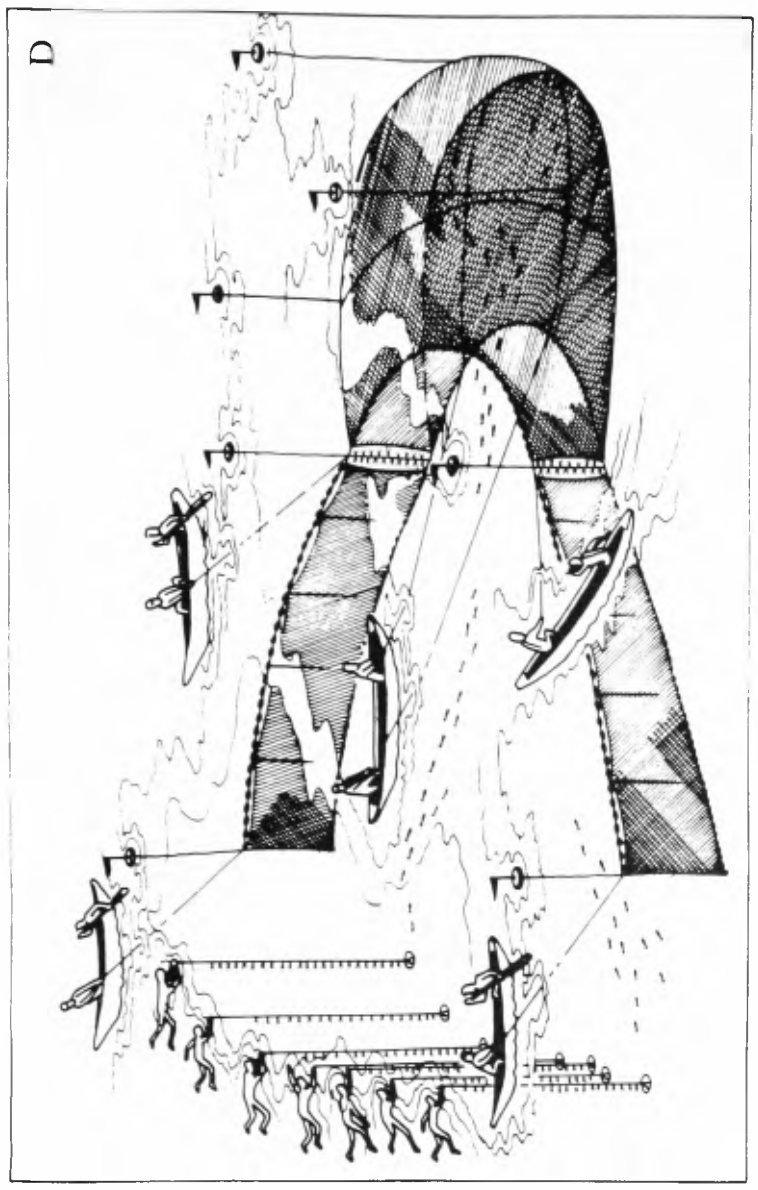
If these figures and those for the commercial purse seiners are correct, then some 2,000–3,000 dolphins may be dying in purse seining operations based at one Philippine town alone. It may be possible to estimate the kill for the Philippines overall if the total number of registered commercial and municipal purse seiners and the total number of fishing days were known; this, in addition to the accumulation of more reliable incidental capture data, should be made the goal of a long-term research programme.

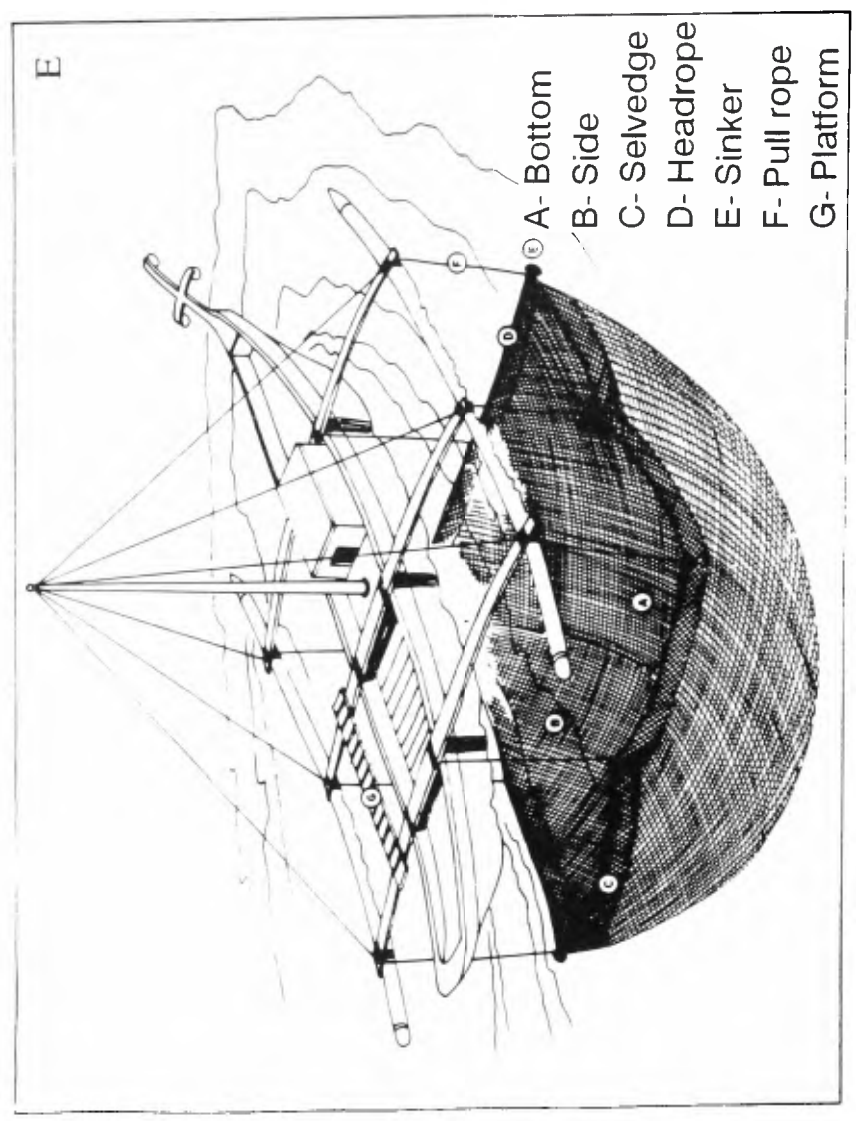
Driftnets

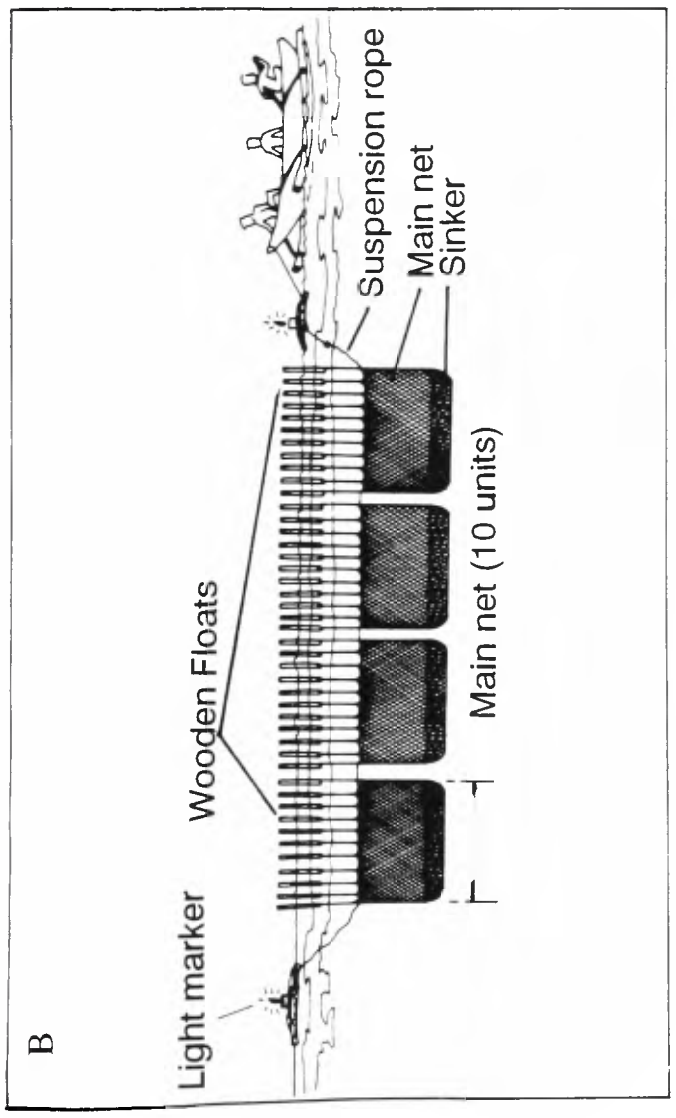
Driftnet fisheries in the study sites visited in the central Visayas and northern Mindanao involve the use of a 10m inboard-powered boat with outriggers, a 500–3,000m x 18m multifilament net with a mesh size of 15cm and kerosene lamps floated on the surface at regular intervals to mark the position of the net (Fig. 2B). The lamps prevent the net from being run over by other boats at night and aid in retrieval of the net in problem sets.

Malabuhan, Siaton, Negros Island

There are 50 driftnet vessels based in Malabuhan and fishing in the Sulu Sea (Fig. 1). Their nets range from 1–3km in length and are 18m deep. Fifteen of the vessels are







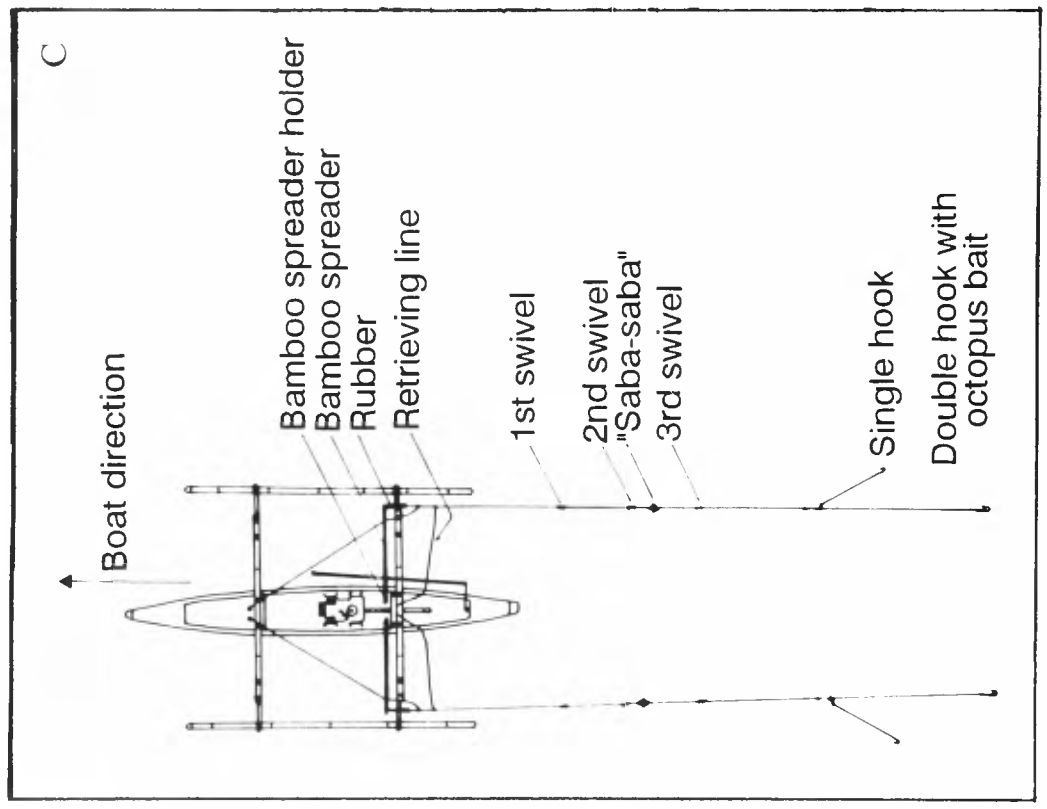


Fig. 2B–E. Other gear in which dolphins are incidentally caught.
(B) Driftnet for tuna.
(C) Troll lines.
(D) Drive net.
(E) Bagnet.

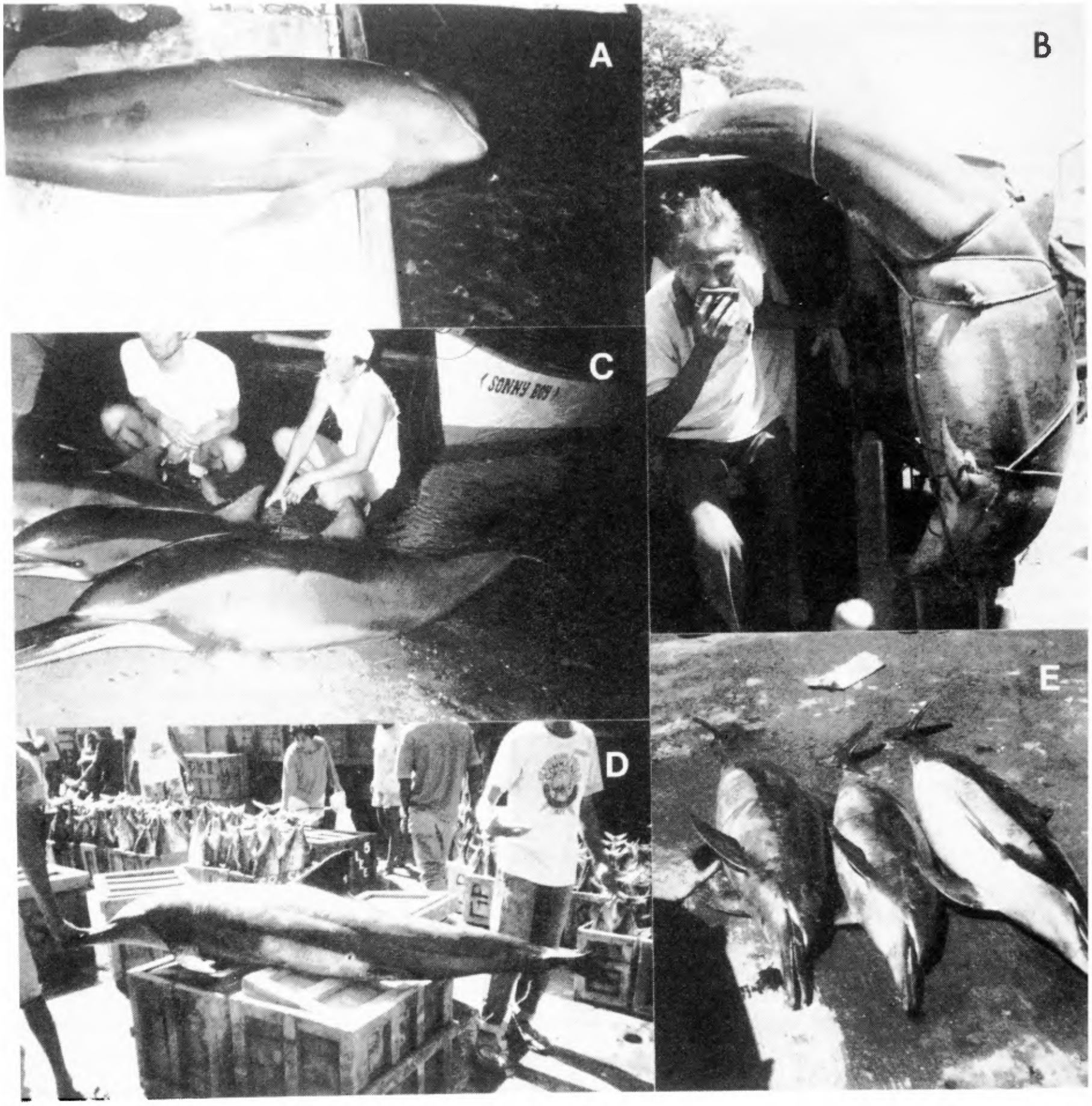


Fig. 3. Dolphins caught in driftnets (A-D) and purse seine (E). (A) Risso's dolphin. (B) Fraser's dolphin. (C) Spinner dolphin. (D) Spinner dolphin, with yellowfin tuna at the Dumaguete fish market, Negros. (E) Spinner dolphin caught by purse seiner off Basay, Negros; at Bayawan fish market.

owned by village residents who fish year round. The other 35 are owned by residents of northeastern Mindanao, who are based in this area during the principal fishing season from January to June. During this period, vessels usually fish 23 days a month, taking about seven days a month to repair the nets, boats and other gear. On any one day from January to June (seven days a week), 11–19 driftnet vessels are at sea fishing (1,980–3,420 vessel fishing days). Estimates of effort during the rest of the year (monsoon season) cannot be made, because fishing is highly variable, depending on the weather.

These driftnetters depart at 1500–1630hrs and reach the fishing grounds between 1700 and 1800hrs, setting their nets as soon as possible thereafter. Nets are often set when dolphins are seen in the area, as the fishermen believe that tuna schools are associated with dolphins. During my voyage with the fishermen, we observed Risso's (*Grampus griseus*), spinner and Fraser's dolphins. Setting the net usually takes 45–90 minutes; soaking time is usually 5–6 hours. The nets are pulled manually, which usually takes 2–3 hours. The catch usually consists mainly of yellowfin tuna ranging from 50 to 80cm in length. Other species caught (based on direct observations and photographs) include swordfish, *Xiphias gladius*; and manta rays, *Manta* sp.

The catch was monitored at the landing site for 16 days between 17 February and 4 June 1991. A total of 50 dolphins were landed (Fig. 3): 20 (40%) Fraser's dolphins (147–240cm long), 18 (36%) spinner dolphins (78–225cm) and 12 (24%) Risso's dolphins (105–300cm) (Table 2). The

Table 2

Dolphin bycatch of the driftnet fishery off Malabuhan, Siaton Negros, during the sixteen observation days. F = female; M = male; T = total; * sex not determined; nc = not counted.

Date	*S. longirostris*			*L. hosei*			*G. griseus*			Total	No. boats went fishing	No. boats with dolphin bycatch
	F	M	T	F	M	T	F	M	T			
17/02/91						1 *				1	nc	1
12/02/91									1 *	1	nc	1
23/03/91						4 *				4	nc	3
26/03/91						1 *			2 *	3	nc	3
06/04/91		4	4	1	1	2	1	2	3	9	19	5
08/04/91	1		1		1	1				2	15	2
09/04/91		2	2							2	11	2
19/04/91		1	1	1	2	3	3		3	7	16	5
20/04/91	3	5	8	1	1	2		1	1	11	nc	8
14/05/91					1	1				1	nc	1
20/05/91		1	1							1	nc	1
21/05/91						2 *				2	nc	2
22/05/91			1 *						1 *	2	nc	2
23/05/91									1 *	1	nc	1
03/06/91						2 *				2	nc	1
04/06/91						1 *				1	nc	1
Total	4	13	18	3	6	20	4	3	12	50	x=15	x=2.4
%		36%			40%			24%				
Lactating females	2 (167 & 180cm)			2 (190 & 22.5cm)			2 (180 & 267cm)					
Size range (cm)	78-225			147-240			105-300					
Mean no. of dolphins caught/day (all boats) = 3.1 ± 1.8												

majority (62%) of the dolphins caught were between 175 and 225cm long. The sex ratio (M:F) was 3:1 for both spinner and Fraser's dolphins and 1:1 for Risso's dolphins. At least half of the females of each species (all landed from April to June) were lactating (Table 2). One female was entangled together with a 105cm calf.

Four more species have been reported caught in recent years: the melon-headed whale, *Peponocephala electra* (1992); the pygmy killer whale, *Feresa attenuata* (1993, 1994), the bottlenose dolphin, *Tursiops truncatus* (1992, 1993) and the spotted dolphin (1992, 1993, 1994).

During the four days when the number of boats fishing was noted, 11–19 boats went out and 2–5 caught dolphins. The average dolphin bycatch per day during the 16 days of observation was 3.1±1.8. If these preliminary figures are taken as representative of the fishing effort and catch from January to June, the total bycatch would be about 428 dolphins (3.1 x 23 fishing days/month x 6 months). I learned through interviews with fishermen and market vendors that there is no dolphin bycatch during the rest of the year.

Pamilacan Island

There are 30 0.5–3km x 14–18m driftnets with a mesh size of 2.5cm at Pamilacan Island. They are used to catch clupeids and needlefishes. The nets are set for 12 hours, often at night, each day during the fishing season, March-June. They are known to entangle a few dolphins (roughly 20 per season). During visits to the island, I found a Fraser's dolphin which had been recently caught and a few skulls of spinner dolphins scattered on the beach. Based on descriptions by fishermen, the pantropical spotted dolphin may also be caught in the area.

Aliguay and Selinog

Fishermen from Aliquay and Selinog, two small islands (*ca* 60ha) in the Sulu Sea off northern Mindanao (Fig. 1) use a total of 40 driftnets (1km x 18m, mesh size 11cm) from December to May. Cetacean species caught probably include spinner, spotted, Fraser's and Risso's dolphins.

Setnets

At Selinog Island, 30 setnets (120 x 54m, mesh size 35cm), mainly used to catch manta rays, also catch some dolphins. This fishing gear has been used here longer than driftnets and is the first known to capture dolphins here. The fishermen estimate that roughly three to four dolphins are caught per net each fishing season. This amounts to about 90–120 dolphins per year.

Other fishing methods

Other gear known to catch dolphins on rare occasions (Fig. 2) are multi-hook longlines set to catch pelagic fishes (Selinog), troll lines (Bonawon), drive nets (in waters around Palawan), bagnets (Rio Tuba, Palawan) and bottom setnets (Rio Tuba and Brooke's Point, Palawan). Estimates of bycatches cannot be made.

Utilisation of the bycatches

Dolphin meat is acceptable for human consumption in some places in the Philippines but not in others. Markets known to sell dolphin meat are located in Basay, San

Francisco, Bonawon, Malatapay, Bayawan and Bais in Negros and Dipolog and Dapitan in Mindanao (Fig. 1). In the first four of the above, a 50kg dolphin can be sold for P6.00/kg ($US=P27). Visceral organs, including heart, liver, stomach and intestines, are also sold; liver fetches a higher price of P9.00/kg. In Bais and Bayawan, a 50kg dolphin can sell for P400 at the market place (to vendors); the retail price for meat and viscera is P15/kg. Dolphins caught at Selinog Island are sold to middlemen for P100–150 (for a 80–100kg dolphin). In addition, teeth are sold at P1.25 each in Zamboanga in Mindanao, where they are set in gold and worn as pendants. In addition to being sold in fish markets, dolphin meat is also consumed locally in Selinog, Pamilacan and Aliguay.

Dolphins are also used as bait for tiger sharks, *Galeocerdo cuvieri* and blacktip sharks, *Carcharinus springeri*. Fishermen at Pamilacan and Selinog Islands and in some parts of Negros use blood and blubber as shark bait. They place blood inside a plastic bag tied shut with a long cord and weighted with lead. The bag is lowered into the water and the blood released by pulling on the cord. Blubber is considered by some to be a superior bait for sharks, because it is difficult to remove from the hook. The shark makes several passes at the bait, increasing the chances of it being caught. At Brooke's Point, dolphin meat is used as bait for nautilus.

DISCUSSION

The high dolphin mortality in the Basay area during the months November – May period may be attributed not only to increased fishing effort due to fair weather but also to increased abundance of small tuna, which move close to the coast at this time of year (personal observation). Local people often refer to this season as *tingkapaw* or 'season for small tuna' when large schools of small tuna move inshore. The Sulu Sea off the west coast of Mindanao and the South China Sea off the west coast of Palawan have been identified as principal spawning areas and nursery grounds for yellowfin tuna and skipjack tuna, *Katsuwonus pelamis*, in the West Pacific. Peak spawning time is April to July for skipjack and October to December for yellowfin tuna (Aprieto, 1987).

The use of FADS to aggregate fish, especially juvenile tuna, needs to be reviewed. Combined with purse seining, it can increase cetacean mortality and reduce tuna stocks to suboptimum levels. The efficiency of *payaw* in aggregating juvenile tuna makes dolphins more susceptible to being caught by *kubkubs*, since dolphins are attracted to the schools of small tuna which aggregate to feed on smaller fish. In addition, the *payaw*/purse-seine operation may cause overexploitation of tuna by catching juveniles before they reach reproductive maturity. If tuna catches decrease, fishermen may be encouraged to catch more cetaceans to compensate for the reduced fish catches, as has been observed in Peru (Perrin, 1989) and Sri Lanka (Leatherwood and Reeves, 1989).

The use of driftnets is becoming more popular on the Island of Negros. For example, seven years ago, there were only three driftnets owned by locals in Malabuhan, Siaton. The number has since increased to fifteen and there are plans to buy more. This increasing popularity of driftnets may have been engendered by fishermen visiting from Surigao, Mindanao who obtained their nets and boats through a government loan about ten years ago, under the *Biyayang dagat* or 'Blessings from the sea' program.

In December 1992, the Department of Agriculture issued Administrative Order No. 185, banning the 'taking or catching, selling, purchasing, possessing, transporting and exporting of dolphins'. Although the order stopped the sale of dolphins openly in the markets, it did not stop incidental or direct killing of dolphins in many places (e.g. Malabuhan, Selinog and San Francisco). The impact of the ban on incidental catches requires investigating.

Observations to date indicate that there are significant numbers of cetaceans killed during fishing operations in many parts of the Philippines. This is probably the case throughout Southeast Asia (IWC, 1994). Governments have tended to ignore this problem because of the more pressing concerns of increasing population and poverty. The population of the Philippines is growing at an annual rate of 2.9% and that of Indonesia at 2.2%. Poverty in coastal areas forces people to exploit the existing living resources beyond sustainable limits. Regulation is difficult in areas where poverty abounds. In fact, further development of fisheries is encouraged in many parts of Southeast Asia despite evidence of resource depletion. Overfishing seems to be the rule rather than the exception. Pauly (1989) contends that

> 'because the economies of Southeast Asian countries are 'developing', policymakers generally assume that the fisheries sector also needs to be developed...with the exception of Singapore, which imports most of its fish, the fisheries of Southeast Asian countries are in decline due to overexploitation. Fishing effort in the Philippines as a whole is two to three times in excess of optimum exploitation rates and even Brunei Darussalam, although its fishery is not as strongly exploited as in other Southeast Asian countries, shows a declining trend.'

Until poverty is alleviated, governments become serious in their implementation of laws and the public realises that it is counterproductive to 'kill the goose that lays the golden egg', problems of fishery resource overexploitation, together with the slaughter of dolphins, shall prevail.

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A Review of the Japanese Squid Driftnet Fishery with Notes on the Cetacean Bycatch

Akihiko Yatsu, Kazuhiko Hiramatsu and Shigeo Hayase

National Research Institute of Far Seas Fisheries, 7–1 Orido 5 chome, Shimizu-shi, Shizuoka, 424 Japan

ABSTRACT

The Japanese squid driftnet fishery began in 1978 in the northwestern Pacific, targeting the flying squid, *Ommastrephes bartrami*, and was effectively closed in 1992. In response to the rapid growth of the fishery, the Japanese Government adopted a limited-entry licensing system in 1981, under which various regulations were implemented. The regulations established a seven month fishing period from 1 June to 31 December, and a fishing area between 20°N and 46°N and between 170°E and 145°W; the northern boundary changed monthly to minimise the bycatch of salmonids while maintaining the squid catch. Fishing effort was mostly confined to the north of 38°N. Most squid driftnet vessels were also engaged in other fisheries during the year. They were usually converted from salmon driftnet, long-line, jig and trawl vessels. Their gross tonnages ranged from about 60 to 500 GRT. A typical vessel deployed about 1,000 tans of net per operation. A tan is a unit of gillnet with a length and depth of 30–50m and 7–10m respectively. The net material was nylon monofilament and the mesh size ranged from 110–135mm, but mostly 110–120mm. The number of licensed vessels gradually decreased from 534 in 1981 to 231 (actually operated) in 1992, while the number of operations (fishing days) per year fluctuated between 13,775 and 35,549 during 1983–92. The total number of tans (not standardised) deployed per year gradually increased from 21 million (1982) to 36 million (1986) and then became stable at 32–36 million (1987–89). The total number decreased to 16 million tans in 1992. The annual flying squid catch also fluctuated between 123,719 and 215,778 tonnes, resulting in annual average catch rates of 3.8–7.9 t/day or 7.2–8.6 kg/tan. The estimated total cetacean bycatches for the 1989, 1990 and 1991 fishing seasons respectively are: 3,065, 3,093 and 3,204 (Dall's porpoises), 12,449, 7,909 and 9,320 (northern right-whale dolphins), 6,154, 4,447 and 3,784 (Pacific white-sided dolphins), 286, 562 and 1,035 (common dolphins), and 1,079, 624 and 664 (other and unidentified cetaceans). Possibilities for mitigating the bycatch of the cetaceans are discussed with respect to (1) the modification of driftnets including subsurface nets and smaller mesh size, (2) time-area regulation and (3) squid jigging.

KEYWORDS: INCIDENTAL CAPTURE; NORTH PACIFIC; MANAGEMENT; SQUID FISHERIES; DALL'S PORPOISE; RIGHT WHALE DOLPHIN; PACIFIC WHITE-SIDED DOLPHIN; COMMON DOLPHIN; STRIPED DOLPHIN; SPOTTED DOLPHIN; SPINNER DOLPHIN; BOTTLENOSE DOLPHIN; RISSO'S DOLPHIN; SHORT-FINNED PILOT WHALES; FALSE KILLER WHALES; SPERM WHALE; PYGMY SPERM WHALE; CUVIER'S BEAKED WHALE; HUMPBACK WHALE; BLUE WHALE; MINKE WHALE; SEI WHALE; BRYDE'S WHALE; FIN WHALE; RIGHT WHALE

INTRODUCTION

The flying squid, *Ommastrephes bartrami*, is an oceanic species which attains over 50cm in mantle length and over 4kg in weight. Japanese fishermen began a commercial jig fishery for this species in 1974 in order to compensate for the drastic decline in the catch of the Japanese common squid, *Todarodes pacificus*, around Japan (cf. Osako and Murata, 1983). The largest annual catch (124,000 tonnes) of flying squid by the jig fishery was recorded in 1977 (Murata, 1990).

Driftnet fishing, introduced in 1978, proved much more effective for this species than jigging (Osako and Murata, 1983) and as a result jigging effort decreased and driftnet effort rapidly increased. The rapid expansion of the squid driftnet fishery was also influenced by a combination of: (1) the decline of distant water fisheries, especially the Japanese salmon driftnet fishery, in the late 1970s and early 1980s; and (2) the location of the fishing grounds in the high seas of the North Pacific outside the EEZs (exclusive economic zones) of other countries. Korea and Taiwan began squid driftnet fishing in 1979 and 1980 respectively. This fishery became one of the most important fisheries for these three Asian nations. In the late 1980s/early 1990s annual catches were between 200,000 and 300,000 tonnes.

The fishery became a high seas management problem for a number of reasons, including the take of non-target species (marine mammals, sea birds, salmonids and juvenile albacore) and their conservation, and problems of lost and discarded nets and subsequent navigation safety (FAO, 1990; Garcia and Majkowski, 1990). Since 1984, the Fisheries Agency of Japan has conducted scientific research surveys on flying squid using driftnets and jigging gear. A scientific observer programme began in 1988 to obtain catch rates and information on the biology of various marine organisms that were incidentally caught by the commercial fishery. The programme was expanded in 1989 as a cooperative study between Canada, Japan and the USA. It was further expanded in 1990 in order to be able to obtain statistically reliable catch rates. More than 50 documents on this fishery, including those on incidental take and net debris, have been submitted to the International North Pacific Fisheries Commission (INPFC). A worldwide moratorium on the high seas driftnet fishery took effect at the end of 1992 according to the United Nations General Assembly Resolution 46/215. This effectively closed the Japanese squid driftnet fishery. Yatsu *et al.* (1993) described this fishery.

DESCRIPTION OF THE FISHERY

Designated landing ports

Each vessel had to select five out of the 39 ports designated by the Ministry of Agriculture, Forestry and Fisheries for landing the catch from the squid driftnet fishery (Fig. 1). The major landing ports were Hakodate, Hachinohe, Hanasaki, Kushiro, Shiogama and Kesennuma.

Target species

The target species was the flying squid, *Ommastrephes bartrami*. Its biology has been discussed by Naito *et al.* (1977), Roper *et al.* (1984), Murata (1989; 1990) and Murata and Hayase (1993) and is summarised below. It is an oceanic species occurring worldwide in subtropical and

temperate waters (7–24°C surface water temperature). The maximum mantle length and body weight are about 50cm and 4.5kg for females and 39cm and 1.6kg for males. Although its life span is assumed to be about one year, some females probably live longer than that. The Japanese driftnet fishery mainly exploited the larger animals (mostly females of 35–50cm in mantle length) due to mesh selectivity.

The flying squid undertakes seasonal migrations. In the North Pacific, spawning occurs south of about 32°N in the winter, spring and possibly autumn. The squid then migrate to the north, feeding around the Sub-arctic Boundary in the summer (females are found in higher latitudes than males) and then returning to the south in the autumn and winter. During the feeding season, diurnal vertical migration has been observed between near surface waters at night and deeper layers (about 300–600m) in the daytime. Flying squid feed on fish (lantern fishes, sardines, saury, etc.), squid (including a high percentage of cannibalism) and pelagic crustaceans.

Okutani (1977) estimated a total potential catch of 150,000–600,000 tonnes for this species in the North Pacific. This figure was obtained prior to the start of the driftnet fishery and although its lower figure has been exceeded by the fishery, the upper figure seems plausible. Osako and Murata (1983) postulated an annual sustainable catch in the jigging grounds west of 170°E in the North Pacific at 80,000–150,000 tonnes.

Regulation of fishing season and area

The Japanese squid driftnet fishery began in 1978 in the northwestern Pacific and then expanded rapidly to the central North Pacific in 1979 and 1980 (Osako and Murata, 1983). In response to its rapid growth, the Japanese Government adopted a limited-entry licensing system for this fishery in 1981 under which various regulations were implemented. The regulations established a seven month fishing period, from 1 June to 31 December and a fishing area between 20°N and 46°N and between 170°E and 145°W. The northern boundary changed monthly to minimise the incidental take of salmonids while catching squid (Fig. 2). In 1981 the northern boundary was designated as 40°N for June and December, 42°N for July and November, 44°N for August and October, and 46°N for September (Fisheries Agency of Japan, 1982; 1985b; Nakata, 1987). After 1989, it was designated as shown in Fig. 2. Fishing effort has been mostly confined within 2–3° latitude of the northern boundary.

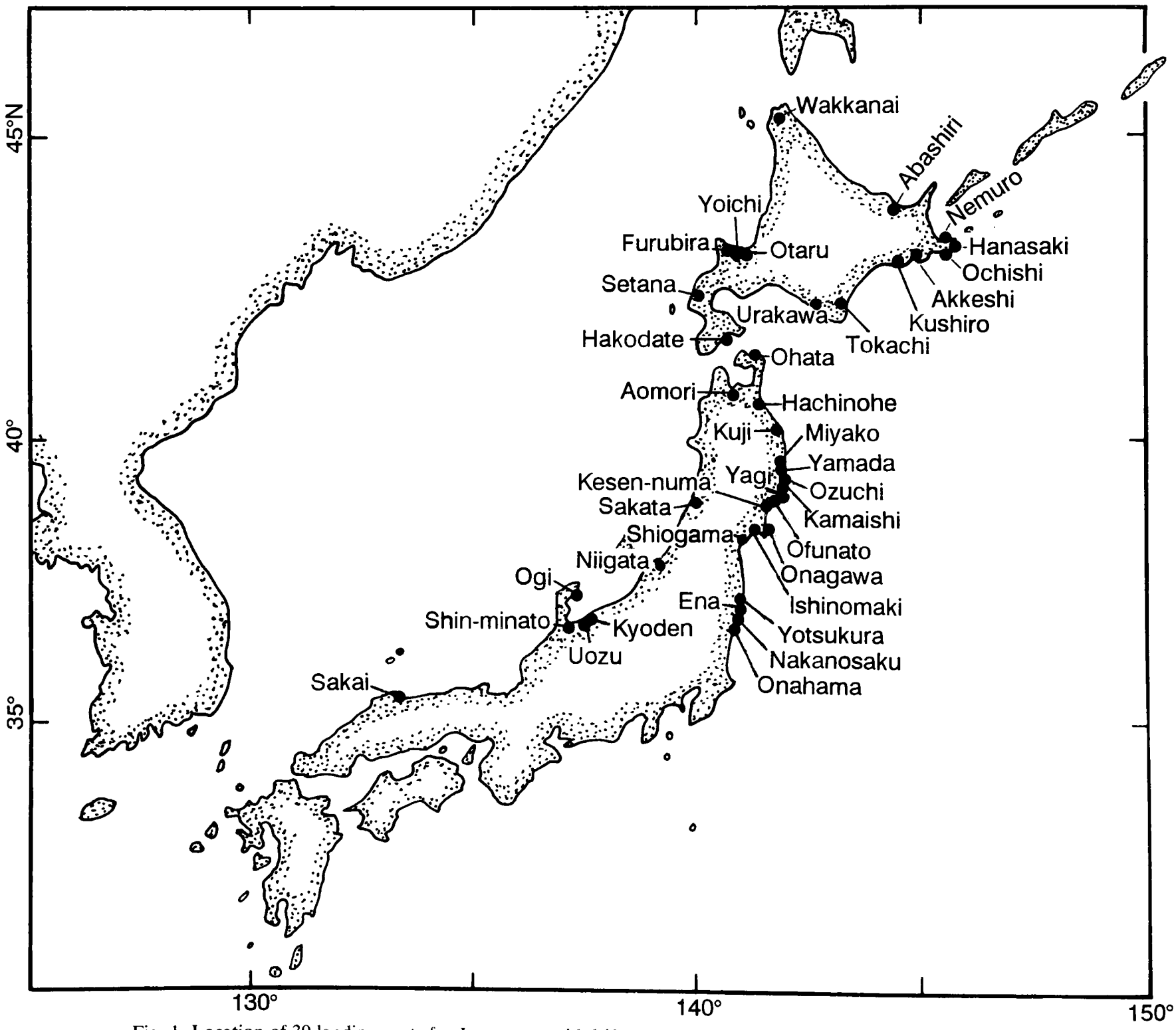

Fig. 1. Location of 39 landing ports for Japanese squid driftnetters. Landing is not permitted for other ports.

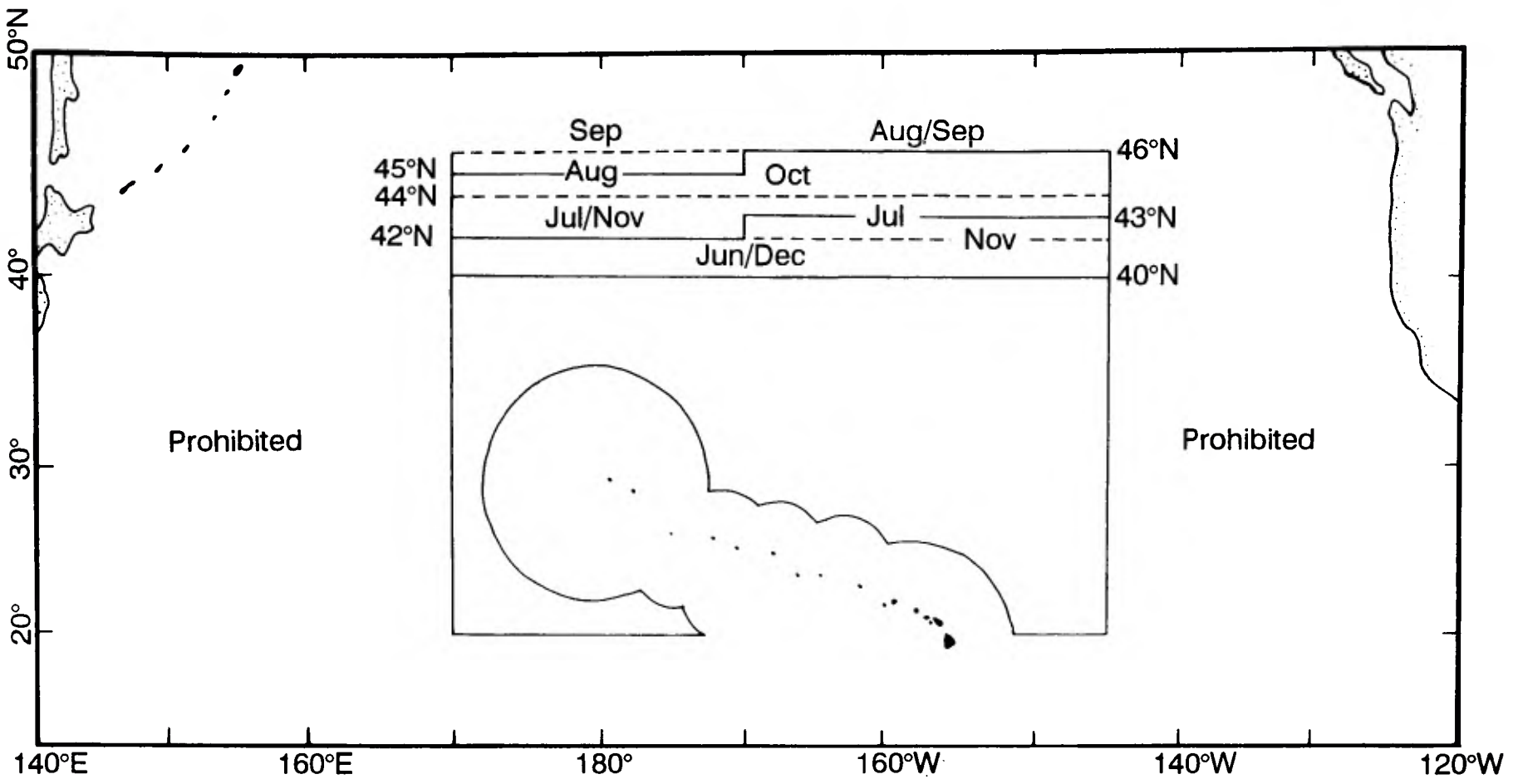

Fig. 2. Japanese squid driftnet fishing area (1989–1992).

Vessels and crew

(a) Type of vessel (Fig. 3)

The Japanese squid driftnetters comprised several different vessel types. They were converted from, or were actually engaged in, other fisheries even during the approved period for the squid driftnet fishery. The other fisheries include salmon driftnet fisheries, tuna fisheries, the Pacific saury fishery, squid jigging fisheries, distant water trawl fisheries, the North Pacific longline and gillnet fishery, and the offshore trawl fishery (Nakata, 1987).

(b) Vessel size and capacity

The vessel length followed a bimodal curve, with larger class vessels measuring 40–60m and smaller class vessels 25–30m. The gross tonnage (GRT) of the 457 licensed vessels in 1990 ranged from 59.5 to 499.9 GRT with modes at 100–150 GRT and 250–350 GRT. The smaller vessels had 100–150m^3 of fish hold capacity and 4–7 tonnes per day freezing capacity, whilst the larger had 350–500m^3 fish hold capacity and a daily freezing capacity of 10–20 tonnes.

(c) Number of licensed vessels

The number of approved vessels by size class since the introduction of the licensing system is shown in Table 1a.

In the 1990 fishing season, 93 of the 457 licensed vessels did not conduct squid driftnet operations. The Ministry of



Fig. 3a. Stern view of a typical squid driftnetter.



Fig. 3b. Retrieval operation at main deck.

Table 1a

Number of approved vessels by size class since the introduction of the licensing system.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991[1]	1992[1]
Small	371	326	285	265	259	237	209	202	196	195	104	80
Large	163	203	230	240	243	255	269	261	264	262	180	151
Total	534	529	515	505	502	492	478	463	460	457	284	231

[1] Only actually operating vessels are included.

Table 1b

Number of licensed Japanese driftnetters by port in 1990.

Prefecture	Port	No.	Prefecture	Port	No.
Aomori	Hachinohe	45	Ibaragi	Hasaki	2
Aomori	Aomori	5	Ibaragi	Hitachi	1
Ehime	Uwajima	2	Ishikawa	Noto	9
Fukushima	Iwaki	36	Ishikawa	Uchiura	25
Hokkaido	Erimo	2	Iwate	Miyako	5
Hokkaido	Matsumae	1	Iwate	Yamada	5
Hokkaido	Wakkanai	14	Iwate	Kamaishi	21
Hokkaido	Esashi	1	Iwate	Ozuchi	4
Hokkaido	Shiriuchi	3	Kagoshima	Kushikino	2
Hokkaido	Hirowo	8	Miyagi	Kesen-numa	20
Hokkaido	Akkeshi	12	Miyagi	Natori	1
Hokkaido	Rumoi	2	Miyagi	Shiogama	29
Hokkaido	Kushiro	27	Miyagi	Ishinomaki	16
Hokkaido	Urakawa	6	Miyagi	Onagawa	1
Hokkaido	Setana	2	Niigata	Niigata	5
Hokkaido	Otaru	9	Shimane	Nishinoshima	1
Hokkaido	Abashiri	3	Shizuoka	Shimizu	2
Hokkaido	Nemuro	53	Shizuoka	Omaezaki	1
Hokkaido	Hakodate	35	Tokyo	Tokyo	4
Hokkaido	Samani	1	Tottori	Sakai	3
Hokkaido	Iwanai	2	Toyama	Uozu	5
Hokkaido	Muroran	2	Toyama	Nyuzen	12
Hokkaido	Monbetsu	4	Toyama	Kurobe	8

Agriculture, Forestry and Fisheries has been reducing the number of licensed vessels for this fishery each year. The number of licensed vessels by home port in 1990 is shown in Table 1b.

(d) Fish handling
The following products were processed on board: (1) whole squid (round); (2) mantle with fins; (3) mantle without fins; (4) mantle without fins and skin; (5) fins; and (6) arms. All products are cleaned, graded, packed in freezing pans (usually 20kg size) and frozen daily.

(e) Vessel crew
The crew size was usually 14–18 including officers. Crew nationality is Japanese.

Gear

(a) Mesh size
The squid driftnet regulations specified a stretched mesh size of 100–135mm. About 90% of the vessels used 110–120mm mesh, which is effective for large flying squid. The 121mm mesh driftnet has the highest efficiency for squid 37–47cm in mantle length (Kubodera and Yoshida, 1981).

(b) Material
An example of a Japanese squid driftnet is shown in Fig. 4. The fishing net is made of nylon monofilament. The corkline is composed of an S-twist rope, a Z-twist rope and

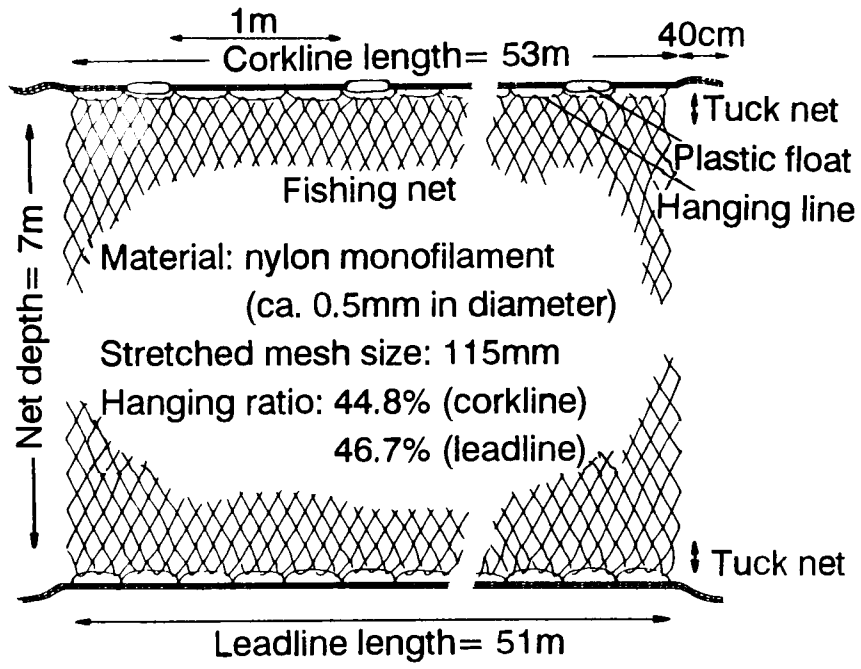

Fig. 4. An example of the construction of a tan of a Japanese squid driftnet.

floats. The leadline is composed of an S-twist rope and Z-twist rope, both of which contain leadlines. The corkline and leadline are made of polypropylene.

(c) Twine size
The diameter of both the corkline and leadline ropes was about 10mm. The filament diameter was about 0.5mm.

(d) Panel length and depth
The corkline length of a panel (tan) ranged from about 30–60m, with a mode at 45–50m. The panel depth at sea was usually 7–10m (8–12m when stretched).

(e) Number of panels carried
Japanese squid driftnetters usually carried 600–1,800 panels or tans per vessel. This included extra net to replace any that was lost or damaged.

(f) Float size and spacing
The length and diameter of a float was about 20cm and 4–5cm respectively. Floats were usually spaced at 1m intervals (Fig. 4). The buoyancy of a float was about 200g.

(g) Beacons
Usually a radio buoy, a light buoy, a plastic buoy and occasionally also a radar buoy was attached to one or both ends of a net section, which consisted of 70–200 tans.

(h) Net-hauling gear
Two hydraulic devices were located on the port main working deck (rarely starboard). The forward device, the 'line-hauler', was used to retrieve the leadline. The other device, about 5–7m aft of the line-hauler, was called the 'ball-roller' and consisted of two rubber balls rotating in

opposite directions. The ball-roller retrieved the corkline (Fig. 3 bottom). There was also a pair of ball-rollers above the net pit which was located aft of the vessel; these were used to pull the nets into the net pit, where nets were stored for the next deployment.

(i) Other information
New fishing nets were used at the start of each fishing season, but the corkline and leadline were sometimes re-used. As the season progressed, nets were often torn by the entanglement of large animals such as sharks, billfish and marine mammals, and/or by the crew while removing albacore, pomfret and other fish. Smaller tears were not repaired. Nets with larger holes or tears were replaced during or after the retrieval operation each day. Corklines and leadlines were recycled.

Operations

(a) Usual length of trips
Trips usually lasted from 1–4 months, primarily depending on the amount of catch and the size of the vessel, since the trans-shipment of products is prohibited. Trips by smaller vessels were usually less than 2 months whereas larger vessels were able to cruise up to four months. It took about seven days to sail from Japan to the western border of the fishing grounds (170°E). The average number of operations (net deployments) per vessel per season was about 70.

(b) Usual number of trips per year
The number of trips per fishing season, from June to December, was usually 1–2 for larger vessels and 1–3 for smaller vessels, depending on the other fisheries in which each driftnetter also participated.

(c) Number of panels fished
The average number of tans fished per operation gradually increased from 663 in 1982 to about 1,000 after 1986 (cf. Table 3). These figures are not standardised. The average length of a tan is about 45m.

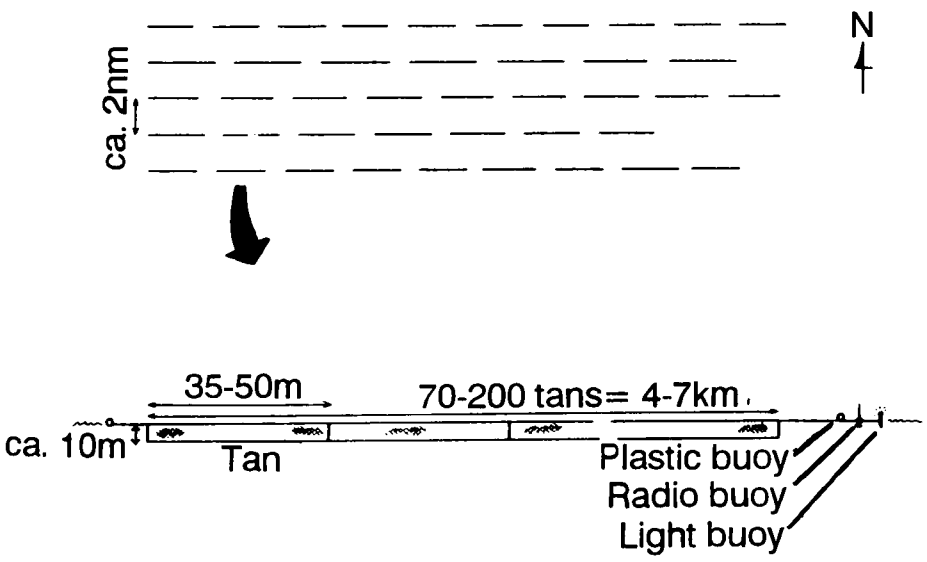

Fig. 5. Hypothetical example of array fishing by five Japanese squid driftnetters, each vessel deploying 7–10 sections from a particular longitude to the East at 2 n.miles distance (top). General construction of a section (bottom).

About 70–200 tans of driftnet were connected to form one net section (Fig. 5). Usually 6–10 sections were set in an operation. Sections are usually set separately with several hundred metres between them (Fig. 5). The distance between sections sometimes expanded to several miles before retrieval due to wind and sea currents. When sea conditions were good, sections were often connected to each other by ropes to make the retrieval operation easier.

(d) Soaking time
Typically, driftnet deployment occurred a few hours before sunset and took 2–4hrs. The net retrieval operation began 2–3hrs before sunrise. It usually took from about 40 minutes to 3hrs to retrieve one net section, depending on the catch and the condition of the nets. The soak time for a section of driftnet varied from 4hrs to more than 15hrs depending on the amount of catch and retrieval direction (from the start of the set or end of the set). In rare cases, nets were left for more than one night, primarily where catches were too large to process (an extended or *tome ami* operation in Japanese terminology).

(e) Usual catches (per operation)
The average catch of flying squid was 3.8–7.9 tonnes per operation during 1983–92 (see below).

(f) Array fishing
To avoid gear conflict between driftnetters, representatives of driftnetters from Japan, Korea and Taiwan agreed on a fishing protocol in 1987. The major items were: (1) vessels operating in proximity will always exchange net deployment information before the start of a set; (2) the vessel must maintain its setting course at 90° or 270° with an allowance of 20°; and (3) the vessel must keep at least 2 n.miles away from neighbouring vessels (Fig. 5).

Economics and history

(a) Price per kilo to fishermen
Table 2 shows the landing and price of the major flying squid products for 1985–91. Unprocessed squid, i.e., whole squid in the round, comprised about one third of the total landed product in the early 1980s. However, more recently the major product became the mantle without the internal organs and cut at the ventral midline (*hiraki*). This shift in processing on board was primarily aimed at saving freezing space and hence enabled a higher total income per cruise. It was enhanced by a higher price for *hiraki* than whole squid.

(b) Market
Flying squid was sold in the domestic Japanese market.

(c) Processing
Flying squid is suitable for processing and cooking, due to its thick and tender mantle as well as its large size. The landed squid products were further processed, mainly into: (1) *roll*, frozen mantle without fins and skin; (2) *ika-kun*, smoked and sliced; or (3) *daruma*, seasoned and dried mantle. *Roll* is sold at retail stores as either frozen mantle or as frozen food with bread-crumbs or flour. Most *daruma* was further processed to make *soft-saki-ika* by tearing it into pieces. The estimated domestic demand for flying squid in 1987 was 72,000 tonnes for *roll*, 20,000 tonnes for smoked squid and 35,000 tonnes for *daruma* (Taya, 1989).

(d) Locations of processors
Squid processors are distributed throughout most of Japan. Major processors for flying squid were located at Hakodate and along the Pacific coast of northern Honshu, from Hachinohe to Onahama (Fig. 1).

Table 2

Landings and price of major flying squid products sold in Japan, 1985-1991 (Japan Squid Driftnet Fishery Association).

Year	1985	1986	1987	1988	1989	1990	1991
Catch (t)							
Whole squid	6,348	3,175	849	287	175	-	-
Nuki[1]	29,915	14,032	16,669	14,492	17,765	18,864	6,698
Hiraki[2]	34,147	33,020	48,076	30,681	36,107	44,099	16,981
Hiraki-mimitori[3]	15,836	15,143	26,564	20,552	22,603	27,845	29,073
Arms[4]	9,228	14,116	12,120	17,052	15,301	12,275	14,612
Fins	2,261	3,608	2,630	2,164	3,143	2,470	3,777
Others	849	3,145	2,454	1,101	741	27	228
Total	98,584	86,239	109,362	86,329	95,835	105,580	71,369
Price (Yen/kg)							
Whole squid	303	304	275	288	190		
Nuki[1]	536	532	295	418	324		
Hiraki[2]	582	565	321	423	381		
Hiraki-mimitori[3]	636	635	371	481	442		
Arms[4]	138	199	187	200	99		
Fins	285	236	147	200	139		
Overall	500	483	310	382	330	353	452

[1] Mantle without internal organs but not cut.
[2] Mantle without internal organs and cut at longitudinal axis.
[3] *Hiraki* without fins.
[4] Arms, tentacles and distal part of head.

(e) Total annual ex-vessel value

The average annual ex-vessel value per vessel ranged from 71 to 124 million Yen during 1981–88.

(f) History of the development of the fishery and trends

Flying squid had been unexploited before the early 1970s, when the catch of Japanese common squid, *Todarodes pacificus*, drastically declined (Osako and Murata, 1983). The flying squid fishery commenced in 1974 with jigging operations off the Pacific coast of Japan. Driftnets were introduced in 1978 and were found to be much more effective than jigging (Osako and Murata, 1983). The number of squid driftnetters was estimated to be over 800 in November 1978 (Murata, 1989). This resulted in a conflict with the existing jigging fishery (Nakata, 1987). To avoid this conflict, the Japanese Government separated the fishing grounds for these fisheries at 170°E in 1979 (Fig. 6). As noted above, the Government established a set of restrictive regulations including a limited entry system for the squid driftnet fishery in 1981 (Nakata, 1987).

Fig. 6 shows the general distribution of the fishing grounds for jigging and driftnets until 1982. The annual

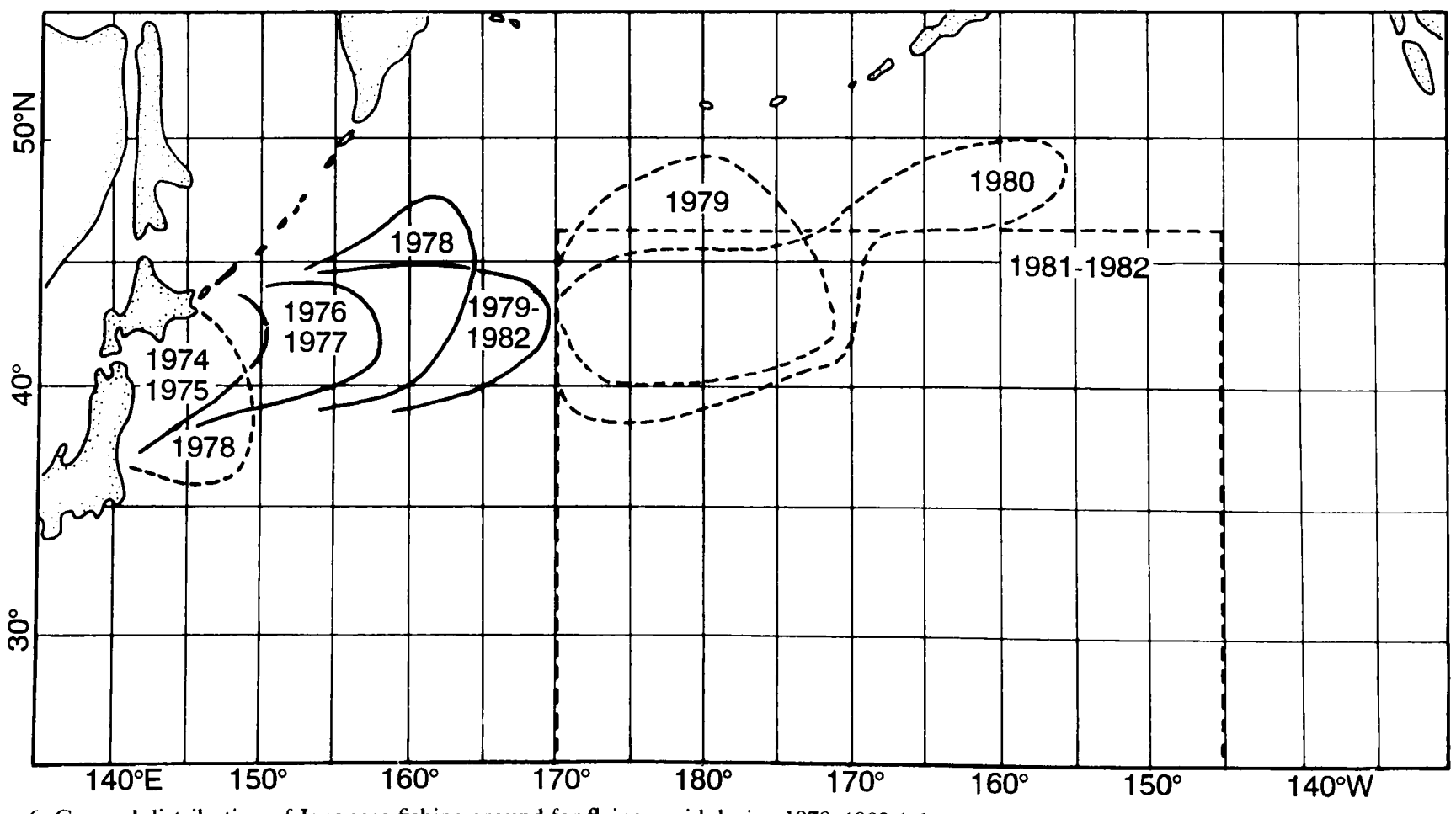

Fig. 6. General distribution of Japanese fishing ground for flying squid during 1978–1982 (after Murata, 1989). Solid line, jig fishery; broken line, driftnet fishery.

Table 3

Annual number of fishing days, deployed tans, catch in round weight, CPUE and landings for the Japanese squid driftnet fishery, 1978-1992.

Year	Fishing day[1]	Deployed tans[3]	Catch[1] (t)	CPUE kg/tan	CPUE t/day	Product landed[2] (t)
1978	[6]	[6]	*ca* 45,000 [4]			
1979	[6]	[6]	*ca* 45,000 [4]			
1980	[6]	[6]	121,585 [4]			76,884 [3]
1981	[6]	[6]	103,163 [4]			61,960 [3]
1982	33,073	21,928,768	158,760	7.2	4.8	100,235
1983	32,685	25,224,746	215,778	8.6	6.6	105,758
1984	32,645	29,251,829	123,719	4.2	3.8	73,991
1985	35,132	34,023,355	197,795	5.8	5.6	98,584
1986	35,549	36,367,294	152,226	4.2	4.3	86,239
1987	29,613	32,017,130	208,319	6.5	7.0	109,362
1988	31,998	36,055,567	157,773	4.4	4.9	86,329
1989	33,646	34,385,032	171,014	5.0	5.1	95,835
1990[5]	23,656	22,769,857	187,660	8.2	7.9	105,580
1991	19,453	21,709,643	101,638	4.7	5.2	71,369
1992	13,775	15,656,091	99,800	6.4	7.3	

[1] Fisheries Agency of Japan (1984, 1985b, 1986, 1987, 1988, 1989a, 1990, 1991, 1992, 1993) for 1982-92.
[2] After The Japan Squid Driftnet Association.
[3] Standardized at 50m per tan for only 1989 and 1990.
[4] By Murata (1989).
[5] Including experimental fishing in May.
[6] No reliable data.

flying squid catch by jigging was about 124,000 tonnes in 1977 and this gradually decreased to about 20,000 tonnes in the late 1980s (Murata, 1989). In spite of the reduction in the number of vessels from over 800 in 1978 to 534 in 1981, the driftnet catch increased rapidly in 1980 and the annual catch fluctuated between 124,000 tonnes and 216,000 tonnes during 1983–90 (Table 3). This presumably resulted from the development of new fishing grounds and from the increased size of vessels. In 1991–92, the total catch decreased to about 100,000 tonnes as fishing effort declined. Based on the catch and number of fishing days, the CPUE (tonnes per day) also fluctuated between 4.3 and 7.9 during 1982–92 with no apparent trend (Table 3).

However, the CPUE (in kg per tan) decreased from over 7 in 1982 and 1983 to 4.2 in 1984 and fluctuated between 4.2 and 8.2 after 1984. A considerable decline in the number of tans in 1990 resulted from (1) a decrease in the number of vessels which actually operated and (2) a good catch of flying squid. There are no CPUE data before 1982 (Mamoru Murata of the Hokkaido National Fisheries Research Institute, pers. comm.).

There has been a similar pattern in the relationship between the monthly number of fishing days and CPUE since 1982 when reliable statistics became available (Fig. 7). The highest monthly fishing effort occurred in August (1982–86) or July (1987–90). The highest CPUE usually occurred in June or July.

The geographic distribution of fishing effort in 1989 is shown in Fig. 8. Fishing effort was mostly confined to the waters between the northern boundary and 38°N and usually within 2–3° of the monthly northern boundary. Fishing effort was bimodal longitudinally from June to October, whereas effort was reduced and concentrated in the waters west of the dateline in November and December. These patterns are similar from 1983 to 1989 (Fisheries Agency of Japan, 1984; 1985a; 1986; 1987; 1988). The surface water temperature on the fishing grounds is usually 13–18°C.

Total landings (by year)

Table 2 shows annual landings by type of product. Table 3 shows annual catches in round weight. Total annual values ranged from 38 to 62 billion Yen during 1981–88 (Ministry of Agriculture Forestry and Fisheries, 1990).

Effort data

The total annual fishing days and the number of tans deployed from 1982 to 1992 are shown in Table 3. The monthly number of fishing days from 1983 to 1990 and the distribution of fishing effort by month and by 1° square are shown in Figs 7 and 8 respectively.

Interactions with cetaceans

(a) Species

Of the 24 cetacean species recorded in the fishing grounds by sighting surveys (Jones, 1988; Miyashita, 1989), at least 18 have been incidentally taken by the Japanese squid driftnet fishery (Tables 4 and 5). The delphinids in the North Pacific can be classified as cold or warm water species based on surface water temperature (Kasuya and Jones, 1984; Miyashita, 1989). Given the water temperature preference of large squid (13–18°C), the three cold water species of Dall's porpoise (*Phocoenoides dalli*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) and northern right whale dolphin (*Lissodelphis borealis*), would be expected to be the major bycatch species.

(b) How and when entangled

Amano (1990) observed eight cetacean entanglements and reported that (1) all entanglements occurred in the upper two-thirds of the nets, (2) entanglement was more frequent in the central section among 1,000 tans deployed, but there was no obvious tendency in the horizontal distribution of entanglements within a section comprising 125 tans and (3) entangled body parts were flukes (caudal fin, 3 individuals), head (1 individual) and unknown including complicated entanglements (4 individuals). Snow (1987)

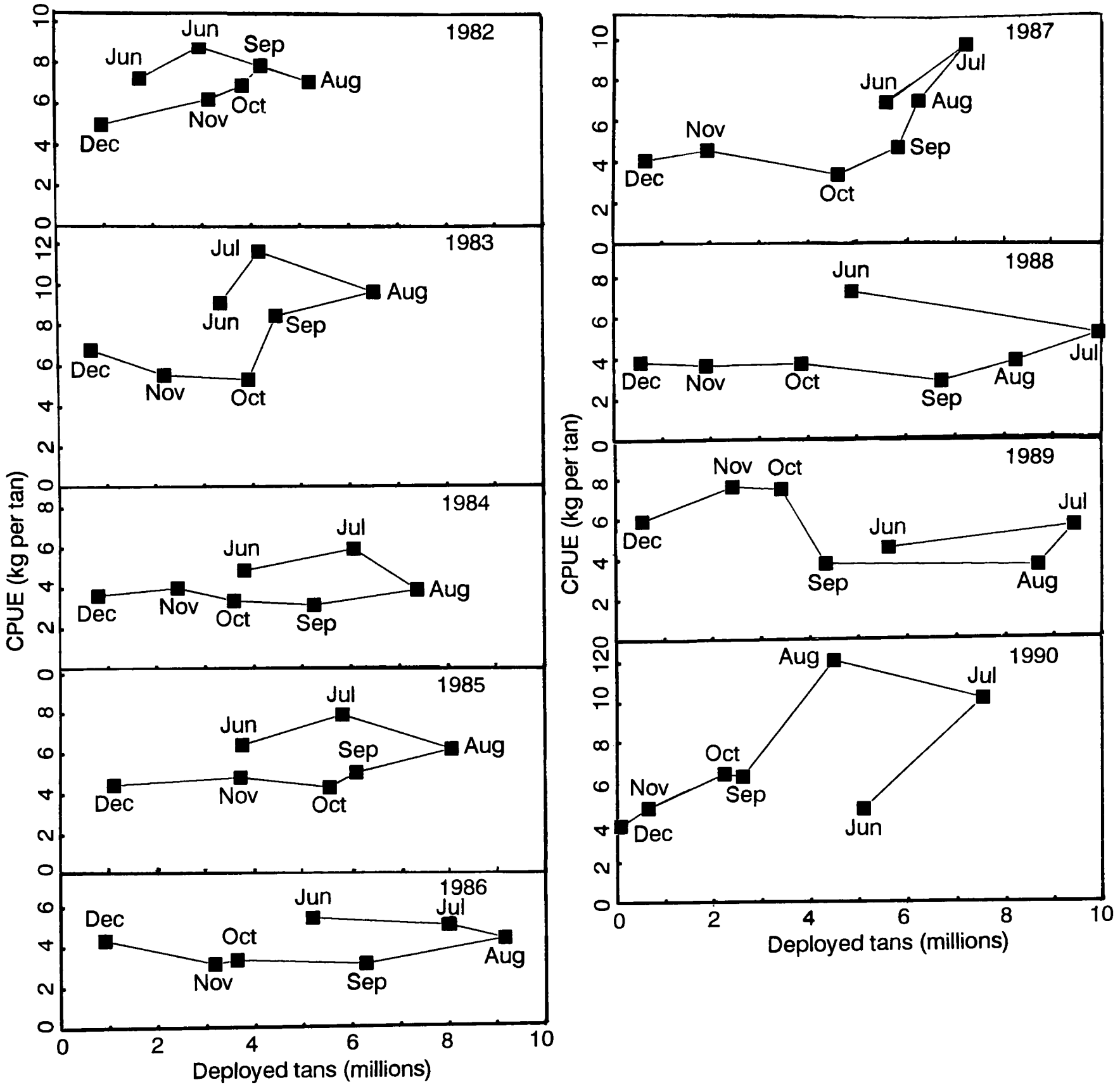

Fig. 7. Relationship between number of fishing days and CPUE (ton/operation) by month, 1982–1990.

and Jones *et al.* (1987) reported a similar tendency in the vertical position of entanglements for Dall's porpoise incidentally taken by the salmon driftnet fishery, i.e., a higher percentage of entanglements in the upper and middle parts than the lower third of the gillnet. Jones *et al.* (1987) reported (1) no difference between the three sections (110 tans each) of the salmon driftnet in the number of Dall's porpoise entangled and (2) higher entanglement rates for areas near the ends of a net section than for the central portion.

Liau and Hwang (1990) reported that marine mammals were more easily caught by large mesh sizes, especially 16, 18 and 20cm mesh, when comparing nine mesh sizes from 6–20cm. Yatsu *et al.* (1994) found a positive relationship between mesh size and cetacean catch rates among 16 different mesh sizes from 33mm to 197mm (Fig. 9) and considered that flukes and beaks (if present) are the primary parts entangled, because fluke lengths or beak girths are similar to the larger mesh sizes.

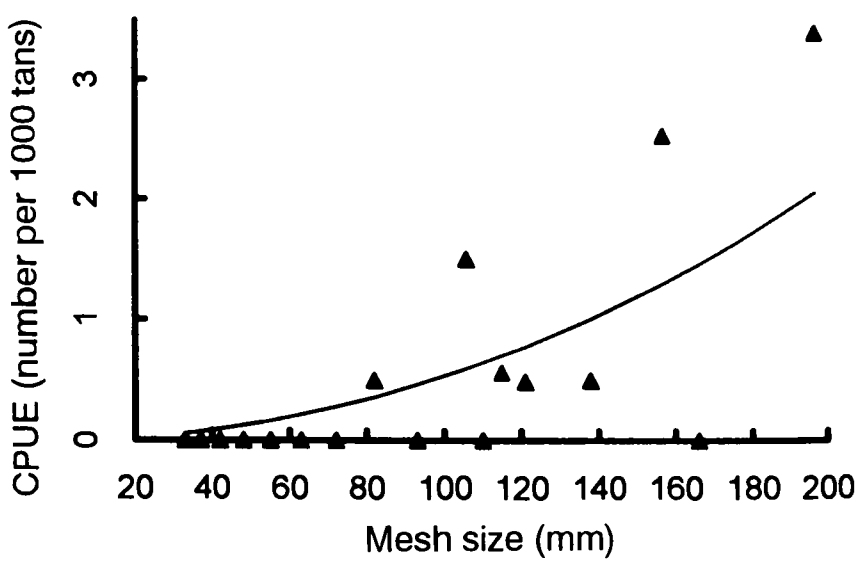

Fig. 9. Relationship between mesh size (M) and cetacean CPUE (Y) obtained from the Japanese squid driftnet research cruises in the North Pacific, 1984–90 (modified from Yatsu *et al.*, 1994). Solid line, $Y=5.29 \times 10^{-5} M^2$.

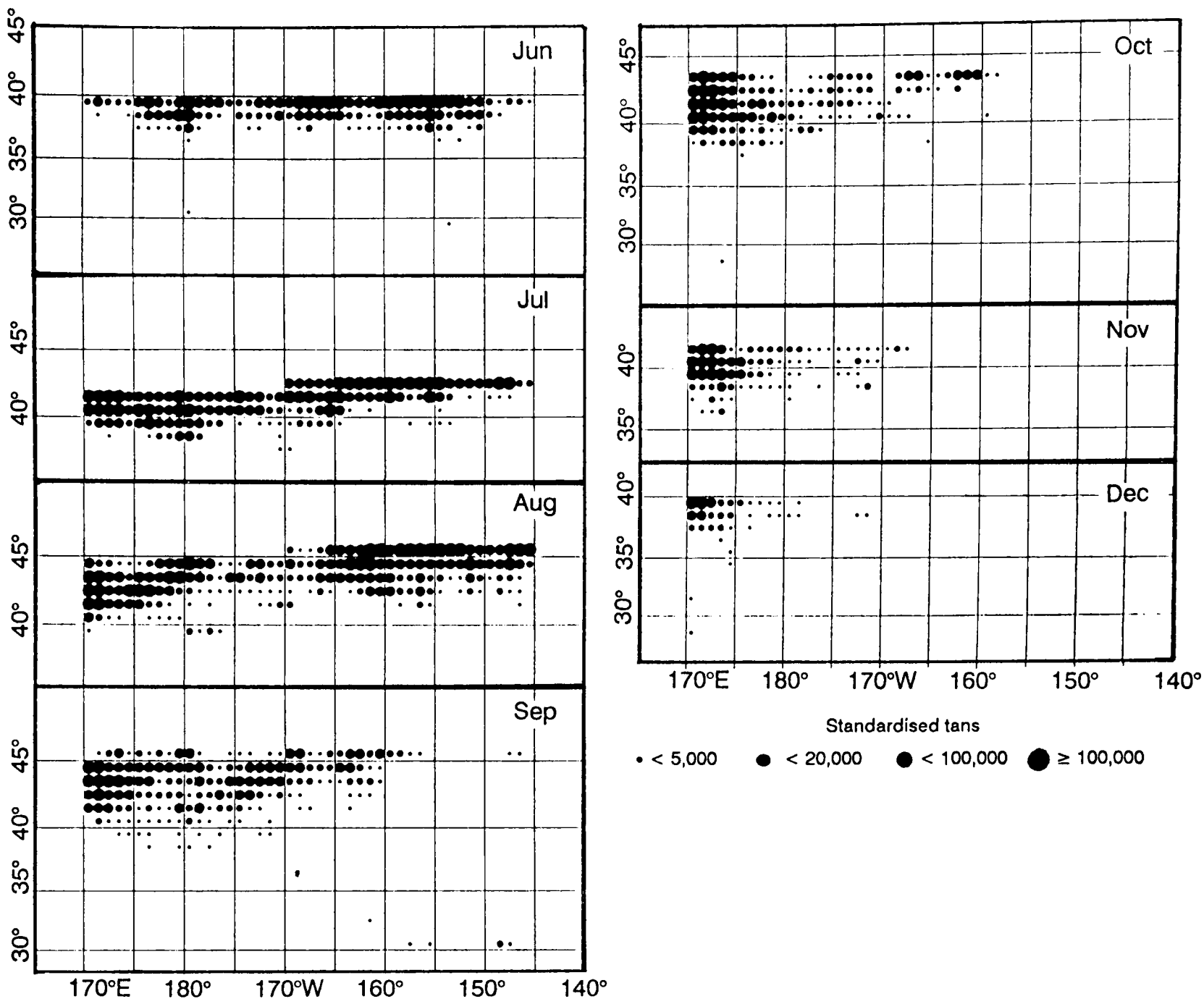

Fig. 8. Geographic distribution of fishing effort in number of days by month by 1°x1° block (latitude x longitude) in 1989 (after Fisheries Agency of Japan, 1990).

Table 4

Observed effort and bycatch of cetaceans for Japanese commercial squid driftnetters. Observations were made on fishing vessels except for 1985. In 1985, retrieval operations were usually observed from a US Coastguard cutter and its motor launch. Tan length standardised at 50m.

Species/effort	1982[1]	1985[3]	1986[7]	1988[2]	1989[4]	1990[8,5]	1990[9,5]	1991[8,6]
Number of operations observed	11	10	30	464	1,402	2,864	2,879	2,659
Number of tans observed				533,618	1,427,225	2,244,400	2,281,896	2,063,965
Observed driftnet length (km)	440	135	1,656	26,681	71,361	112,220	114,095	106,767
Mean observed tan (net) length per operation (km)	40	14	55	58	51	39	40	40
Number of bycatch								
Dall's porpoise	0	0	7	57	141	298	318	311
Northern right whale dolphin	7	0	43	114	455	812	840	939
Pacific white-sided dolphin	0	0	8	77	254	437	459	411
Common dolphin	11 [10]	0	0	5	12	69	69	87
Striped dolphin	0	0	1	0	0	6	6	5
Others/unknown	0	0	0	0	52	41	44	34
Total	18	0	59	253	914	1,663	1,736	1,787
CPUE (No. per 1000 tans)								
Dall's porpoise	0.00	0.00	0.21	0.11	0.10	0.13	0.14	0.15
Northern right whale dolphin	0.80	0.00	1.30	0.21	0.32	0.36	0.37	0.45
Pacific white-sided dolphin	0.00	0.00	0.24	0.14	0.18	0.19	0.20	0.20
Common dolphin	1.25	0.00	0.00	0.01	0.01	0.03	0.03	0.04
Striped dolphin	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Others/unknown	0.00	0.00	0.00	0.00	0.04	0.02	0.02	0.02
Total	2.05	0.00	1.78	0.47	0.64	0.74	0.76	0.87

[1] Cary and Burgner (1983); [2] Fishery Agency of Japan (1989b); [3] Ignell, Bailey and Joyce (1986); [4] INPFC (1990); [5] INPFC (1991); [6] INPFC (1992); [7] Tsunoda (1989); [8] Excluding extended operations; [9] Including extended operations; [10] Identification in doubt, more likely Pacific white-sided dolphin (Cary and Burgner, 1983).

Table 5

List of cetaceans entangled in squid driftnet and sighted in the Japanese squid driftnet fishing ground, 20-46°N, 170°E-145°W. SST: surface water temperature where cetacean species were sighted (after Miyashita, 1989). Key: 1 = Fisheries Agency of Japan (1989b); 2 = INPFC (1990); 3 = INPFC (1991); 4 = INPFC (1992); 5 = Jones (1988); 6 = Miyashita (1989); 7 = Miyazaki (1986) and 8 = Tsunoda (1989).

English name	Scientific name	Entangled	Sighted	SST (°C)
Dall's porpoise	*Phocoenoides dalli*	2 3 4 1 8	5 6	< 18
Northern right whale dolphin	*Lissodelphis borealis*	2 3 4 1 8	5 6	10-23
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*	2 3 4 1 8	5 6	10-23
Common dolphin	*Delphinus delphis*	2 3 4 1 7	5 6	18-28
Striped dolphin	*Stenella coeruleoalba*	3 4 8	6	18-28
Spotted dolphin	*Stenella attenuata*		6	22-28
Spinner dolphin	*Stenella longirostris*		6	22-25
Bottlenose dolphin	*Tursiops truncatus*	3 4	6	16-28
Risso's dolphin	*Grampus griseus*	3	6	> 22
Short-finned pilot whale	*Globicephala macrorhynchus*	3	6	16-18
False killer whale	*Pseudorca crassidens*	3	6	> 22
Killer whale	*Orcinus orca*		6	16-28
Unidentified dolphin			6	
Sperm whale	*Physeter macrocephalus*	4	5 6	> 12
Pygmy sperm whale	*Kogia breviceps*	3		
Unidentified *Kogia*	*Kogia* sp.	4 7		
Cuvier's beaked whale	*Ziphius cavirostris*	3 4		
Unidentified Ziphiidae			6	
Unidentified *Mesplodon*	*Mesplodon* sp.	3	6	
Unidentified beaked whale		3 4		
Humpback whale	*Megaptera novaeangliae*		5	
Blue whale	*Balaenoptera musculus*		6	14-26
Mink whale	*Balaenoptera acutorostrata*		6	14-23
Sei whale	*Balaenoptera borealis*		5 6	12-23
Bryde's whale	*Balaenoptera edeni*		6	16-28
Fin whale	*Balaenoptera physalus*		5 6	14-23
Unidentified large whale			5 6	
Unidentified medium whale		3 4		
Unidentified small whale		3 4	5 6	
Unidentified black whale		3 4		
Unidentified whale			5 6	
Others/unknown		2 3 4		

Based on observations of bottlenose dolphins in aquaria, Akamatsu *et al.* (1991) concluded that during the daytime, dolphins primarily recognise nets visually and that at night they cannot recognise nets by echolocation sufficiently to avoid them (although see Au, 1994). The soaking time of squid driftnets is usually from 2–3hrs before sunset to several hours after sunrise. Yatsu *et al.* (In press) presented preliminary analysis of the relationship between section number (as an index of soaking time) and CPUE of the major incidentally-caught species. Although the relationships were unstable due to the small sample sizes, the CPUE for the Pacific white-sided dolphin and for the northern right whale dolphin appeared to increase as soak time increased.

(c) How removed

When cetaceans were completely entangled, they were brought aboard and then disentangled. When cetaceans were lightly entangled or too large to bring aboard, they were disentangled outside the vessel by cutting the nets and/or caudal fins and by shaking and pulling.

(d) Proportions of live and dead

The proportion of live cetaceans among total entanglements was 3.6%, 3.1% and 3.5% in 1988, 1989 and 1990 respectively according to observer programme data (Fisheries Agency of Japan, 1989a; b; INPFC, 1990; 1991).

(e) Utilisation of cetacean bycatch

Usually, squid fishermen did not want to dissect cetaceans on board because they believed the blood spoils the quality of squid products. Some incidentally taken cetaceans were sold on the Japanese market, but the amount is thought to be negligible. The landing of cetaceans was prohibited in 1990 to deprive the fishermen of any incentive to kill cetaceans.

(f) Cetacean catch data

Tables 4 and 5 summarise the incidental take of cetaceans reported by scientific observers on board Japanese commercial squid driftnet vessels. The three cold water species accounted for 98% and 93% of the total cetacean take in 1988, and 1989–91 respectively. The monthly geographic distribution of catch rates for these three species is shown in Figs 10–12.

Table 6 shows the estimated total cetacean bycatch for this fishery during the years 1989–1991. To obtain these estimates we used data collected by scientific observers on the Japanese squid driftnet fishery during 1989–1991 (INPFC, 1990; 1991; 1992), catch and effort statistics (Fisheries Agency of Japan, 1990; 1991; 1992) and related information. The 1990 and 1991 observer data included data from extended retrieval sections but excluded data from subsurface net sections and data from the month of May, because only a subsurface experiment was carried out in May. A total of 460 (1989), 364 (1990) and 284 (1991) driftnetters operated in this fishery and each vessel usually

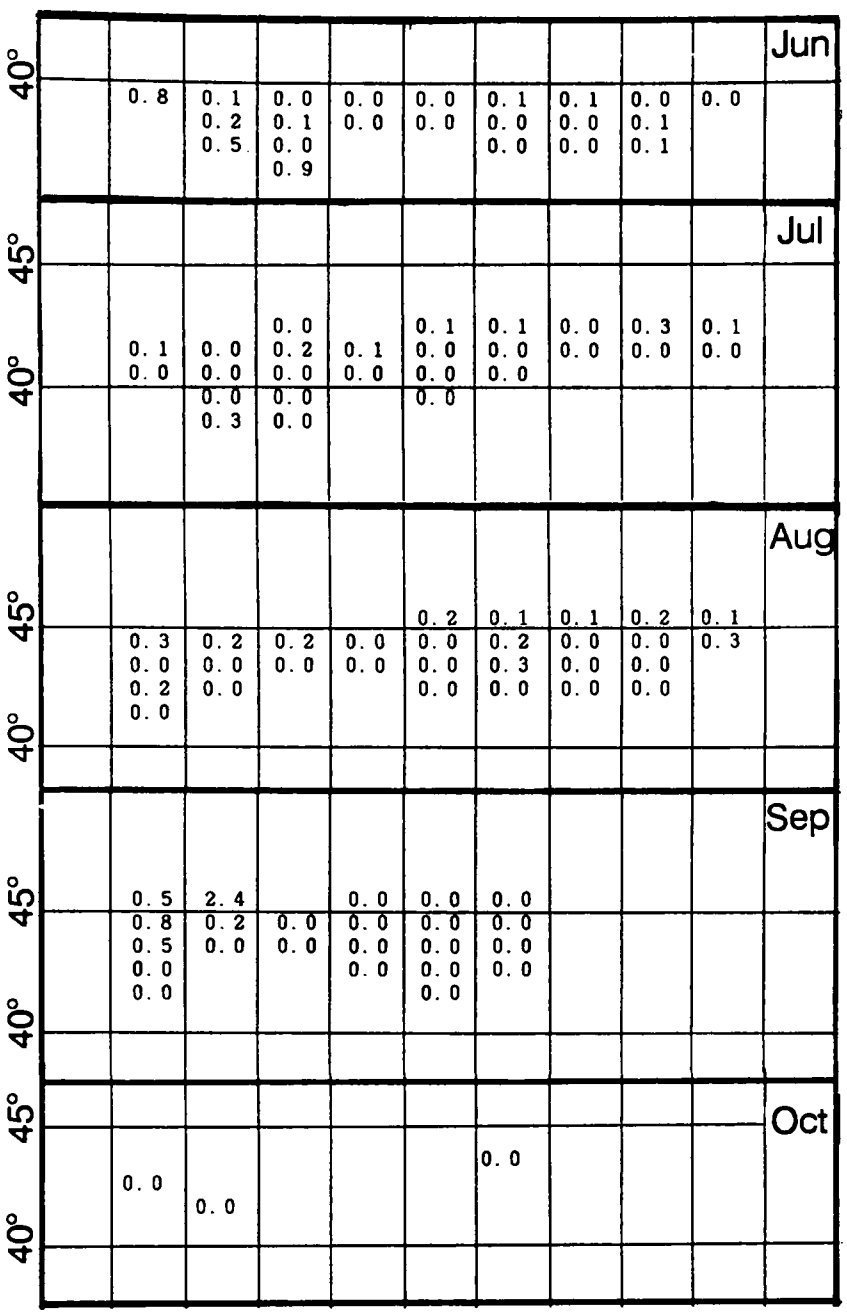

Fig. 10. Catch rate of Dall's porpoises by month by 1x5° block in 1989 calculated from INPFC (1990); no. per 1000 tans.

Table 6

Estimated bycatch of cetaceans for the Japanese squid driftnet fishery in 1989, 1990 and 1991 with approximate 95% confidence intervals.

Species	Estimated bycatch	-2 SD	+2 SD
1989			
Dall's porpoise	3,065	898	5,231
Northern right whale dolphin	12,449	4,706	20,192
Pacific white-sided dolphin	6,154	2,441	9,868
Common dolphin	286	0	914
Other, unidentified cetaceans	1,079	0	3,287
1990			
Dall's porpoise	3,093	2,279	3,907
Northern right whale dolphin	7,909	6,286	9,531
Pacific white-sided dolphin	4,447	3,605	5,289
Common dolphin	562	106	1,017
Other, unidentified cetaceans	624	372	876
1991			
Dall's porpoise	3,204	2,481	3,928
Northern right whale dolphin	9,320	7,417	11,223
Pacific white-sided dolphin	3,784	2,553	5,014
Common dolphin	1,035	350	1,719
Other, unidentified cetaceans	664	307	1,021

made 1–3 cruises during the fishing season. Scientific observers monitored about 3% of cruises in 1989, 12% in 1990 and 13% in 1991.

A scientific observer was placed on one of the cruises for each selected vessel. Although selection of the vessel's

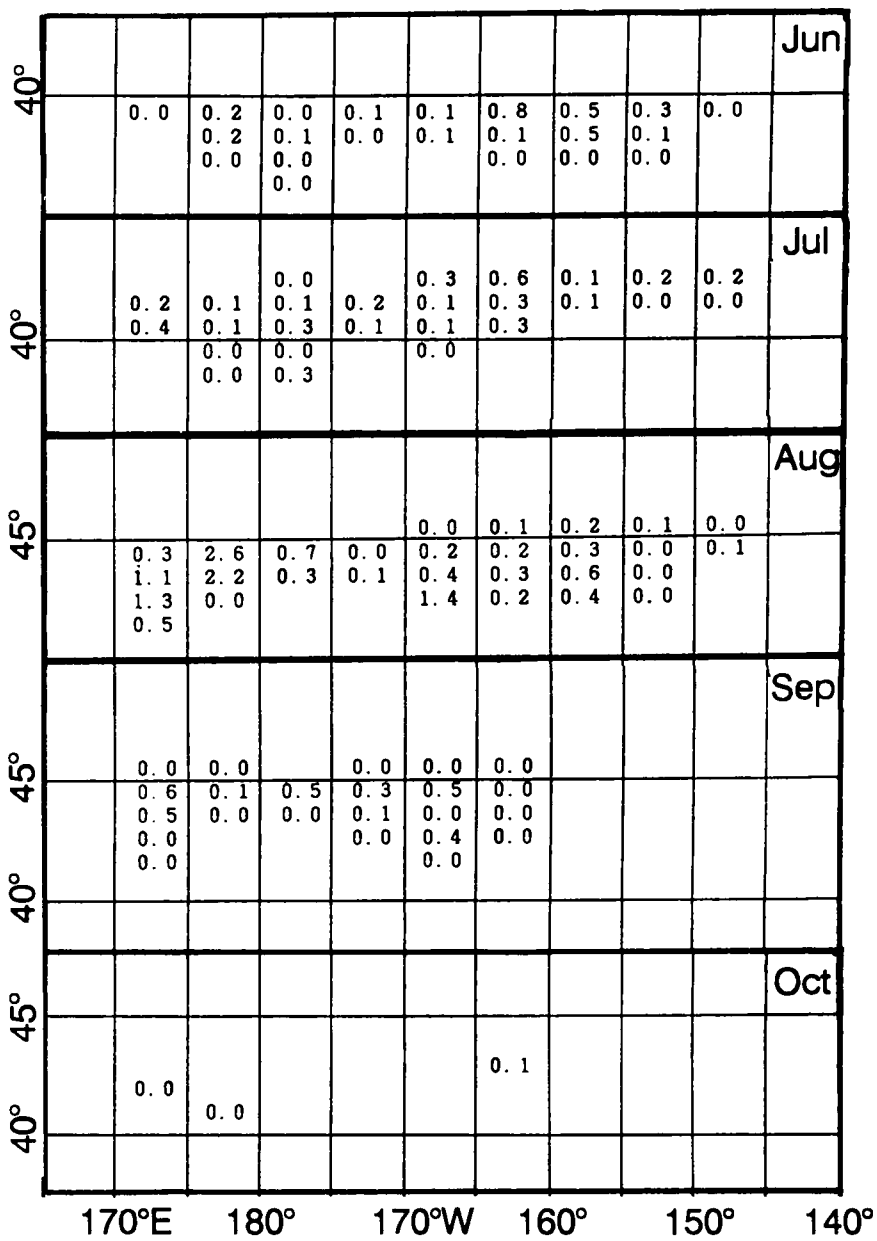

Fig. 11. Catch rate of northern right whale dolphin by month by 1x5° block in 1989 calculated from INPFC (1990); no. per 1000 tans.

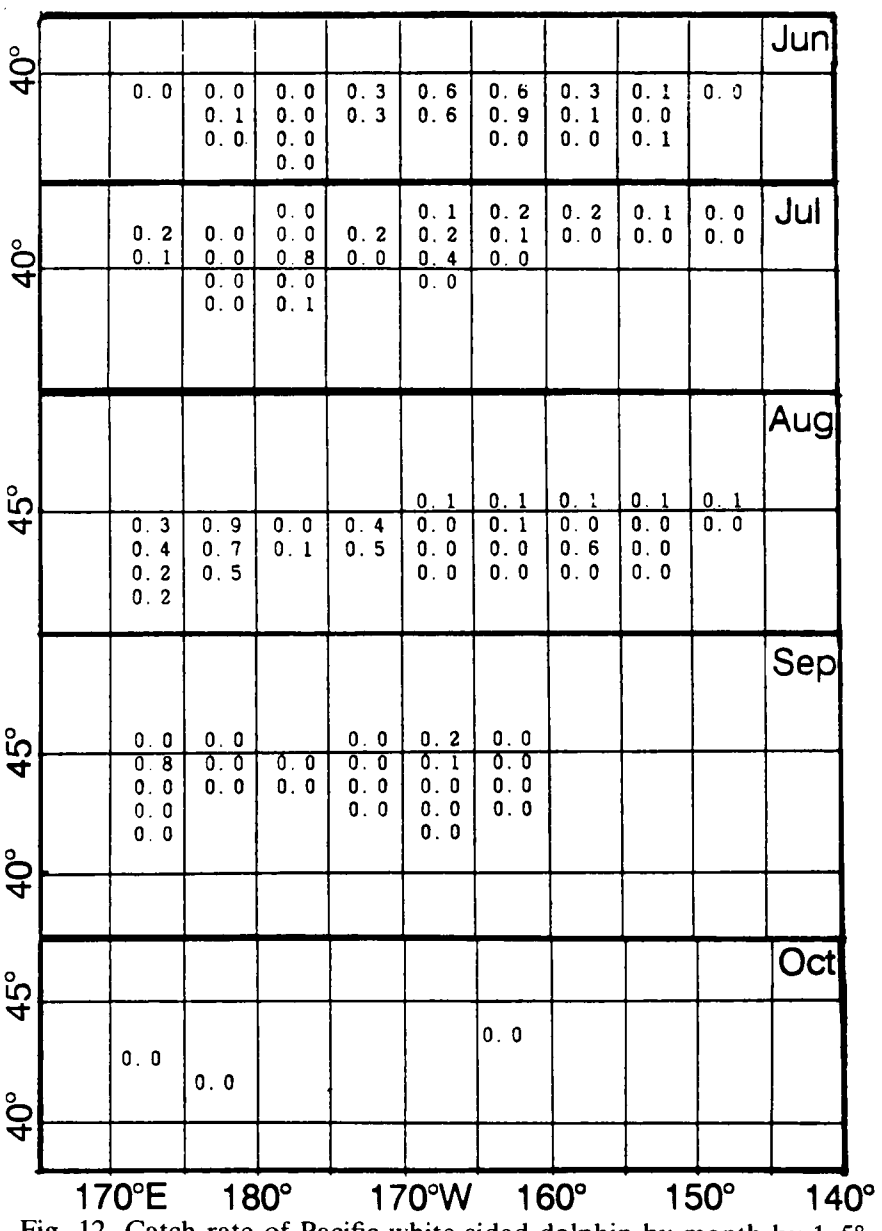

Fig. 12. Catch rate of Pacific white-sided dolphin by month by 1x5° block in 1989 calculated from INPFC (1990); no. per 1000 tans.

cruises was not based on a formal statistical design, we consider that the distribution of monitored operations well represented the total fishing activities in 1990 and 1991 and to some extent in 1989. Observers were instructed to monitor operations for five consecutive days and omit observations on the sixth day. Most of the observations were made on randomly selected 6 or 7 net sections in an operation (INPFC, 1990; 1991, 1992). The catch and effort statistics are based on fishing logbooks submitted by the fishermen.

Since data at the net section level are not available from the 1989 observer programme or from the catch and effort statistics, it is convenient to consider a two-stage sampling plan with cruises as a primary sampling unit and operations as a secondary sampling unit. We also assume that the sampling of observer data was made randomly at cruise and operation levels. Data were not stratified by time or by area.

Estimators of total bycatch ($\hat{Y}$) and its variance V[$\hat{Y}$] are as follows (Cochran, 1963).

$\hat{Y} = \hat{R}X$ where

$$\hat{R} = \frac{\sum_{i=1}^{n} M_i \bar{y}_i}{\sum_{i=1}^{n} M_i \bar{x}_i} \left(\bar{y}_i = \frac{1}{m_i} \sum_{j=1}^{mi} y_{ij},\ \bar{x}_i = \frac{1}{m_i} \sum_{j=1}^{mi} x_{ij} \right)$$

$$V[\hat{Y}] = \frac{N(N-n)}{n(n-1)} \sum_{i=1}^{n} M_i^2 (\bar{y}_i - \hat{R}\bar{x}_i)^2 +$$

$$\frac{N}{n} \sum_{i=1}^{n} \frac{M_i(M_i - m_i)}{m_i(m_i - 1)} \sum_{j=1}^{mi} ((y_{ij} - \bar{y}_i) - \hat{R}(x_{ij} - \bar{x}_i))^2$$

where, M_i = number of total operations in i-th cruise
m_i = number of observed operations in i-th cruise
N = number of total cruises (801 in 1989, 643 in 1990, 428 in 1991)
n = number of observed cruises (27 in 1989, 75 in 1990, 55 in 1991)
X= number of total tans (34,385,032 in 1989, 22,636,075 in 1990, 21, 660, 852 in 1991)
x_{ij} = number of observed tans in j-th operation of i-th cruise
y_{ij} = number of observed animals in j-th operation of i-th cruise.

(g) Efforts to reduce the cetacean bycatch

Acoustic and subsurface driftnet experiments have been conducted by Japan (Snow, 1987; Hayase *et al.*, 1990; Hayase and Yatsu, 1993; Hatakeyama *et al.*, 1994). A study of the modification of driftnets in northern Australian waters revealed that neither bead chain nor plastic tubing had a significant effect on dolphin bycatch, whereas a reduction in cetacean catch rates was observed for subsurface nets set 4.5m below the sea surface (Hembree and Harwood, 1987). Snow (1987) and Jones *et al.* (1987) independently evaluated modified salmon driftnets whose acoustic reflectivity was increased by attaching hollow strands of monofilament or plastic blisters. Snow (1987) reported a 3–45% (usually 5–25%) decrease in the incidental take of Dall's porpoise for modified nets, but Jones *et al.* (1987) found no detectable difference between standard and modified nets. Hatakeyama *et al.* (1994) summarise the studies carried out largely, but not exclusively, on the Dall's porpoise.

Experimental fishing by six Japanese commercial squid driftnetters was conducted in May-July 1990 by simultaneously using surface nets and subsurface nets set at 1m or 2m below the sea surface (Hayase *et al.*, 1990). The results suggest that cetacean catch rates in subsurface nets were lower in May, but were statistically inconclusive for June and July, at least in part due to the small number of experiments.

Hayase and Yatsu (1993) also reported a similar fishing experiment using six commercial vessels during June-August 1991. In this experiment, about 400 tans of surface and subsurface nets set at 2m below sea surface were simultaneously used for an operation. Scientific observers monitored 107,844 tans of surface nets and 103,163 tans of subsurface nets. They recorded 12 and 7 Dall's porpoise, 13 and 4 Pacific white-sided dolphin and 50 and 47 northern right whale dolphin for surface and subsurface nets respectively. Although CPUE of subsurface nets for the former two species were somewhat lower than those of surface nets, no statistical differences were detected between them.

(h) Laws and regulations applying to cetaceans

In August 1990, the Government of Japan prohibited the retention and landing of cetaceans taken incidentally by driftnets.

(i) Impacts on cetacean populations

A scientific review on the impacts of large-scale pelagic driftnet fishing on living marine resources of the North Pacific was held from 11–14 June 1991 in Sydney, British Columbia. The following are the major results of the review of five cetaceans actually caught in large quantities by the large-scale pelagic driftnet fisheries and/or species of potential great concern.

(1) NORTHERN RIGHT WHALE DOLPHIN

There has been a decline in the population over the past 10 years due to the impact of the driftnet fishery. The population would continue to decline if current catch rates and levels of effort were maintained.

(2) NORTHERN RIGHT WHALE

The population in the eastern Pacific is thought to be near extinction and is probably no larger than about 50 individuals. Although there is no record of any bycatch in the squid driftnet fishery, any catch will move these whales closer to extinction.

(3) HUMPBACK WHALE

No humpback whale has yet been observed entangled in the large scale driftnet fishery, but concern was expressed about their migration route from the breeding areas around the Ryukyu and Hawaiian Islands to their North Pacific summering area across the driftnet fishing grounds. Japanese vessels do not fish in May in the area of concern.

(4) PACIFIC WHITE-SIDED DOLPHIN

The upper range of the bycatch in all the pelagic driftnet fisheries in the North Pacific is currently about 5% of the stock size and a calculation using the 'worst case' parameter estimates suggested that with high probability the population is near or above the assumed MSY (Maximum Sustainable Yield) level of 60% of the unexploited population size. This species is probably at a high level but is declining as a result of its bycatch.

(5) DALL'S PORPOISE

Most of the driftnet mortality is probably inflicted on three putative stocks (those found south of Kamchatka, south of the Aleutian Islands and in the Central Gulf of Alaska). Given the large size of these stocks, the total takes are not sufficient to cause the combined populations to decline. Although the status of the *truei*-type of this species is of great concern (e.g. IWC, 1992), none are taken incidentally in the Japanese squid driftnet fishery.

DISCUSSION AND RECOMMENDATIONS

The Japanese squid driftnet fishery was important for Japan. About 450 vessels employing about 8,000 fishermen landed approximately 100,000 tonnes of flying squid products equivalent to 40–50 billion Yen annually. The impact of this fishery on cetaceans, however, may have been significant for some stocks or species, especially the northern right whale dolphin. Given the uncertainties surrounding both cetacean population estimates and bycatch levels, it is necessary not only to collect more information to improve our assessments of the status of affected stocks but also to consider methods to reduce incidental takes. The following are possible methods for this purpose (the order does not indicate priority).

(1) Modification of driftnets

Subsurface nets have been found to be effective in reducing cetacean bycatches in some experiments (e.g. Hembree and Harwood, 1987), but the effect in the squid driftnet fishery is still uncertain despite the large-scale experiments in 1990 and 1991. Since small cetaceans in general tend to be entangled in the upper or middle portions of the nets, it is necessary to study the reasons for this difference (e.g., area, species and design of subsurface nets, especially depth and suspension lines). Restriction of mesh size to smaller mesh appears to be effective to reduce cetacean bycatch rates.

(2) Time-area regulations

This method would be effective for the Dall's porpoise, whose spatial distribution is somewhat different from the major squid driftnet fishing grounds. Dall's porpoise were entangled at the surface water temperature of 12–15°C in 1986 and 6–14°C in 1987 (Jones, 1988). A relatively high catch rate for this species was recorded in the northern part of the Japanese fishing grounds (Fig. 10). Closure of the northern part of the current fishing grounds could reduce the incidental take of Dall's porpoise, but, if a shift in fishing effort to the southern area occurred, the incidental take of cetaceans in those regions would increase. The distribution of Pacific white-sided dolphin and northern right whale dolphin, the other major cetaceans incidentally caught by this fishery, largely overlaps with the major fishing grounds (Figs 11–12). The Korean squid driftnet fishery operated in a more southerly area than the Japanese fishery, using smaller mesh sizes (76–115mm; usually 105mm in spring and 86mm in summer and autumn) than the Japanese fishery (Gong *et al.*, 1993). Although the fishing grounds for these fisheries differ considerably from each other in an east-west direction, the cetacean catch rates (all species combined) in 1990 for the Korean fishery (0.17, data from US and Korean observers combined; 0.27, US observers; 0.08 Korean observers; calculated from Park *et al.* (1991)) are considerably smaller than that of the Japanese fishery (0.74 or 0.76; Table 4). The catch rates of the Korean fishery for Dall's porpoise, northern right whale dolphin and Pacific white-sided dolphin are 0.06, 0.12 and 0.08, respectively (data from US observers in Park *et al.* (1991)). These values are less than half of those for the Japanese fishery. Therefore, a combination of smaller mesh sizes and a southward shift of fishing grounds would probably reduce the cetacean catch rates of the Japanese squid driftnet fishery.

(3) Development of alternative fishing techniques

The possibilities and problems associated with squid jigging, mid-water trawling and long-lining as alternative fishing methods have been discussed by the INPFC members. The bycatch rate for jigging is small and limited to fish and squids (Anonymous, 1990). We consider jigging to be the most promising alternative technique because it was successful in obtaining large catches of flying squid (up to 124,000 tonnes in 1977) in the northwestern Pacific (Murata, 1990). However, most of the larger flying squid drop off the jigs due to their weak tentacles (Murata *et al.*, 1981). The Fisheries Agency of Japan has recently begun studies to mitigate the drop-off of large squid by modifying jigs and jigging machines (Yatsu, 1990; Hayase and Yatsu, 1991).

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SC/O90/G55

Regulation of the Japanese High Seas Driftnet Fisheries

Kazuhiko Nagao

Offshore Fisheries Division, The Fisheries Agency Ministry of Agriculture, Forestry and Fisheries
1–2–1 Kasumigaseki, Chiyoda-ku, Tokyo, Japan 100

ABSTRACT

Two different high seas driftnet fisheries were operated by Japanese fishermen: the squid driftnet fishery and the large-mesh driftnet fishery. The squid fishery targeting flying squid started in the North Pacific in 1978. In 1981, the Government of Japan implemented a limited entry licensing system for this fishery, under which various regulations were imposed. The number of licensed vessels has decreased since 1981. In order to minimise the incidental take of salmon, a northern boundary was established based on the distribution data of salmon and flying squid. The large-mesh driftnet fishery targeting tunas and billfish has been conducted in Japanese coastal waters for more than 100 years. Expansion of this fishery to the high seas began around the middle of the 1970s. In 1990, a limited entry licensing system was introduced for this high seas fishery. Japan has been working in cooperation with the USA and Canada to collect detailed scientific data from these two high seas fisheries. Adoption of the UN Resolution in December 1989 has provided the opportunity for Japan to work more closely with other nations on a regional basis to strengthen the management of these fisheries. The Government of Japan decided not to issue licenses for large-scale pelagic driftnet fisheries on or after 1 January 1993 to implement UN General Assembly resolution 46/215.

KEYWORDS: NORTH PACIFIC; FISHERIES; SQUID; FISH; MANAGEMENT

INTRODUCTION

Driftnetting is an effective fishing method for catching flying squid (*Ommastrephes bartrami*). The squid driftnet fishery has become an important Japanese fishery, supplying around 100,000 tons of squid products per year to the Japanese market. The large-mesh driftnet fishery has a relatively long history and plays an important seasonal role for many fishermen. This paper describes the regulations for these high seas fisheries imposed by the Government of Japan.

DESCRIPTION OF REGULATIONS

Squid driftnet fishery

This fishery started in 1978 in the northwestern Pacific and expanded into the high seas of the North Pacific in the following year. It targets on flying squid, which, because of their soft, large bodies cannot be caught efficiently by other fishing methods such as jigging.

In 1981, the Government of Japan introduced a limited entry licensing system for this fishery under which various regulations were imposed. The system and regulations have been reinforced and improved based upon scientific and other relevant information from the fishery.

Under this system, the number of licensed vessels has decreased from 534 in 1981 to 457 in 1990, as the Government has not authorised new entries. In 1991 and 1992, the number of vessels operating was reduced substantially (Table 1).

A northern boundary was established in 1981 to minimise the incidental take of salmonids. In 1989, the northern boundary for July and August was revised based on the available information concerning habitat segregation of salmon and flying squid (Fig. 1).

Major provisions of the regulations

The main measures covered by the regulations are:

(1) limitation of the number of the vessels engaged in the fishery;
(2) geographical and temporal restrictions on the fishing ground, in particular, the establishment of the northern boundary by month;
(3) prohibition of the retention of anadromous species, cetaceans and fur seals taken incidentally;
(4) prohibition of the transfer of catch at sea;
(5) mandatory display of the vessel's name, registration number and license number on its hull to facilitate the identification of the vessel at sea;
(6) mandatory marking on fishing gear for identification;
(7) restrictions on mesh size for squid stock conservation;
(8) mandatory record keeping of Naval Navigational Satellite System (NNSS) data in order to identify operational positions;
(9) mandatory vessel position reports; and
(10) mandatory submission of catch reports to the Government.

Measures taken consistent with the 1989 UN Resolution

In addition to the above regulations, a number of further measures (see below) were taken in accordance with the UN Resolution on gillnetting adopted in 1989.

Table 1

Licensed vessels in the Japanese squid driftnet fishery, 1981-92.

Year:	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Vessels:	534	529	515	505	502	492	478	463	460	457	284*	231*

* Total number of vessels conducting squid driftnet fishing operations during the season.

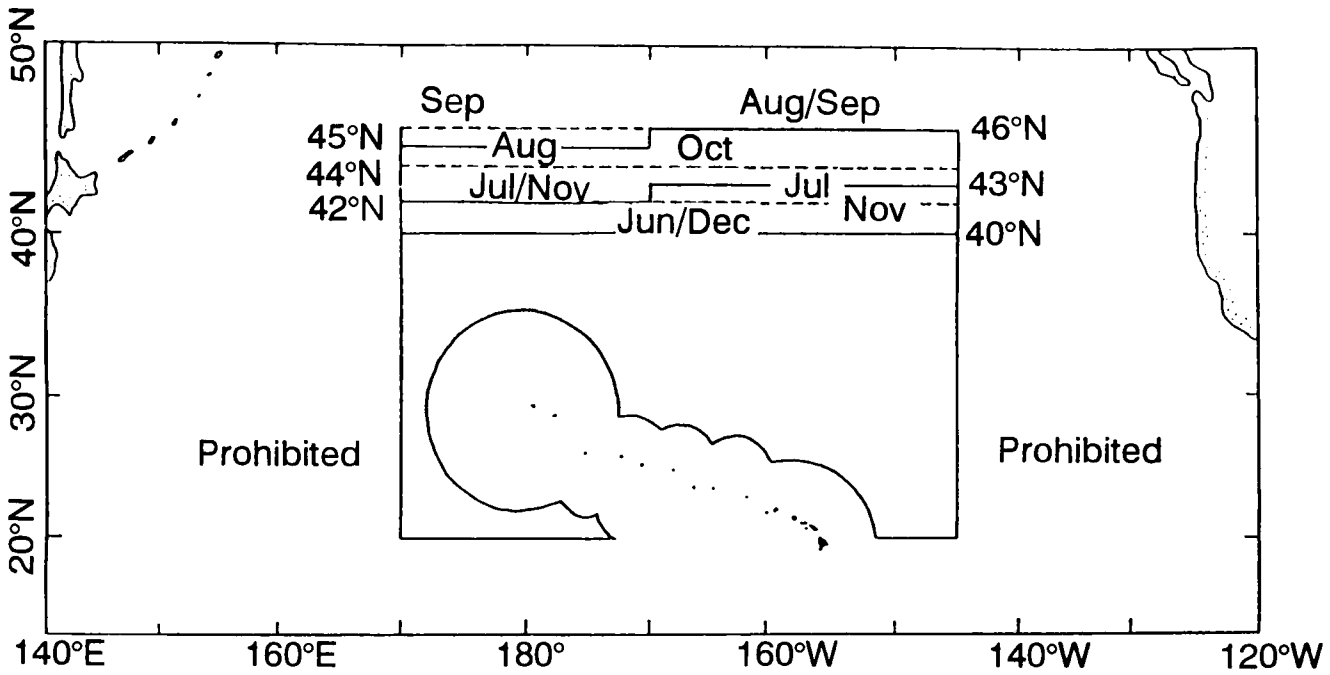

Fig. 1. North Pacific fishing grounds for Japanese squid driftnet fishery.

(1) *Restrictions on the scale of operations and the prohibition of expansion*
The number of vessels licensed in the 1991 fishing season (June-December) was 453 or less, which is a reduction of more than 80 from 1981. In addition, the Government formally prohibited this type of fishing in all areas outside the North Pacific from 15 August 1990.

(2) *Collection and exchange of scientific data*
A scientific observer programme for this fishery was initiated in 1988. In 1989, under agreements with the USA and Canada, a joint pilot scientific observer programme was implemented. Based upon these results, a full scale joint scientific observer programme was agreed and implemented in order to ensure the collection of statistically reliable data upon which conservation and management measures for this fishery might be based. Under the 1990 programme, 74 squid vessel cruises were observed. A similar programme was implemented for the 1991 and 1992 fishing seasons, when 75 cruises and 55 cruises were observed respectively.

(3) *Expansion of scientific survey and research*
Japan has continued to conduct and expand its scientific research on the catch of target species and other marine living resources taken incidentally in this fishery. A number of research vessels have been sent to the fishing grounds since 1984; four vessels conducted research in 1990. The participation of Canadian and US scientists on the Japanese research vessels has been encouraged. Scientists of Japan, Canada and the United States have discussed the relevant research results submitted by Japan to the International North Pacific Fisheries Commission (INPFC) established under the International Convention for the High Seas Fisheries of the North Pacific Ocean (effective 1952).

(4) *Installment of transponders*
From July 1990, under agreements with the USA and Canada, the Government of Japan ordered all squid driftnet fishing vessels to install satellite transmitter equipment (transponders) enabling identification of vessel positions from land on a real time basis. These data are also made available to the Canadian and the US authorities, thus enabling the authorities of the three countries to identify the position of each fishing vessel. In addition to the 1990 scientific observer programme, this enables Canada, the USA and Japan to know the actual location of fishing operations by Japanese fishing vessels. The Japanese enforcement authority can monitor observance of regulations concerning operation areas through the systematic use of this state-of-the-art transponder system and enforcement vessels at sea.

During the 1991 fishing season, the Government of Japan required a mechanical check of the transponders on board each fishing vessel before departure in order to ensure their normal operation during navigation. If a transponder ceases to function normally, the vessel is not allowed to continue fishing.

Large-mesh driftnet fishery
This fishery, which targets on tunas and billfish, has been conducted in Japanese coastal waters for more than 100 years. Expansion of the fishery to the high seas began around the middle of the 1970s. The Government of Japan instituted regulations in 1973 as a means, among other things, of avoiding competition with existing coastal fisheries.

Since August 1989, a vessel registration system has been in force, that requires fishing vessels to submit operation plans before their departure and operation reports after their return. From August 1990, the vessels engaged in large-mesh driftnet fishing on the high seas have been placed under a limited entry licensing system.

Major provisions of the regulations
The main features of the measures implemented under this system are as follows:

(1) limitation of the number of the vessels engaged in the fishery;
(2) geographical and temporal restrictions on the fishing ground (Fig. 2);
(3) prohibition of the retention of anadromous species, cetaceans and fur seals taken incidentally;
(4) prohibition of the transfer of catch at sea;
(5) mandatory display of vessel's name and registration number on its hull to facilitate identification of the vessel at sea;
(6) mandatory marking of fishing gear for identification;
(7) restrictions on mesh size for stock conservation; and
(8) mandatory submission of catch reports to the Government.

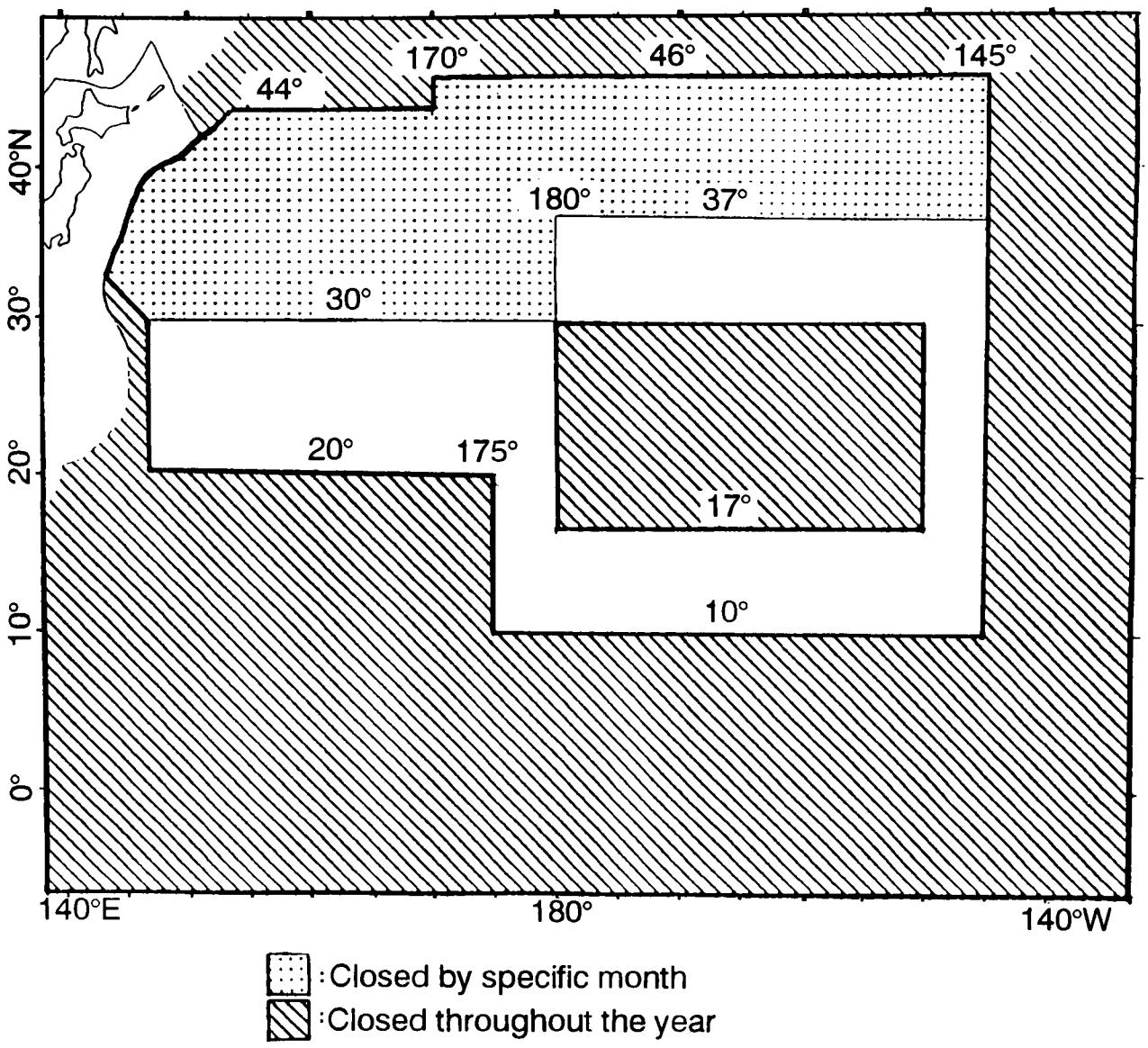

Fig. 2. North Pacific fishing grounds for high-seas large-mesh driftnet fishery.

Measures consistent with the 1989 UN Resolution

(1) *Large-mesh driftnet fishing on the high seas of the North Pacific*

(A) RESTRICTIONS ON THE SCALE OR OPERATIONS AND THE PROHIBITION OF EXPANSION

From August 1990, a limited entry licensing system was introduced. For the period from August 1990 to June 1991, the Fisheries Agency set an upper limit on the number of licensed fishing vessels of 149; 70 licenses were issued.

(B) COLLECTION AND EXCHANGE OF SCIENTIFIC DATA

From 1990, in accordance with agreements with the USA, a joint scientific observer programme for this fishery was initiated. Under this programme, 24 large-mesh driftnet vessel cruises were observed during the 1990/1991 fishing season.

(C) EXPANSION OF SCIENTIFIC SURVEYS AND RESEARCH

In the summer of 1989, the Fisheries Agency conducted a scientific research survey with the participation of a US scientist. Early in 1991, another research vessel was sent to the fishing ground (Fisheries Agency of Japan, 1991; Nakano *et al.*, 1993).

(D) INSTALLMENT OF TRANSPONDERS

From October 1990, in accordance with an agreement with the USA, the Government of Japan ordered all the fishing vessels engaging in this high seas large-mesh driftnet fishery to install transponders enabling the identification of vessel positions on a real time basis.

(2) *Large-mesh driftnet fishing in the South Pacific*

In accordance with the UN Resolution and with due attention to regional characteristics embodied in the Resolution, Japan suspended driftnet fishing in the South Pacific one year in advance of the 1 July 1991 date of cessation stipulated in the UN Resolution.

Japan took this decision taking into account, in particular, the serious concerns of the South Pacific Island countries over driftnet fishing in the region. These countries, whose economic base depends, to a large extent, on marine resources, have strong intentions of developing the albacore fishery for their own economic benefit.

The above measures will be continued until such time as appropriate conservation and management arrangements for South Pacific albacore tuna resources as referred to in the UN Resolution are entered into and appropriate regulatory measures for driftnet fishing are established under such arrangements by the parties concerned.

(3) *Large-mesh driftnet fishing in other areas*

In accordance with the UN Resolution, the Government of Japan took measures (effective 15 August 1990) prohibiting large-mesh driftnet fishing in all waters other than the Pacific Ocean.

Measures consistent with the 1991 UN resolution

The Government of Japan decided not to issue licenses for large-scale pelagic driftnet fisheries on or after 1 January 1993 to implement UN General Assembly resolution 46/215.

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SC/O90/G52

The Japanese Large-Mesh Driftnet Fishery in the Pacific Ocean

Yoh Watanabe

National Research Institute of Far Seas Fisheries, 5–7–1 Orido 5 Chome, Shimizu, Shizuoka 424, Japan

ABSTRACT

The Japanese large-mesh driftnet fishery started in the 19th century in the coastal waters of Japan. The modern large-mesh driftnet fishery began in 1970 and gradually expanded to offshore North Pacific waters. By 1983, it had reached the South Pacific. In 1973, the Government of Japan initiated regulations for this fishery. In 1990, responding to a United Nations resolution, the Government introduced a limited entry system for the high seas North Pacific driftnet fishery and prohibited such operations in all other high seas waters. The number of large-mesh driftnet vessels in 1988 was 459. Most vessels have multiple-type fishing licences. The total annual catch in 1983–88 ranged from 25,000 to 40,000 tonnes. Albacore is the main target species, accounting for about 30% of the total. Skipjack and billfish are also targeted. One panel of net ('tan') ranges from 32–54m in length and from 9–10m in depth. Mesh size varies between 151 and 210mm, with 170–180mm being the most common for albacore. The nets are constructed of nylon multistranded monofilament or nylon multifilament. The nets are set before sunset and hauling begins at midnight. The number of net panels used varies, from a few hundred for small vessels to 1,000–1,300 for large vessels. In the North Pacific, the fishing season lasts all year, with a peak from February to April. In the South Pacific, the fishery operated only during the austral summer. The fishing grounds have included a broad region extending from the Japanese 200-mile limit to north of Hawaii in the North Pacific and the Tasman Sea and waters east of New Zealand in the South Pacific. Driftnet surveys by research vessels in the North Pacific recorded bycatches of several cetacean species, including striped dolphins, common dolphins and northern right whale dolphins. The Japan Marine Fishery Resource Research Centre carried out experiments aimed at reducing bycatches by using subsurface driftnets in the South Pacific and obtained positive results. Japan, the USA and Canada agreed to initiate a joint scientific observer programme to collect biological information on the Japanese large-mesh fishery in the North Pacific during the 1990 fishing season. The Government of Japan decided not to issue licenses for large-scale pelagic fisheries on or after 1 January 1993 in response to the 1991 UN Resolution.

KEYWORDS: INCIDENTAL CAPTURE; NORTH PACIFIC; SOUTH PACIFIC; SWORDFISH; STRIPED MARLIN; BLUE MARLIN; SHORTBILL SPEARFISH; BLUEFIN TUNA; ALBACORE; BIGEYE TUNA; YELLOWFIN TUNA; SKIPJACK; SALMON SHARK; POMFRET; SLENDER TUNA; NORTHERN RIGHT WHALE DOLPHIN; COMMON DOLPHIN; PACIFIC WHITE-SIDED DOLPHIN; STRIPED DOLPHIN; BOTTLENOSE DOLPHIN; RISSO'S DOLPHIN; PANTROPICAL SPOTTED DOLPHIN; PYGMY KILLER WHALE; SHORT-FINNED PILOT WHALE; FALSE KILLER WHALE; PYGMY SPERM WHALE; SOUTHERN BOTTLENOSE WHALE; ARNOUX'S BEAKED WHALE; ZIPHIIDAE

INTRODUCTION

The Japanese large-mesh driftnet fishery, called *oome-ami* or *oome-nagasiami* and officially registered as the 'marlin and others drift gillnet fishery', is one of two large-scale Japanese driftnet fisheries; the other is the squid driftnet fishery. Until August 1989, the large-mesh fishery operated under a free-entry system regulated by the Government of Japan. Since that time, the system has changed to a registration system for vessels larger than 10 gross tonnes (GRT). These vessels are required to submit operational schedules, catch-and-effort statistics and other information. The Government applied a limited entry system outside the Japanese 200-mile fishing zone in August 1990 (Nagao, 1994). In response to UN General Assembly Resolution 46/215, the Government decided not to issue licenses for lage scale pelagic driftnet fisheries on or after 1 January 1993.

DESCRIPTION OF THE FISHERY

History of development and current trends

The fishery has a long history, dating back more than 100 years. A prototype fishery using driftnets to catch bluefin tuna began off the Pacific coast of Japan in the 1840s. In those days fishing vessels were small and limited their operations to coastal waters (Kando, 1990). The modern large-mesh fishery developed during the 1970s. During this period, the main fishing grounds were off Sanriku District and off the Boso Peninsula (Sasaki, 1974). The fishing area was extended to include other coastal as well as offshore waters of Japan. The number of targeted species also expanded to include marlins, swordfish and other species of tuna. In the early 1980s in a quest for albacore, the vessels increased in size and the fishing grounds expanded to the east in the North Pacific. In 1982, total catch of this fishery was over 40,000 metric tonnes (Table 1). Because of a desire to operate year round, 17 driftnetters entered the high seas areas of the South Pacific in the 1983/84 southern summer season to search for new fishing grounds. Subsequently, about 20 vessels operated in the South Pacific each summer until 1988/89, when 64 Japanese driftnetters and approximately the same number of Taiwanese fishing vessels fished in the region. At the same time and in the same region, the USA and New Zealand rapidly increased their troll catches of albacore. The South Pacific nations were concerned about the condition of the albacore stock and the impacts of the driftnet fishery on the marine ecosystem. Owing to this concern, the Japanese Government limited the number of driftnetters in the region to 19 in the 1989/90 season and ended the fishery completely before the 1990/91 season.

Vessels and crew

The numbers of vessels operating in the fishery from 1973 to 1988 are shown in Table 1. These numbers exclude small vessels (<10GRT) which operate only in the coastal waters of Japan. Following the 1978–1982 increase, the number of vessels gradually dropped, from 717 in 1982 to 459 in 1988. Table 2 shows the number of vessels by size and the types of fishing licenses held in 1988. Most vessels over 50 GRT had multiple licenses, e.g., squid driftnet, salmon driftnet, etc. Vessels operating large-mesh nets throughout the year comprised less than 10% of the total.

The number of crewmen per vessel is less than 20, with 15–16 being typical for a large vessel (over 200 GRT) operating on the high seas.

Gear

Fig. 1 shows the general specifications of a Japanese large-mesh driftnet. The length of one panel or 'tan' (the minimum unit) ranged from 32–54m in length after shrinkage and from 9–10m in stretched depth (6–7m fishing depth). Mesh size varied among vessels and according to the target species, from 151–210mm stretched mesh (for albacore, mesh of 170–180mm was commonly used and for marlin, 200mm). The number of vessels by mesh size is shown in Table 3. Large mesh (over 190mm) was common for vessels of less than 200 GRT. Net shrinkage in the water ranged from 50–60%. The nets were constructed of the recently developed nylon multi-stranded monofilament or nylon multifilament. About 100 'tan' linked together formed a section, or *hari*. Various numbers of these sections, usually less than 10, were deployed unconnected to each other in a single operation. Each section was equipped with a radio buoy and a light buoy at the hauling end and an orange buoy at the terminal end. The amount of net used varied with the size of the vessel; 1,000–1,300 'tan' were used by large vessels working on the high seas, whereas a few hundred were used by vessels of less than 50 GRT.

Operations

Setting of the net usually began in the afternoon and was completed before sunset. This took 2–4 hours. The net was cast from the stern. Retrieval started at midnight and was completed in the morning. The nets, therefore, were deployed at the surface (surface to 6–7m) for about 5–15 hours. The entire set was usually made in a straight line, with each *hari* separated from its neighbours by a gap of about 50–200m. Sometimes the nets were set in a curved line due to bad weather, direction of currents, adjacent operations by other vessels, etc. Typical sea-surface temperatures were 15–23°C; 18–19° is most suitable for albacore.

The duration of a trip depended on the size of the vessel and the distance to the fishing grounds. The number of trips during a year is shown in Table 4. A trip commonly lasted 20–40 days for a 100 GRT vessel and 40–140 for a vessel of more than 200 GRT. The average number of trips, travelling days and operating days for vessels of over 200 GRT are shown in Table 5. Most large vessels spent one trip per year in the large-mesh fishery.

Areas and seasons of operations

Fig. 2 shows the fishing grounds by quarter of the year. In January the fishery began off Japan and gradually extended to the east. In February and March, the grounds extended into the area north of the Hawaiian Islands. Skipjack was the main catch in this quarter. Then the grounds shifted westwards for albacore. Most large vessels changed to squid driftnetting in May, when squid landings were the largest of the year (Table 6). The fishing grounds off Japan are occupied by mid- and small-sized vessels from June to December. Some large vessels (>200 GRT) formerly went to the South Pacific grounds in November or December after the squid season, to catch albacore during the austral summer.

Table 1

Catches of Japanese large-mesh driftnet fishery, in metric tonnes by species, 1973-1988 (compiled from landing reports submitted by prefectures).

Year	No. of boats	Catches in metric tonnes					
		Marlin	Tuna	Albacore	Skipjack	Others	Total
1973	501	5,239	220		429	2,595	8,483
1974	380	5,079	587		370	2,022	8,057
1975	351	11,432	780		469	2,711	15,394
1976	396	8,912	2,168		708	5,019	16,807
1977	314	8,851	2,558		1,377	5,937	18,723
1978	292	10,050	6,582		1,965	6,904	25,501
1979	394	4,986	5,388		1,014	12,683	24,071
1980	457	8,050	6,049		1,273	17,777	33,149
1981	559	7,524	17,585	16,825	2,828	5,601	33,537
1982	717	4,603	19,079	17,217	7,940	12,884	44,505
1993	620	4,587	10,123	8,307	5,883	17,294	37,887
1984	547	4,216	12,086	10,776	6,810	10,638	33,750
1985	470	6,259	14,939	12,894	4,521	5,921	31,640
1986	474	8,301	12,184	7,269	8,785	7,200	36,469
1987	460	4,532	8,006	7,221	7,733	4,798	25,070
1988	459	5,124	15,623	15,132	13,038	6,299	40,083

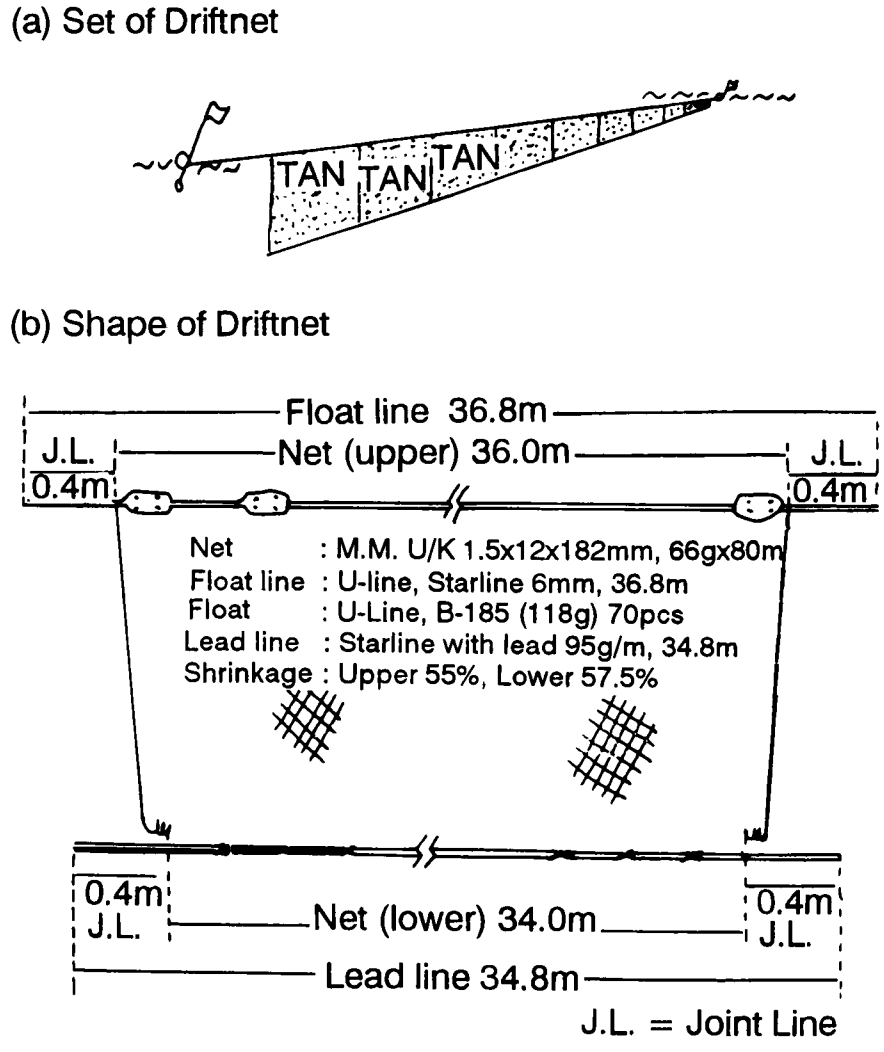

Fig. 1. General specifications of Japanese large-mesh driftnets.

Table 2

Number of large-mesh driftnet fishing vessels by size and kinds and number of fishing licenses held by large-mesh fishing vessels in 1988 (compiled from landing reports submitted by prefectures).

Size of vessel (GRT)	10-49	50-99	100-199	200-299	300-399	400-499	Total
No. of large-mesh driftnet vessels registered	134	74	133	55	38	25	459
Kinds of fishing licenses:							
Squid drift gillnet	**	39	58	47	32	21	197
Salmon drift gillnet	**	36	58	-	-	-	94
Tuna longline and pole-and-line	**	20	55	2	-	-	77
Saury stick-held dip net	**	28	63	-	-	-	91
Squid angling	**	9	15	1	2	8	35
NPO long line and gillnet*	**	-	-	1	1	4	6
Off-shore trawl	**	1	4	-	-	-	5
Others	**	1	1	2	-	-	4
Sub-total	**	134	254	53	35	33	509

* North Pacific Ocean longline and gillnet.
** No information.

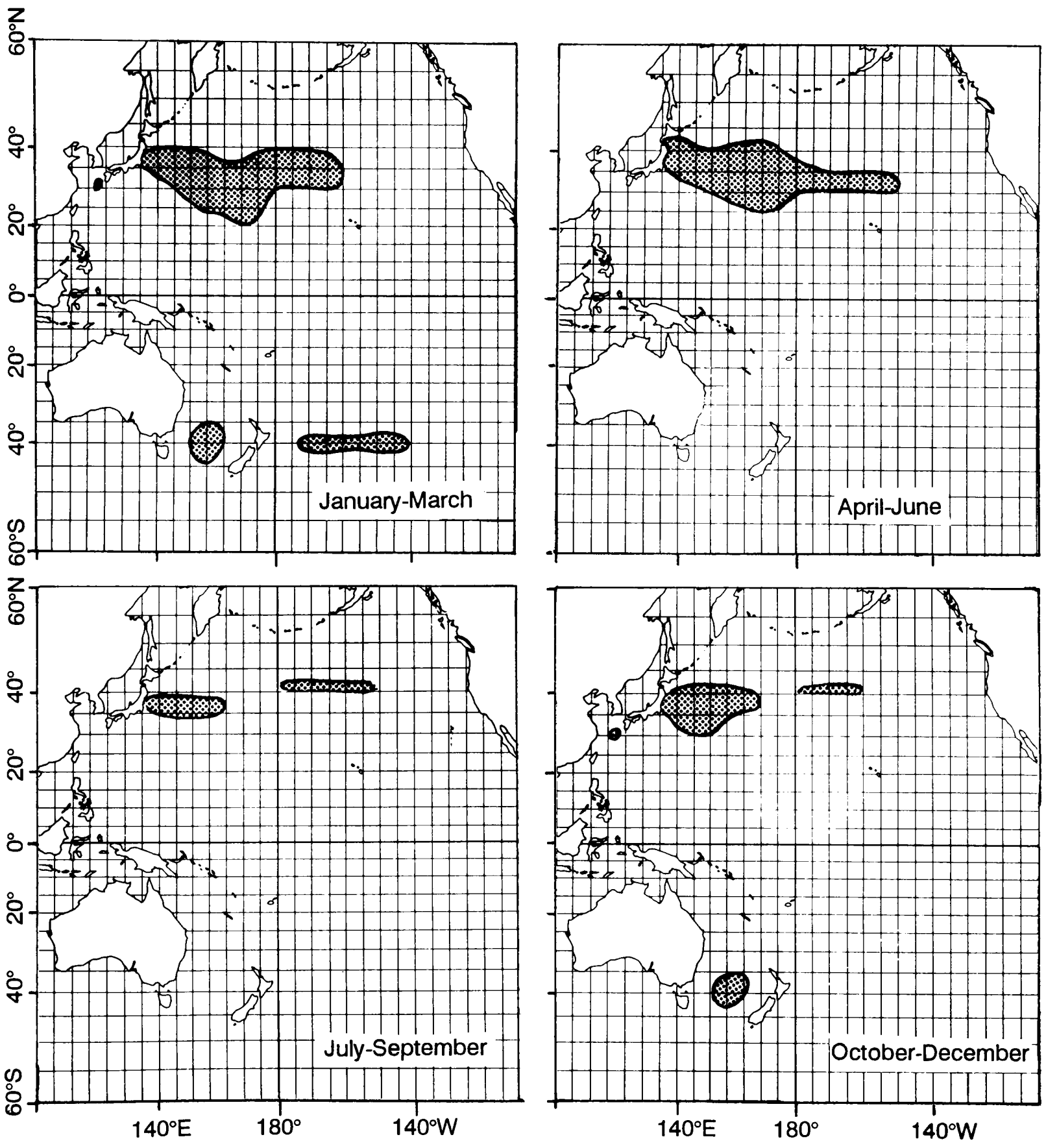

Fig. 2. Quarterly distribution of fishing grounds for the Japanese large-mesh driftnet fishery in 1988.

Table 3

Number of fishing boats by mesh size used and GRT in 1988 (compiled from landing reports submitted by prefectures).

Mesh size (mm)/ Size of boat (GRT)	151-155	156-160	161-165	166-170	171-175	176-180	181-185	186-190	191-195	196-200	201-	n.d.
50-99	6	4	3	3	1	36	3	2		1	7	8
100-199	8	9	9	11	2	66	7	3	3	2		13
200-299	2	4	4	12	1	20	5					7
300-399	2	1	4	4	1	17	1	2				6
400-499	5	2	2	3		7	3				1	2
Total	23	20	22	33	5	146	19	7	3	3	8	36

Table 4

Number of fishing boats by length of voyage and GRT in 1988 (compiled from landing reports submitted by prefectures).

Voyage days/ Size of boat (GRT)	-20	21-40	41-60	61-80	81-100	101-120	121-140	141-
50- 99	25	23	12	4	3	1	1	4
100-199	46	57	16	8	1	3		2
200-299	2	4	13	13	4	4	6	8
300-399	4	8	3	6	7	1	1	8
400-499	2	10	5	2	4		1	1

Table 5

Mean effort of fishing boats (over 50GRT), 1981-1988 (compiled from landing reports submitted by prefectures).

	Per boat			Per trip	
Year	No. of trip	Trip day	Operation day	Trip day	Operation day
1981	2.8	72.8	46.0	26.2	16.6
1982	2.0	67.9	42.2	34.7	21.6
1983	1.6	53.8	34.0	33.7	21.3
1984	1.6	50.9	32.0	31.1	19.5
1985	1.7	50.0	32.1	29.5	18.9
1986	1.8	52.1	33.5	28.8	18.5
1987	1.9	51.3	32.5	27.2	17.2
1988	1.9	53.1	34.1	27.4	17.5

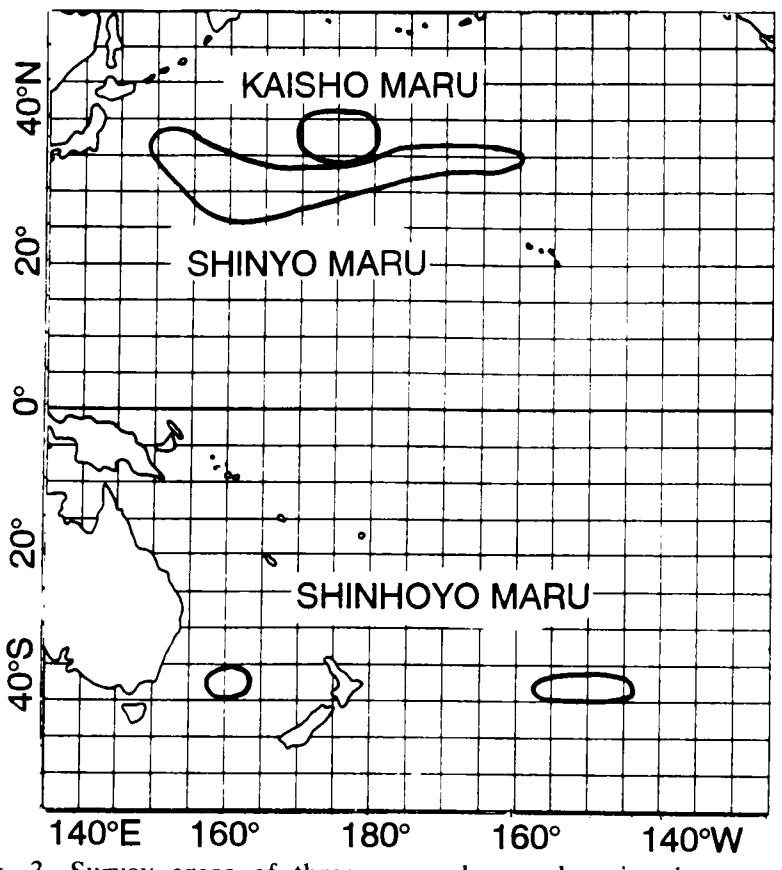

Fig. 3. Survey areas of three research vessels using large-mesh driftnets (Data presented in Table 9).

Target species

The target species have changed over time. In the first period, when the fleet operated near Japan, marlins and swordfish were targeted, with a mesh size of about 200mm. In the early 1980s, with the expansion of the fishery, the emphasis changed to albacore. More recently, the catch of skipjack was about the same as that of albacore (Table 1). Table 7 shows examples of the species composition of catches. The albacore catch in the South Pacific was relatively higher than in the North Pacific, whereas the reverse was true for skipjack.

Total landings and ports

Annual catches are shown in Table 1. These data were compiled using landing reports submitted to the Fisheries Agency of Japan (FAJ) by the prefectures where the vessels landed their catches. Some catches by vessels of less than 10 GRT may be included in these statistics. The total annual catch ranged from 25,000 to 40,000 tonnes in the 1980s; the albacore component fluctuated between 7,200 and 17,200 tonnes.

Landings at the major ports in 1988 are shown in Table 8. Fish caught in the East China Sea are landed at Nagasaki.Catches from other regions are landed mainly at ports on the Pacific coast from Hokkaido south to Chiba Prefecture; largest landings are at Kesennuma, Shiogama, Hachinohe and Ishinomaki. The albacore and skipjack are quick-frozen on board and processed into canned products ashore. Catches in coastal waters are iced in the hold and sold as raw fish in the market.

Regulations (*and see Nagao, 1994*)

The Government of Japan introduced certain regulatory measures for the fishery in 1973 by issuing a ministerial ordinance and a notice. These were designed to regulate the fishery and to solve conflicts with other coastal fisheries and with pole-and-line and longline fisheries for tuna and skipjack. In 1982, in order to avoid potential incidental

catches of salmon in the North Pacific area closures were implemented, similar to those for the squid driftnet fishery. In addition to these national regulations, various other regulatory measures were implemented by prefectural governments to solve conflicts among coastal fisheries, other driftnet fisheries and this fishery. These regulations included limiting the number of vessels and time area restrictions. In 1989, the Government enforced a new registration system for this fishery which included required submission of catch reports. Responding to the 1989 resolution on high seas large-scale pelagic driftnetting by the United Nations, the Government introduced a limited entry system for this fishery on the high seas of the North Pacific in order to strengthen control and to gather scientific information. The number of licensed vessels was reduced from previous seasons. The fishery was prohibited in high seas waters other than in the North Pacific from August 1990. In August 1990, the Government prohibited retention and landing of cetaceans, even those taken incidentally in driftnets. Finally, in response to the 1991 UN Resolution, the Government stopped large-scale driftnet fishing after January 1993.

Cetacean bycatches

Survey cruises

It is known that cetaceans are incidentally caught in driftnets. Following a request by the Japanese Government, some of the fishermen in the large-mesh fishery volunteered to submit bycatch reports. However, the severe problems of species identification for both seabirds and cetaceans in these data make them unsuitable for scientific analysis. Therefore, in this paper, data from survey cruises conducted by two organisations using large-mesh driftnets on the commercial fishing grounds (Fig. 3 and Table 9) are considered. The Japan Marine Fishery Resource Research Centre (JAMARC) collected catch and by-catch data for two fishing surveys in the North and South Pacific. In the North Pacific, a total of 186 surveys for a Pacific pomfret assessment were conducted in a large area from 22–47°N and 148°E-133°W from April 1982 to February 1983. The analysis here is limited to the 51 surveys carried out in the area of the commercial fishery during the fishing season. Nine species of cetaceans were incidentally caught during these surveys: striped dolphins (*Stenella coeruleoalba*), northern right whale dolphins (*Lissodelphis borealis*) and common dolphins (*Delphinus delphis*) made up 37%, 29% and 21% of the total, respectively. Most of the entangled cetaceans suffocated, but two unidentified medium-sized whales escaped during net hauling near the vessel. In addition, a southern bottlenose whale (*Hyperoodon planifrons*) was cut free from the net by the crew but probably did not survive, because it sank with the net wrapped around it.

In 1989, the FAJ conducted a survey cruise with a chartered large-mesh driftnetter in the North Pacific. One Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) and an adult female pygmy sperm whale (*Kogia breviceps*) and calf were captured and died during this survey (Table 9). Bycatches in the driftnet fisheries in the North Pacific are more fully discussed in Hobbs and Jones (1993).

Experiments to reduce entanglement

JAMARC carried out an exploratory cruise with a driftnet research vessel in the South Pacific from November 1989 to March 1990. During this cruise, 42 experimental operations were carried out using standard surface nets and subsurface nets (2m below the surface) in order to determine whether a subsurface net would allow cetaceans to pass and reduce their entanglement. The results of these experiments are shown in Table 10. The CPUE (fish per 1,000 'tan') for was higher for albacore for the subsurface net but lower for skipjack. About one tenth as many cetaceans were caught in the subsurface nets as in the surface nets. No turtles or seabirds were caught in the subsurface nets. Following these encouraging results, seven Japanese commercial squid driftnetters used the subsurface net in the North Pacific in 1990 (Hayase and Watanabe, 1990). However, the search to find gear and practices that retain the benefits of driftnets to the fishermen but reduce bycatches remains (e.g. Dawson, 1994; Goodson *et al.*, 1994; IWC, 1994).

Table 6

Monthly landing by species in 1988 (compiled from landing reports submitted by prefectures).

	Catches in metric tonnes					
Month	Marlin	Tuna	Albacore	Skipjack	Others	Total
January	82	387	348	77	128	675
February	264	2,965	2,924	345	208	3,780
March	474	2,162	2,109	746	455	3,837
April	713	1,427	1,369	4,261	1,666	8,067
May	691	2,609	2,549	4,633	1,439	9,372
June	108	2,976	2,866	831	677	4,592
July	387	1,342	1,293	252	320	2,301
August	865	315	276	371	363	1,914
September	628	219	204	350	211	1,408
October	426	269	261	256	203	1,154
November	344	513	506	702	472	2,030
December	144	439	427	214	157	953
Total	5,124	15,623	15,132	13,038	6,299	40,083

Table 7

Species composition of catches by four Japanese large-mesh driftnetters operating in the Pacific Ocean, 1989-1990.

Area:	North Pacific						South Pacific	
Sample boat	A		B		C		D	
(GRT)	(299)		(274)		(200)		(443)	
Fishing ground	29-32N 165E-164W		29-31N 158-177E		29-32N 149-162E		Tasman Sea	
Period of operation	Jan-Apr 1990		Feb-Apr 1990		Apr 1990		Dec 1989-Feb 1990	
Species	No. %	Wt. %	No. %	Wt. %	No. %	Wt. %	No. %	Wt. %
Swordfish	0.4	5.7	1.9	16.7	0.1	0.3	0.1	1.4
Striped marlin	0.4	4.4	0.1	1.1	0.3	3.1	0.1	2.3
Blue marlin	0.0	0.8	0.0	0.1			0.0	0.5
Shortbill spearfish			0.2	0.3			0.2	0.5
Bluefin tuna	0.0	0.0						
Albacore	6.7	7.8	8.5	12.3	8.2	12.1	60.1	65.0
Bigeye tuna	0.1	0.3	0.2	0.6	0.2	0.6	0.0	0.0
Yellowfin tuna	0.0	0.3	0.1	0.2	0.1	0.0	0.0	0.1
Skipjack	53.1	33.3	66.6	48.7	24.8	24.4	39.4	29.4
Salmon shark	0.1	0.7	0.0	0.0			0.1	0.7
Pomfret	39.2	26.5			25.7	n.d.		
Slender tuna							n.d.	0.2
Others	n.d.	20.1	21.8	19.3	39.8	59.5		
No. of fish	30,159		27,443		1,684		61,608	
Catches (kg)	189,397		160,386		6,030		342,381	

Table 8

Landings in metric tonne by species, by main driftnet landing port in 1988. This Table was compiled by landing reports submitted from prefectures and only includes those ports with landings of over 100 tonnes.

		Catches in metric tonnes					
Name of prefecture	Name of port	Marlin	Tuna	Albacore	Skipjack	Others	Total
Hokkaido	Kushiro	237	702	554	631	306	1,876
	Tokachi	99	0	0	37	42	177
	Hakodate	74	861	861	676	188	1,799
Aomori	Hachinohe	191	1,851	1,822	1,514	413	3,969
Iwate	Miyako	313	80	66	68	175	636
	Kamaishi	115	159	124	60	80	414
	Yagi	53	346	341	262	87	748
Miyagi	Kesennuma	1,939	3,201	3,154	4,929	2,330	12,399
	Onagawa	197	761	749	752	360	2,071
	Ishinomaki	261	1,547	1,522	1,130	431	3,369
	Shiogama	1,058	4,775	4,718	2,274	1,284	9,391
Fukushima	Ena	57	182	178	254	58	551
	Onahama	51	703	687	149	75	977
	Nakanosaku	6	201	200	149	35	392
Chiba	Choshi	198	149	52	109	375	831
Nagasaki	Nagasaki	230	0	0	15	2	246
Total catch (tonnes)		5,124	15,623	15,132	13,038	6,299	40,083
Total amount (million Japanese yen)		2,985	3,464	3,207	1,668	1,248	9,366

Table 9

Occurrences of cetaceans taken by large mesh driftnet survey cruises in the Pacific Ocean.

Area:	North Pacific		South Pacific
Type of survey	Pacific pomfret resources survey	Driftnet fishery survey	Driftnet new fishing ground
Name of vessel	*Shinyo maru*	*Kaisho maru*	*Shinhoyo maru*
Organiser	JAMARC	FAJ	JAMARC
Period	Apr 1982-Feb 1983	July 1989	Nov 1989-Mar 1990
Survey area	26-39N 148E-160W	35-40N 172-178E	34-39S 155E-144W
Surface water temperature	14-22C	15-25C	18-21C
Mesh size (mm)	150,160,170,180	180	178
Number of operations	51	15	75
Number of net (tan)	42,059	4,200	66,538
Species			
Northern right whale dolphin	22	-	-
Common dolphin	16	-	97
Pacific white-sided dolphin	1	1	-
Striped dolphin	28	-	17
Bottlenose dolphin	1	-	3
Risso's dolphin	4	-	-
Pantropical spotted dolphin	2	-	-
Pygmy killer whale	1	-	-
Short-finned pilot whale	-	-	1
False killer whale	-	-	1
Pygmy sperm whale	-	2	-
Southern bottlenose whale	-	-	2
Arnoux's beaked whale	-	-	1
Ziphiidae	1	-	-
Unidentified whale (medium sized)	-	-	2
Total	76	3	124

Table 10

Results of bycatch reduction experiment by JAMARC, November 1989 - March 1990, Tasman Sea. CPUE: No. of fish/1,000 tans.

Type	Standard surface		Experiment subsurface	
No. of operations	42		42	
Total net used (tan)	57,940		6,898	
	No.	CPUE	No.	CPUE
Albacore	30,917	534	4,446	645
Skipjack	13,282	229	772	112
Swordfish	104	2	15	2
Striped marlin	33	1	3	0
Blue shark	229	4	28	4
Mako shark	104	2	14	2
Dolphin and whale	123	2	1	0
Sea turtles	4	0	0	
Sea birds	4	0	0	

IMPACT OF DRIFTNET CATCHES ON MARINE RESOURCES

North Pacific

Albacore

This stock has been fished by various surface fisheries, including pole-and-line fishing, trolling, longlining and driftnetting. Only in recent years have concerns about the status of the stock been expressed. The North Pacific Albacore Workshop held in 1989 recognised that the stock is in poorer condition than was previously thought (Bartoo and Watanabe, 1989). Because the total catch by large-mesh and squid driftnet fisheries by Japan, Korea and Taiwan is assumed to have been higher than the catch by other surface fisheries (i.e. the Japanese pole-and-line fishery and the US troll fishery), fishing mortality from the driftnet fisheries is expected to have had an impact. However, the actual impact is not yet known, partly due to incomplete catch and effort statistics. Japanese and US scientists are undertaking a joint stock assessment that will take into account the driftnet fisheries.

Skipjack and bluefin tuna

Driftnet catches for these species are small compared with those of the pole-and-line and purse seine fisheries and thus the impact of the driftnet catches should be small.

Marlins and swordfish

The North Pacific stock of striped marlin has been fished by longline and driftnet. The driftnet share has been increasing, and became comparable with the longline share after the mid-1980s. Suzuki (1989) inferred that the overall fishing impact on the northern stock has not been high enough to be a dominant factor in changing stock size. Swordfish are captured more by longline than by driftnet. The Pacific swordfish stock is thought to be relatively healthy (Bartoo and Coan, 1989) and thus the driftnet fishery appears to have had no appreciable impact on the population size.

Marine mammals

In the 1980s there was little information on the population size and general biology of most species of marine mammals affected and the size of the incidental catches that the impact of the driftnet fishery on these species is difficult to quantify. As noted above, in surveys using large-mesh driftnets several species of cetaceans were caught and killed. Thus, it was reasonable to expect that the stocks of marine mammals were affected by the fishery. Under agreements for observation of the Japanese driftnet operations, Japan, the USA and Canada began collecting by-catch information in the large-mesh fishery during the 1990 season. Scientific observers were deployed on 24 vessels from September 1990 to April 1991. These and other data are discussed in Hobbs and Jones (1993) who found that the northern right whale dolphin (*Lissodelphis borealis*) appeared to be the most depleted cetacean species.

Seabirds

There is almost no documented information on incidental catches of seabirds by large-mesh driftnets. According to the results of interviews of fishermen by the author, the catches are smaller than in squid driftnetting. The above-mentioned cooperative observer programme will also collect data on bird catches.

South Pacific

Albacore

Catches of southern-stock albacore by Asian large-mesh driftnetters increased greatly in the 1988/89 season but decreased drastically in the following season. The 1989/90 catch was about the same as the combined US-New Zealand troller catch. Due to the lack of biological information and incomplete statistics, there have been no assessments of the impact of driftnet fishing on the stock. The National Research Institute of Far Seas Fisheries (NRIFSF) carried out a scientific survey of albacore drop-out during net retrieval in driftnet operations in the Tasman Sea in November-December 1989. The drop-out ratio was 7.3% (Watanabe, 1990).

Skipjack

Catches are so small that the impact must be negligible.

Southern bluefin tuna

There have been no records of catch of this species in driftnet operations in the Tasman Sea. In the waters east of New Zealand, large bluefin tuna were caught sporadically. The catches by other than Japanese driftnets are unknown. It is thus not possible to assess the impact of the driftnet fisheries on this species.

Marlins and swordfish

Driftnet catches have been very small compared with longline catches and probably have negligible impact.

Marine mammals

Especially high mortality of cetaceans was recorded by the JAMARC survey in the Tasman Sea (Table 10). Japan suspended its fishery there from the 1990/91 season.

Seabirds

According to the JAMARC survey, incidental catch of seabirds was quite small. The impact is likely less than that of longline fisheries and takes by New Zealand and Australian native peoples.

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A Brief Review of Stock Identity in Small Marine Cetaceans in Relation to Assessment of Driftnet Mortality in the North Pacific[1]

William F. Perrin and Robert L. Brownell, Jr.

Southwest Fisheries Science Center, La Jolla, California, USA

ABSTRACT

Dolphins of several species are killed incidentally in driftnet fisheries on the high seas in the North Pacific. Information on stock identity, necessary for assessment and management of the dolphin populations, is lacking. The review of such information for other species and populations for which it is available indicates that further research may uncover stock divisions in the fishery region, although uniformity of habitat over the large region can be construed to suggest that such divisions may be absent.

KEYWORDS: REVIEW; STOCK IDENTITY; SMALL CETACEANS-GENERAL; MANAGEMENT; FRANCISCANA; WHITE WHALE; NARWHAL; HARBOUR PORPOISE; VAQUITA; FINLESS PORPOISE; INDO-PACIFIC HUMP-BACKED DOLPHIN; TUCUXI; DUSKY DOLPHIN; PACIFIC WHITE-SIDED DOLPHIN; WHITE-BEAKED DOLPHIN; ATLANTIC WHITE-SIDED DOLPHIN; BOTTLENOSE DOLPHIN; ATLANTIC SPOTTED DOLPHIN; PANTROPICAL SPOTTED DOLPHIN; SPINNER DOLPHIN; STRIPED DOLPHIN; COMMON DOLPHIN; IRRAWADDY DOLPHIN; COMMERSON'S DOLPHIN; FALSE KILLER WHALE; KILLER WHALE; LONG-FINNED PILOT WHALE; SHORT-FINNED PILOT WHALE; BAIRD'S BEAKED WHALE

INTRODUCTION

The several pelagic driftnet fisheries in the North Pacific kill small cetaceans incidentally (Northridge, 1991; INPFC, 1992a; b; IWC, 1992; Jones *et al.*, 1992; Hobbs and Jones, 1993). The major species in this bycatch are the northern right whale dolphin (*Lissodelphis borealis*), striped dolphin (*Stenella coeruleoalba*), common dolphin (*Delphinus delphis*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) and Dall's porpoise (*Phocoenoides dalli*). Several other species are taken in relatively small numbers. In order to assess the impact of these kills, the stocks involved must be identified, or, lacking that, some judgement must be made about how far to divide up the range of the species for purposes of management. However, little or nothing is known about the stock structure or even the distribution of most of the species in the region. The purpose of this brief review is to summarise what is known about the stock identity of small marine cetaceans in the North Pacific and in other regions, and to use this to attempt to deduce hypotheses for the likely stock structure of the affected species in the areas of the driftnet fisheries.

The term 'stock' is defined here to mean any existing or potential management unit comprised of a single breeding population and includes entities recognised as subspecies, geographical forms or isolated populations (the assumption being that geographic isolation implies some degree of genetic isolation).

In this paper we do not attempt to review the rationale or analyses upon which the decisions for stock identity were based. Such a review, along the lines suggested by Dizon *et al.* (1992a), is in order but is beyond the scope of this paper.

One or more stocks (in the sense defined above) have been identified for 19 of the 62 small marine cetaceans (Table 1). Information indicating the possible existence of more than one population is available for another seven species. For the remaining thirty-six species nothing is known of geographical variation or stock structure. Species accounts follow for the twenty-six species in the first two categories.

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SPECIES ACCOUNTS

Franciscana (*Pontoporia blainvillei*)

The franciscana inhabits the coastal waters of southern Brazil, Uruguay and northern Argentina. The results of multivariate analyses of skull measurements of specimens stranded or killed in gillnet fisheries indicate that the dolphins from the northern part of the range off Brazil differ slightly from those from farther to the south off southern Brazil, Uruguay and Argentina in cranial proportions (Pinedo, 1991). Whether this means the existence of a morphological cline or separate populations will not be known until material from more intermediate localities has been examined. The overall study is based on several hundred specimens, although the sample of intact adult skulls of known sex is much smaller.

White whale (*Delphinapterus leucas*)

This species lives in subArctic and Arctic waters of North America, Asia and Europe (Klinowska, 1991). Most of the populations migrate between summering and wintering grounds; the summer months are spent in shallow estuaries and near-shore waters and the winter months in deeper coastal and ice-edge waters. Some populations on the periphery of the range at lower latitudes (e.g. the St. Lawrence Estuary in Canada and Cook Inlet in Alaska) are resident year round. Animals from several summering grounds winter in the same area.

The present model used in management in Canada and the USA is that the summering populations represent discrete stocks that mingle with but probably do not breed with animals on the wintering grounds from other summering grounds. This conservative hypothesis (from the perspective of conservation) is supported by a

Table 1

Status of information on stock structure of small marine cetaceans. The three categories used: no information available ('None'); some relevant information available but no stocks identified ('Some'); at least one stock delineated ('Stocks'). The last category includes those species (*Phocoena sinus* and *Cephalorhynchus hectori*) for which there is known to be only a single small and local population.

Species	None	Some	Stocks	Species	None	Some	Stocks
Pontoporia blainvillei		X		*Cephalorhynchus commersonii*			X
Delphinapterus leucas			X	*Cephalorhynchus eutropia*	X		
Monodon monoceros			X	*Cephalorhynchus heavisidii*	X		
Phocoena phocoena			X	*Cephalorhynchus hectori*			X
Phocoena spinipinnis	X			*Peponocephala electra*	X		
Phocoena sinus			X	*Feresa attenuata*	X		
Neophocaena phocaenoides			X	*Pseudorca crassidens*	X		
Australophocaena dioptrica	X			*Orcinus orca*			X
Phocoenoides dalli			X	*Globicephala melas*			X
Steno bredanensis	X			*Globicephala macrorhynchus*			X
Sousa chinensis		X		*Tasmacetus shepherdi*	X		
Sousa teuszii	X			*Berardius bairdii*			X
Sotalia fluviatilis			X	*Berardius arnuxii*	X		
Lagenorhynchus albirostris		X		*Mesoplodon pacificus*	X		
Lagenorhynchus acutus		X		*Mesoplodon bidens*	X		
Lagenorhynchus obscurus			X	*Mesoplodon densirostris*	X		
Lagenorhynchus obliquidens		X		*Mesoplodon europaeus*	X		
Lagenorhynchus cruciger	X			*Mesoplodon layardii*	X		
Lagenorhynchus australis	X			*Mesoplodon hectori*	X		
Grampus griseus	X			*Mesoplodon grayi*	X		
Tursiops truncatus			X	*Mesoplodon stejnegeri*	X		
Stenella frontalis		X		*Mesoplodon bowdoini*	X		
Stenella attenuata			X	*Mesoplodon mirus*	X		
Stenella longirostris			X	*Mesoplodon gingkodens*			
Stenella clymene	X			*Mesoplodon carlhubbsi*	X		
Stenella coeruleoalba			X	*Mesoplodon peruvianus*	X		
Delphinus delphis			X	*Ziphius cavirostris*	X		
Lagenodelphis hosei	X			*Hyperoodon ampullatus*	X		
Lissodelphis borealis	X			*Hyperoodon planifrons*	X		
Lissodelphis peronii	X			*Kogia breviceps*	X		
Orcaella brevirostris		X		*Kogia simus*	X		

traditional use of summering grounds by individual whales and independent responses to exploitation by at least some of the summering populations (IWC, 1980; Finley *et al.*, 1982; Reeves and Mitchell, 1987; Hazard, 1988).

Some morphological differences have been found between white whales from different areas in Canada (Sergeant and Brodie, 1969; Finley *et al.*, 1982), although later comparisons of Russian specimens from different summering grounds did not yield differences (Ognetov, 1981; Ognetov and Potelov, 1982). Doidge (1991) confirmed the existence of size differences between whales from Hudson Bay and those from Alaska, West Greenland, the St. Lawrence River and the MacKenzie Delta. The morphological studies were based on several hundred specimens.

Preliminary results of the use of mitochondrial DNA markers to distinguish white whale stocks indicate that whales in eastern Hudson Bay are distinct from those in the Mackenzie Delta and also suggest that they are distinct from those in western Hudson Bay, Cumberland Sound and Jones Sound (Helbig *et al.*, 1989). These studies are continuing.

Frost and Lowry (1991), on distributional grounds, recognised three provisional stocks in western Alaska and one shared with Canada. Seven stocks are provisionally recognised in Canada and five in Russia (IWC, 1992).

Although much remains to be done in delineating the populations, and opinions have changed as more data were collected, at least 16 stocks have been provisionally recognised (Reeves and Mitchell, 1987; Hazard, 1988; Helbig *et al.*, 1989; Richard *et al.*, 1990; Frost and Lowry, 1991; Klinowska, 1991; IWC, 1992).

Narwhal (*Monodon monoceros*)

Stock divisions for this Arctic species have been based on distribution and migration; no morphological or genetic studies have been carried out, and it is not known if there is site fidelity. Three stocks were tentatively recognised in 1980 (IWC, 1980; Klinowska, 1991): Davis Strait-Baffin Bay, Foxe Basin and East Greenland-Spitzbergen. The affinities of animals in northwestern European and eastern Siberian waters are unknown. More recently, within the overall aggregation that winters in Davis Strait-Baffin Bay, the Canadian Government has recognised three management units: one summering in northwest Greenland, one in northwestern Hudson Bay, and one in the Canadian High Arctic (Strong, 1988).

Harbour porpoise (*Phocoena phocoena*)

The harbour porpoise is primarily a coastal species, although recent surveys have revealed that it is more common in offshore waters than previously believed (IWC, 1990). It inhabits the temperate coastal waters of Europe, West Africa, North America and Asia and the Black Sea (Klinowska, 1991).

The Black Sea population is totally isolated (Gaskin, 1984), but stock structure elsewhere is less clear. Gaskin (1984) postulated 18 stocks based primarily on distributional patterns: one Black Sea; one African; eight European; two Greenlandic; three along the eastern coast of North America; two along the US west coast and Canada/Alaska; and one in Japan. Average morphological differences exist among porpoises from the Black Sea, Mediterranean and eastern North Atlantic; the North Atlantic animals are largest and the Black Sea animals

smallest (Perrin, 1984). The porpoises along the coast of West Africa have larger skulls than those to the north in European waters (Fraser, 1958); this may indicate isolation. Within the eastern North Atlantic, non-metrical cranial analyses and isoenzyme studies suggest the existence of at least two populations (IWC, 1991a). In the western North Atlantic, four populations have been postulated: West Greenland; Newfoundland and Labrador; Gulf of St. Lawrence; and Bay of Fundy-Gulf of Maine. However, recent studies of mtDNA do not support the absence of gene flow among at least three of these (MMI, 1992), and alternative hypotheses of three populations and of one population have been adopted for purposes of management.

In a recent study based on cranial morphometric and non-metrical characters for several hundred skulls, Yurick and Gaskin (1987) demonstrated separation between eastern Pacific, western Atlantic and eastern Atlantic series. Sample-size limitations prevented confident finer comparisons, but the data suggested segregation of Dutch, Baltic and eastern English (North Sea) animals. In a similar study, Amano and Miyazaki (1992) found 'good differences' between eastern and western Pacific porpoises as well as between those from the North Pacific and North Atlantic. They concluded that distant populations are well differentiated morphologically and that this indicates little if any gene flow. Rosel (1992) confirmed this general picture, based on the analysis of mitochondrial DNA sequence data; she found no evidence of gene flow among North Pacific, North Atlantic and Black Sea populations.

In the eastern Pacific, the results of examination of pesticide levels indicate that harbour porpoises from Central California do not mingle extensively with those in Oregon and Washington (Calambokidis and Barlow, 1991), but analyses of mitochondrial DNA suggest the possibility of some gene flow or seasonal mixing between these areas (Rosel, 1992).

Vaquita (*Phocoena sinus*)
The vaquita is endemic to the upper portion of the Gulf of California; there is only one population. It has the smallest geographic range of any marine cetacean (Brownell, 1986; IWC, 1990).

Finless porpoise (*Neophocaena phocaenoides*)
A freshwater race of this species inhabits the Yangtze River; it is morphologically and physiologically different from the marine form found in adjacent coastal waters and specimens from India (Fraser, 1966; Gao Anli, 1991). Pilleri and Gihr (1972; 1980) compared the riverine form with specimens from Pakistan and described a new species *N. asiaeorientalis* based on the Yangtze material. Pilleri and Chen (1980) discussed differences between the two putative species. Pilleri and Gihr (1975) described yet another species, *N. sunameri*, from Japan. These species have not been accepted, because the morphological differences between the various series of specimens are average rather than distinct (Honacki *et al.*, 1982). Gao (1991) concluded, based on morphological and genetic studies, that 5–6 populations should be recognised: (1) South Asia; (2) South China Sea; (3) Yellow Sea; (4) Yangtze River; and (5) Japan (probably two populations, on eastern and western coasts). He proposed that three subspecies be recognised: *N. p. phocoenoides* (southern Asia and South China Sea); *N. p. sunameri* (Yellow Sea and Japan); and *N. p. asiaeorientalis* (Yangtze River). His morphological analyses were based on 218 specimens.

Dall's porpoise (*Phocoenoides dalli*)
Dall's porpoise is a pelagic animal of the North Pacific. It is found off the coasts of the USA, Canada, USSR, Korea and Japan. Stock structure in this species has been under intensive study in recent years because of large directed and incidental kills, mainly in the central and western North Pacific.

There is evidence for several stocks. Two colour morphs occur: the *truei*-type and the *dalli*-type; these are found in sharply different frequencies in different areas and were formerly recognised as separate species. Despite the striking dimorphism, however, isozyme studies indicate gene flow between the two forms (Shimura and Numachi, 1987). Osteological studies of several hundred specimens from the eastern North Pacific, Bering Sea and southern fisheries conservation zone of the USA were inconclusive (Walker and Sinclair, 1990), but geographic variation in parasite loads (Walker, 1990) and in pollutant levels (Subramanian *et al.*, 1986) and patterns of migration and breeding areas as determined from sightings of mother-calf pairs (Yoshioka *et al.*, 1990) suggest the existence of at least six stocks of *dalli*-type porpoise and one of *truei*-type associated with the main calving grounds (IWC, 1990; Miyashita, in press). However, there is some uncertainty about the existence of a separate eastern Pacific stock and the eastern boundary of a stock in the Bering Sea.

Indo-pacific hump-backed dolphin (*Sousa chinensis*)
This species inhabits shallow coastal waters and estuaries from China throughout Southeast Asia to the northern coasts of Australia and west along the coasts of the Indian Ocean (including the Persian Gulf and the Red Sea) to southern South Africa (Klinowska, 1991). It is highly variable geographically in external shape, size and colouration. Pilleri and Gihr (1980) recognised four species: *S. plumbea* from the east coast of Africa, Red Sea, Persian Gulf, India, Burma and Thailand; *S. lentiginosa* from the same regions; *S. chinensis* from the coast of southern China; and *S. borneensis* from Sarawak in Borneo and northern Australia. Most workers now only recognise a single species (Honacki *et al.*, 1982). The long coastal range and the level of variation suggest that many local breeding populations exist, but the specimens and data that would allow rigorous examination of this hypothesis have not yet been collected.

Tucuxi (*Sotalia fluviatilis*)
A dwarf riverine race of the tucuxi was formerly considered a separate species (Honacki *et al.*, 1982). The larger marine form is distributed in estuaries and shallow bays along the east coast of South America from the Caribbean to Paraná in Brazil (Borobia *et al.*, 1991). Fewer than 100 osteological specimens are available for study. These are sufficient to demonstrate separation between the riverine and marine forms (Borobia and Sergeant, 1989) but not adequate for examining geographical variation and stock structure of the marine form within its very long coastal range.

Dusky dolphin (*Lagenorhynchus obscurus*)
This species inhabits temperate and cold-temperate waters adjacent to all the land masses and island groups in the Southern Hemisphere (Klinowska, 1991). The range is apparently discontinuous, with populations in the waters of New Zealand, South America (Chile, Peru, Argentina and Falkland Islands) and South Africa. Van Waerebeek (1992) examined 415 skulls and concluded that the

populations in Peru, southwestern Africa and New Zealand, at least, are morphologically distinct; samples from other regions (e.g. Peru versus Chile) were too small to allow firm conclusions.

Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)
The Pacific white-sided dolphin occupies temperate waters extending from Baja California in the eastern Pacific across the top of the central North Pacific below the Aleutian Islands and south to Taiwan (Leatherwood *et al.*, 1984). Separate eastern and western Pacific stocks have been proposed because of a supposed region of very low density in the upper central North Pacific (Klinowska, 1991), but more recent surveys have shown apparent continuous distribution across the North Pacific (Miyashita, 1991; Stacey and Baird, 1991). A study of geographical variation based on 243 specimens demonstrated differences between samples from Baja California and from farther north along the west coast of North America (Walker *et al.*, 1986), indicating the possible existence of separate northern temperate and southern temperate stocks in this region. In the western Pacific, specimens from the Sea of Japan are larger than those from the Pacific coast of Japan; cranial differences also exist (based on 86 specimens; Miyazaki and Shikano, 1989).

Given the results of the limited studies to date, there would seem to be a potential for the existence of additional stocks in the northwestern and north-central North Pacific, although considerations of oceanography and continuity of distribution in the region must be taken into account (see Discussion).

Miyashita (1991) noted that there was little variation in sea surface temperatures in the range of the species across the North Pacific in the driftnet fishing region. He estimated population size for the region in two segments (between 150°E and 170°W and between 170°W and 125°W). However, he stated that the division was tentative and had 'nothing to do with a possible stock boundary'. He used the same divisions to estimate abundance of the northern right whale dolphin, *Lissodelphis borealis*.

White-beaked dolphin (*Lagenorhynchus albirostris*)
This species is endemic to the North Atlantic. Based on analysis of 62 skulls, Mikkelsen (1991) concluded that separate populations exist on the western and eastern sides of the Atlantic.

Atlantic white-sided dolphin (*Lagenorhynchus acutus*)
Mikkelsen (1991) also examined skulls (123) of this species, also endemic to the North Atlantic. She found statistically significant differences between samples from the two sides of the North Atlantic, although the level of significance is lower than in the case of *L. albirostris*. She concluded that this may reflect the more pelagic habitat of *L. acutus*.

Bottlenose dolphin (*Tursiops truncatus*)
This has long been considered a coastal species, but recent studies have shown it to occur in large numbers far offshore in some regions, e.g. the eastern tropical Pacific (Scott and Chivers, 1990). It occurs in all temperate and tropical coastal waters.

The bottlenose dolphin is a highly variable species; at least 20 nominal species have been described (Mead and Potter, 1990). Typically, any particular region supports both inshore and offshore forms. This has been demonstrated for the eastern North Pacific (Walker, 1981), Peru (Van Waerebeek *et al.*, 1990), South Africa (Ross, 1984), and the US east coast (Hersh, 1990). The pattern is complicated by the apparent existence of tropical and temperate forms in the western Pacific and Indian Oceans (Zhou, 1987; Ross and Cockcroft, 1990); these may overlap in distribution, with one being more inshore than the other in the region of overlap. Animals in the Mediterranean are larger than those in the Black Sea and smaller than those in the eastern North Atlantic, suggesting separate stocks in these three areas (Perrin, 1984).

The potential for existence of additional unrecognised stock divisions for this species is high.

Atlantic spotted dolphin (*Stenella frontalis*)
This species inhabits coastal waters (usually deeper than 200m) from New England to Argentina in the western Atlantic and from Cape Verde to the Gulf of Guinea in the eastern Atlantic (Perrin *et al.*, 1987). It also occurs far offshore in the mid-tropical Atlantic and in the Gulfstream at least as far east as the Azores. It is highly variable geographically in size, colour pattern and cranial characters (Perrin *et al.*, 1987).

The available specimens are not sufficient for establishing firm stock boundaries, but samples from the US east coast, the Caribbean, Africa, the Gulfstream and the mid-tropical Atlantic are sufficiently different morphologically to suggest that animals in these five regions should be managed as separate stocks. The specimen coverage is especially poor for Central America, South America south of the Caribbean, and Africa, and the emergence of additional stock divisions should be expected as specimens and results of sighting surveys accumulate.

Pantropical spotted dolphin (*Stenella attenuata*)
The pantropical spotted dolphin occurs around the world in tropical waters (Perrin *et al.*, 1987; Perrin and Hohn, 1994). It has been studied most intensively in the eastern tropical Pacific, where large numbers are killed in the tuna purse-seine fishery; the available specimens run into the high hundreds. Three stocks are currently recognised in this region for purposes of management: a coastal form (the subspecies *S. attenuata graffmani*), that ranges from Mexico to Peru, and 'northeastern' and 'western/southern' offshore stocks (Perrin *et al.*, 1985; 1994a; Dizon *et al.*, 1992b). In addition, specimens from Hawaii differ morphologically from those from the eastern tropical Pacific.

Material from other parts of the Pacific and the Indian and Atlantic Oceans is still too limited to support more than very tentative conclusions concerning geographical variation involving these areas (e.g. that the few available specimens from the Atlantic suggest that large coastal forms may also exist in the western North Atlantic and Africa), but it is to be expected that more stock divisions will be discovered as information accumulates (Perrin *et al.*, 1987).

Spinner dolphin (*Stenella longirostris*)
This dolphin is pantropical in distribution and occurs both in coastal waters and on the high seas. It is killed in large numbers in the tuna purse seine fishery in the eastern tropical Pacific and has been intensively studied there. The available material consists of several hundred specimens. Three subspecies have been reported (Perrin, 1990): *S. l. longirostris*, *S. l. centroamericana* (a coastal form) and *S. l.*

orientalis (a more offshore form). The last two correspond to the 'Central American spinner' (formerly Costa Rican spinner) and 'eastern spinner' management units (Perrin *et al.*, 1985). Studies of DNA (Dizon *et al.*, 1992a), external shape and colouration (Perrin *et al.*, 1991) and cranial variation (Douglas *et al.*, 1992) have demonstrated that the current 'whitebelly spinner' management unit constitutes a broad zone of hybridisation or intergradation between *S. l. orientalis* and *S. l. longirostris* to the west.

The species has not been as well studied elsewhere. A dwarf form in the Gulf of Thailand may deserve subspecific designation (Perrin *et al.*, 1989). A distinctive form may also exist in the Gulf of Aden (Robineau and Rose, 1983). It is likely that eventually several more stocks will be recognised.

Striped dolphin (*Stenella coeruleoalba*)
The striped dolphin inhabits tropical and warm-temperate waters around the world (Wilson *et al.*, 1987; Perrin *et al.*, 1994b). It is found in both coastal waters and on the high seas. As for the other tropical dolphins, its known range is likely to expand greatly as knowledge accumulates about the cetacean faunas of South America, Africa and tropical Asia. There are geographical gaps in the locality records, but it is too early to know whether these represent discontinuities in the range or inadequate coverage. For example, there are very few records from the eastern North Pacific, but the range may be continuous across the temperate central North Pacific; it is known to extend from Japan east to at least 155°W (INPFC, 1992b).

Geographical variation in morphology or genetic characters has not been investigated. In the eastern tropical Pacific, two stocks were formerly designated based on a band of very low density between 10° and 15°N: the 'northern striped dolphin' and 'southern striped dolphin' (Perrin *et al.*, 1985), but recently these were pooled because of accumulation of sightings in the supposed gap (Dizon *et al.*, 1992b). Judging from the pattern of pronounced geographical variation in the other dolphins of this genus, it should be expected that numerous stock divisions will emerge as more material becomes available.

Common dolphin (*Delphinus delphis*)
This species is found worldwide in tropical and temperate waters, both along coasts and far offshore (Klinowska, 1991). There are several distinct forms which have been described variously as subspecies, species, races or geographical forms. The species needs to be thoroughly revised, but until this year the name *Delphinus delphis* has been used to include all forms (see below).

The species has been most intensively studied in the eastern Pacific, and several forms have been described there based on morphology and distribution (Perrin *et al.*, 1985). These include the Baja Neritic, Northern, Central and Southern Common Dolphin stocks and a tentative Guerrero Common Dolphin stock. The Baja Neritic and Northern forms are sympatric in Baja California and California waters, but the former occurs very close to shore and the latter more offshore. Recent studies of large series of adult specimens of the two forms have found them to be distinct in several characters (Heyning and Perrin, 1994); the 'long-beaked' is now considered a separate species, *D. capensis*. A comparison of mtDNA sequences indicates an absence of gene flow between the two forms and a closer genetic relationship between the offshore form and common dolphins in the Black Sea than between the two eastern Pacific forms (Rosel, 1992). A similar pattern is emerging on the coast of Peru (pers. comm. from J.C. Reyes, 1990). There are also indications of distinct forms in the Mediterranean, Black Sea and eastern North Atlantic (Perrin, 1984). Two forms exist in the Indian Ocean, one with a very long beak described by van Bree and Gallagher (1978) as *Delphinus tropicalis* and the other more similar to common dolphins elsewhere.

It is clear that dozens of common dolphin stocks may eventually be recognised. The affinities of common dolphins in the areas of the driftnet fisheries in the central North Pacific are unknown, but given their distance from previously studied populations, it is unlikely that they will prove to belong to a currently recognised stock.

Irrawaddy dolphin (*Orcaella brevirostris*)
In some areas this species is confined to fresh water (Marsh *et al.*, 1989). Its range extends from Australia through Southeast Asia to the east coast of India. Given the shallow estuarine and coastal habitat of the Irrawaddy dolphin, it is likely that isolated marine breeding populations exist as well. Geographical variation in morphology and genetics has not been studied.

Commerson's dolphin (*Cephalorhynchus commersonii*)
The range of this species includes the coasts of Argentina, Chilean Tierra del Fuego, the Falkland Islands, Kerguelen Islands, and South Georgia (Brown, 1988; Goodall *et al.*, 1988). The Kerguelen population is morphologically distinct and perhaps deserves subspecific designation (Robineau and De Buffrenil, 1985; Robineau, 1986).

False killer whale (*Pseudorca crassidens*)
The false killer whale inhabits oceanic tropical and warm-temperate waters worldwide. Kitchener *et al.* (1990) found substantial differences among series of skulls from Australia, South Africa and Scotland and suggested that there are a number of disjunct regional populations rather than a global panmictic population as hypothesised by Purves and Pilleri (1978).

Killer whale (*Orcinus orca*)
The killer whale is cosmopolitan, occurring from polar ice to equatorial seas. It has most often been observed in coastal waters (within 800km of land) but also ranges the high seas (Heyning and Dahlheim, 1988). Its stock structure has been investigated in some regions and is complex. Some breeding groups are migratory and others are resident. Long-term studies have shown little or no movement between groups of the two different types in the same region or between 'communities' of the resident type (Bigg *et al.*, 1990).

Two nominal species have been described from the Antarctic: a dwarf form *O. nanus* (Mikhalev *et al.*, 1981) and an ice dwelling form *O. glacialis* (Berzin and Vladimirov, 1982). However, morphological differences between these forms and other Antarctic killer whales are modal, and most workers consider them to be subspecific forms. In any case, they are likely to represent different stocks.

Heyning and Brownell (1990) found differences in total length between killer whales from the Northern and Southern Hemispheres but no differences between whales from the North Pacific and North Atlantic.

The pattern of isolated breeding stocks may be very fine-grained. In recent DNA studies, Hoelzel (1989; 1990)

compared six putative populations from the Northeast Pacific, Iceland, Denmark and Argentina and found marked genetic differences between two sympatric Puget Sound populations (resident and transient), comparable to those found between the samples from different oceans. He also concluded that the level of inbreeding suggested by the data implies that the effective population size of local populations is very low and that conservation policy in any region should take into account the possibile existence of independent sympatric stocks.

Long-finned pilot whale (*Globicephala melas*)
This species is found in cold temperate waters of the North Atlantic and the Southern Hemisphere. The populations in the two hemispheres are geographically isolated from each other; the Southern Hemisphere form has been variously known as *G. edwardii* or *G. m. edwardii* (Klinowska, 1991). The species occurred in northern Japanese waters in historical times but is now extinct there (Kasuya *et al.*, 1988). Morphological and genetic studies of geographical variation have been limited but are increasing (e.g. Amos *et al.*, 1991; Aguilar *et al.*, 1993; Andersen, 1993). As yet there is little firm evidence for the existence of multiple discrete stocks in the North Atlantic. Parasite data from Canada, the Faroe Islands and the western Mediterranean suggest that individual pilot whales do not routinely move between these regions (IWC, 1990). Bloch and Lastein (1992) compared external measurements of pilot whales from Newfoundland and the Faroes and concluded that they came from different populations. However, this conclusion must be considered tentative, because the measurements were not taken by the same investigators in the two areas and were separated by 30 years or more in time. Additional studies based on larger samples from the various regions and on monitoring of movements are needed.

Short-finned pilot whale (*Globicephala macrorhynchus*)
The short-finned pilot whale occurs pantropically and in warm temperate waters of the eastern and western North Pacific. Stock structure has been studied only in the northwestern Pacific, where the whale is taken in directed harpoon and drive fisheries. Studies of distribution, morphology and isozymes have revealed that two genetically isolated populations occur there, a northern form and a southern form (Kasuya *et al.*, 1988; Wada, 1988). There is some disagreement as to the taxonomic level that should be accorded these two forms (Kasuya and Tai, 1993; Miyazaki and Amano, 1994). They occupy waters with different oceanographic regimes, delimited by the southern front of the cold Oyashio Current and the northern front of the warm Kuroshio Current. The two forms are presently managed as separate units. Similar investigations in other regions would probably uncover additional stock divisions (Kasuya and Tai, 1993).

Baird's beaked whale (*Berardius bairdii*)
This large beaked whale is a deep-diving species limited to the North Pacific. In the western North Pacific, patterns of distribution and migration suggest that separate populations inhabit the Sea of Japan, Sea of Okhotsk and the open western Pacific (IWC, 1989). The relation of these to the whales in the eastern North Pacific is unknown. Morphological or genetic analyses have not been carried out for any regions.

DISCUSSION

In almost every case where large sample sizes have been analysed, geographical variation has been found. Based on the patterns of geographical variation in other regions and in other delphinid and phocoenid species, further stock divisions should be expected for at least some of the small cetaceans involved in the driftnet fisheries in the North Pacific.

The results of recent research (e.g. Kasuya *et al.*, 1988; Reilly, 1990; Reilly and Fiedler, 1990) have indicated that geographical populations of pelagic small cetaceans are associated with water masses and currents and that fronts of various kinds often demarcate the boundaries between them. This should be taken into account when evaluating the stock structure in the North Pacific. In the region of the high seas gillnet fisheries, oceanographic conditions are rather uniform over very great distances (Miyashita, in press); this is a countervailing factor consistent with the notion that stock divisions may not exist for some of the impacted species in the region, e.g. the Pacific white-sided and northern right whale dolphins.

The successful examinations of geographic variation in morphology have been based on large samples of specimens, usually more than 100. Where such samples exist or can be collected, they should be examined. However, newer molecular approaches to geographical genetics in cetaceans, such as those used by Hoelzel (1990), Baker *et al.* (1990), Rosel (1992) and Dizon *et al.* (1992b), may make possible adequate analyses based on smaller series of specimens and should be further explored (see IWC, 1991b).

Other promising approaches are the uses of parasite species and loads (e.g. as in Walker, 1990, for *Phocoenoides dalli*). This requires collection of large samples of parasites and life history data in the field but not osteological specimens, which are much more difficult and costly to collect, prepare and house. Consistent methods must be used in such studies if results are to be compared.

The use of contaminant profiles (as by Calambokidis and Barlow, 1991, for *Phocoena phocoena*) also has considerable promise. It cannot determine genetic differences but can provide inferences about the lifetime movements of individual animals. Here again, as for parasite studies, consistency in methodology is extremely important (Aguilar, 1987).

Finally, as stressed by several authors (e.g. Donovan, 1991), the question of 'stock' identity in a management context cannot be divorced from the overall management strategy adopted. The nature of the management procedure will determine the definition of 'stock' (biological versus management) and thus the nature of the evidence required.

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Eastern North Pacific

SC/O90/G28

A Review of Cetacean and Pinniped Mortality in Coastal Fisheries Along the West Coast of the USA and Canada and the East Coast of the Russian Federation

Jay Barlow

Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA 92038, USA

Robin W. Baird

Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6

John E. Heyning

Natural History Museum of Los Angeles County, 900 Exposition Blvd., Los Angeles, CA 90007, USA

Kate Wynne

Marine Advisory Program, University of Alaska, 900 Trident Way, Kodiak, AK 99615, USA

Albert M. Manville, II

Defenders of Wildlife, 1244 19th Street, N.W., Washington, D.C. 20036, USA

Lloyd F. Lowry

Alaska Department of Fish and Game, 1300 College Road, Fairbanks, AK 99701, USA

Doyle Hanan

California Department of Fish and Game, 8604 La Jolla Shores Drive, La Jolla, CA 92037, USA

John Sease

National Marine Fisheries Service, P.O. Box 21668, Juneau, Alaska 99802, USA

Vladimir N. Burkanov

Kamchatka Institute of Ecology and Nature Management, Russian Academy of Sciences, Prospekt Ribakov 19/A, Petropavlovsk-Kamchatsky, Russian Federation 683024

ABSTRACT

Many passive net fisheries exist along the Pacific coastlines of the USA (California, Oregon, Washington and Alaska), Canada (British Columbia) and the Russian Federation. Some incidental marine mammal mortality occurs in almost all of these fisheries. In this report, we examine 14 of the fisheries from this region that cause marine mammal mortality. The reviews include: (1) a discussion of the relevant laws pertaining to marine mammal mortality in fisheries in each of the three countries, (2) a brief synopsis of the target species and the area and method of operation for the fishery, (3) information on the economic importance of the fishery and the size of recent catches and (4) any available information on the levels of take of cetacean and pinniped species. Less complete, sometimes anecdotal information is provided for a number of other fisheries in this area. For the vast majority of all coastal fisheries along the North Pacific rim, insufficient information is available to determine whether the fisheries are having a negative impact on the species of marine mammals that live in this area. Based on our findings for this area, we make four recommendations for the gathering of additional information to evaluate the significance of fishery mortality on marine mammal populations and to help minimize its impact.

KEYWORDS: NORTH PACIFIC; INCIDENTAL CAPTURE; FISHERIES; MANAGEMENT; GRAY WHALE; COMMON DOLPHIN; MINKE WHALE; NORTHERN RIGHT WHALE DOLPHIN; SHORT-FINNED PILOT WHALE; RISSO'S DOLPHIN; BOTTLENOSE DOLPHIN; SPERM WHALE; DALL'S PORPOISE; PYGMY SPERM WHALE; PACIFIC WHITE-SIDED DOLPHIN; KILLER WHALE; HUBBS' BEAKED WHALE; CUVIER'S BEAKED WHALE; WHITE WHALE; SEALS.

INTRODUCTION

Increasing international attention is being focused on the problem of incidental mortality of marine mammals in gillnets and other fishing gear. Evaluating the significance of this problem has been hampered by a lack of information regarding (1) which marine mammals are being taking in which fisheries, (2) how many marine mammals are being taken and (3) the size of the marine mammal populations. Rarely is complete information available for all three. In this review we will attempt to provide information on the first of the above categories. We limit ourselves largely to gillnets and other passive fishing gear. We will concentrate on cetaceans caught in the coastal fisheries of the western USA, western Canada and eastern Russia, and will provide quantitative estimates of kill rates where available. Where available, we will also provide information on mortality of pinnipeds and sea otters. In very few cases has the total marine mammal mortality been estimated. In even fewer cases have

cetacean population sizes been estimated. Clearly we are a long way from being able to evaluate the significance of marine mammal mortality in fisheries.

Cetacean mortality in passive fishing gear is largely limited to gillnets. Gillnets are commonly classified as set nets (nets that are anchored to the bottom) and driftnets (nets that are free-floating). Both types of nets can be fished at the surface or in mid-water. Only set nets are commonly fished at the bottom. Within the general category of gillnets we include trammel nets, suspendered gillnets and other entangling nets. We will also consider traps and discarded fishing gear (including gillnets and trawl nets) as passive fishing gear.

For consistency and comparability, we have converted units of measure to a common system. We use metric measures of length and mass and US dollars for the value of fish catches. Some small errors may be introduced by these conversions. For consistency, information on fisheries will be presented in geographical order starting with southern California and proceeding counter-clockwise around the Pacific rim to southeastern Russia. A list of common and scientific names used in this report is given in the Appendix.

The fisheries to be considered in detail are given in Table 1 and their approximate locations are shown in Fig. 1. We specifically exclude the North Pacific high-seas driftnet fisheries for squid, tuna and salmon which are covered in separate reports (Hayase *et al.*, 1990; Nagao, 1994; Watanabe, 1994; Yatsu, 1994).

Table 1

Fisheries considered in detail in this report.

(A)	the driftnet fishery for sharks and swordfish off California
(B)	the setnet fisheries off California
(C)	the gillnet fishery for salmon in Washington state
(D)	the driftnet fishery for salmon off British Columbia
(E)	a Canadian-sponsored experimental driftnet fishery for flying squid in western Canadian waters and adjacent international waters
(F)	the salmon setnet fishery in Yakutat and driftnet fishery in southeastern Alaska
(G)	the setnet and driftnet fisheries for salmon in the Copper River Delta and Prince William Sound, Alaska
(H)	the driftnet fishery for salmon in Cook Inlet, Alaska
(I)	the setnet and driftnet fisheries for salmon off Kodiak, South Unimak, and the Alaska Peninsula
(J)	the pollock trawl fishery in the Bering Sea/Gulf of Alaska
(K)	the setnet and driftnet fishery for salmon in Bristol Bay, Alaska
(L)	the setnet fisheries in northern Alaska
(M)	the driftnet fishery for salmon off eastern Russia
(N)	the trapnet fishery for salmon off eastern Russia

LEGAL FRAMEWORK

In the USA, all marine mammals are managed under the Marine Mammal Protection Act (MMPA) of 1972 (as subsequently amended). Prior to 1988, incidental mortality in fisheries was permitted if the populations could be shown to be within a range of 'optimum sustainable population' size (OSP). OSP was interpreted to be a population size between the maximum net productivity level and the environmental carrying capacity. However, OSP has not been determined for most of the cetacean species in US coastal waters. In the 1988 amendments to the MMPA, a special exemption program eliminated the OSP requirement for a 5-year period, during which studies were to be undertaken to assess the status of marine mammal populations and the levels of incidental taking in fisheries. Any fisherman receiving a certificate of exemption was allowed to take marine mammals incidental to their fishing activities regardless of the population's OSP status (although still subject to provisions of the Endangered Species Act). The 1994 amendments to the MMPA established a protocol for setting limits on the maximum allowable takes from each marine mammal population to be in place by January 1995.

Both the 1988 and 1994 amendments provided for an observer program to monitor marine mammal mortality in those fisheries with the highest take rates. The US National Marine Fisheries Service (NMFS) has administered these observer programs, either directly or through contracts.

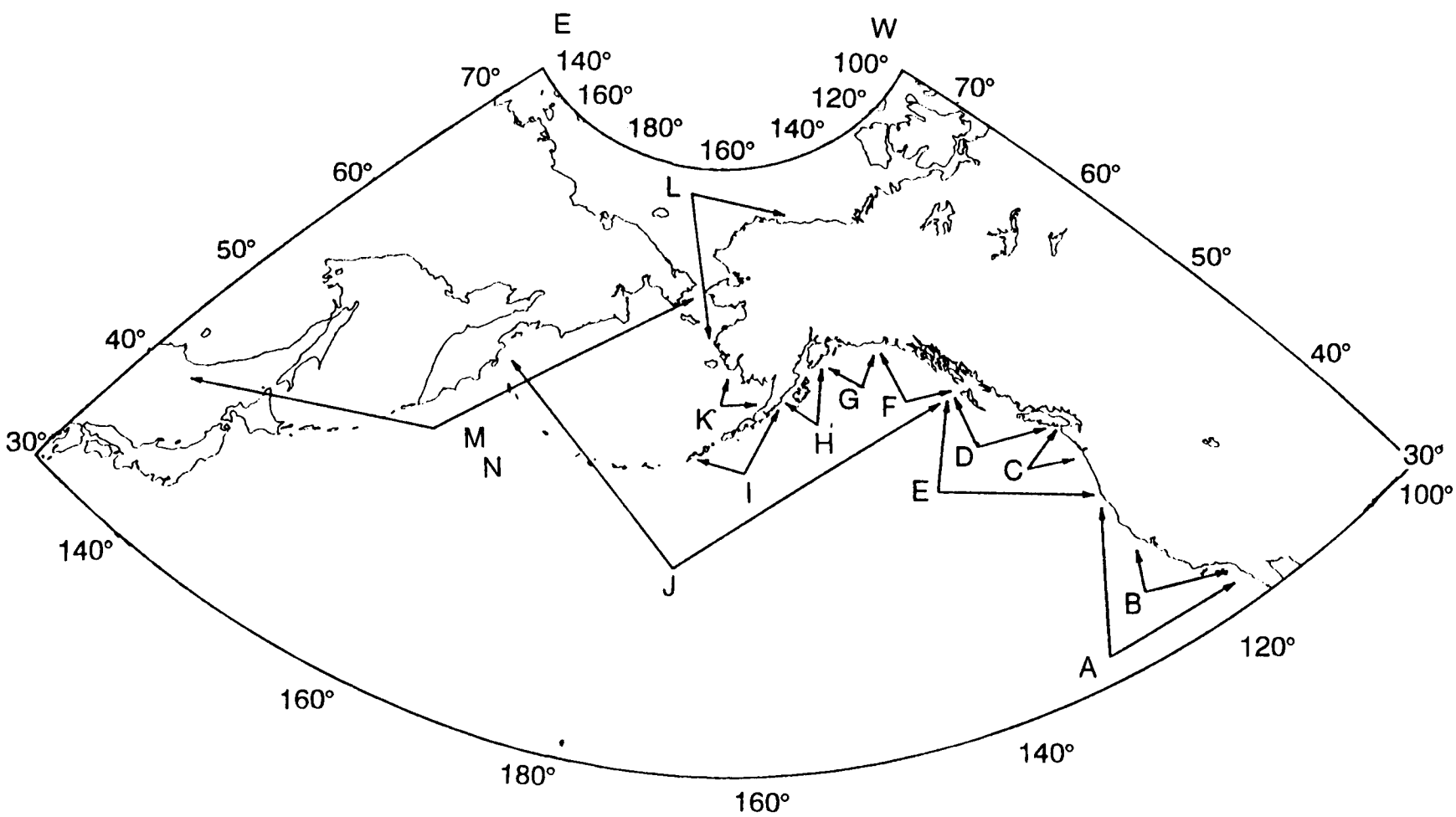

Fig. 1. Approximate location of fisheries considered in detail in this report. Letters refer to Table 1.

In addition, fishermen are required to submit 'logbook' reports detailing all takes of marine mammals in all fisheries that have greater than a 'remote' likelihood of killing marine mammals.

In Canada, marine mammals are protected from all but aboriginal hunting by the 1993 Marine Mammal Regulations of the Fisheries Act of Canada of 1867. Aboriginal hunting can be undertaken for most species without a licence, but only for food, social or ceremonial purposes. Disturbance of marine mammals under these regulations is prohibited, but no definition of 'disturbance' is given. In the case of incidental catches, fishermen are neither encouraged nor required to report catches. When catches are reported, no action is taken.

In the fisheries economic zone of the former USSR, rules stated that incidental catches (including marine mammals) were limited to a maximum of 8% of the total catch by numbers of individuals. If the combined numbers of non-target fish and marine mammals exceeded 8% of the total catch, fishermen were required to move to another area. Fishermen were not punished for incidental catches of cetaceans, but were required to document in their fishing logs the incidental catch of all marine mammal species. In fact, these data were never reported by fishermen or fisheries agencies.

SYNOPSIS OF THE FISHERIES

(A) California driftnet fishery for sharks and swordfish

The driftnet fishery for pelagic sharks began off southern California about 1977 (Hanan *et al.*, 1993). Initially, swordfish were caught incidentally and regulations limited swordfish to no more than 25% of the total catch (Miller *et al.*, 1983). This regulation was later modified and fishermen now fish for both sharks and swordfish (subject to seasonal and area closures) (Hanan *et al.*, 1993). Marine mammal mortality in California gillnets was first documented by Miller (1981). A gillnet observation program was initiated by the California Department of Fish and Game (CDFG) to evaluate the level of marine mammal bycatch in this fishery; this program was discontinued in the late 1980s. A NMFS observation program was initiated in June 1990 and continues today.

Primary ports

The primary ports are San Diego and San Pedro, CA.

Target species

The target species are swordfish, thresher shark, mako (bonito) shark and opah.

Area of operation

The area of operation comprises offshore waters from the Mexican border to Washington, within the US EEZ, principally encompassing sea mounts, escarpments and banks of the continental shelf. The fishery expanded from California to offshore Oregon and Washington, but landings were prohibited in Oregon and Washington due to high incidental catches of marine mammals.

Vessels and crew

Vessels are typically 9–23m long and are made of steel, fiberglass or wood. There are approximately 235 permitted vessels statewide. Of these, currently only about 150 permits are active. Fish are typically held on ice or in brine spray, but a few boats have refrigeration. Crews are typically 2–6 US fishermen.

Gear specifications

Monofilament and 3-strand nylon gillnets are used, with a stretched mesh size of 46–61cm (with an average of 48cm). Nets range from 915–1,830m long by 50–100 meshes deep (mean depth is 40m with a range of 27–62m). The top of the net is typically fished 5–27m below the surface. Surface floats are 30cm in diameter and are spaced 18m apart. The ends of the nets are marked with light beacons and a 25cm radar reflector. Nets are hauled with net reels.

Operations

Trips are typically 1–14 days long and may not end in the same port they begin. Vessels fish one net per night and stay attached to the net. Nets are set in water depths of 122–610m and are free to drift. Nets are set 2hrs before sunset and must be completely hauled by 2hrs after sunrise. Retrieval time is typically 2–4hrs. The fleet typically follows the highest concentrations of fish. The fishery is closed within 75 miles of the coast during the gray whale migration.

Economics and history

The ex-vessel prices range from $4–10/kg for swordfish, $2–4/kg for shark and $0.50/kg for opah. Fish are sold fresh or frozen in the domestic market. The total values of the landings were approximately $5,000,000 for swordfish and $2,000,000 for sharks circa 1990. The fishery developed in the late 1970s, peaked in the 1980s and is now declining.

Total landings

Total landings in 1990 were 680 tonnes of swordfish and 370 tonnes of shark (Hanan *et al.*, 1993).

Effort data

Effort decreased from about 10,000 net pulls per year in the mid 1980s to about 5,000 in recent years (Table 2).

Interactions with cetaceans

Marine mammal mortality was monitored in the mid-1980s by a CDFG observer program and since 1990 by a NMFS observer program. Entangled species included gray whales, short-beaked common dolphins, minke whales, northern right whale dolphins, short-finned pilot whales, Risso's dolphins, bottlenose dolphins, sperm whales, beaked whales, Dall's porpoise, pygmy sperm whales and Pacific white-sided dolphins (Table 2). Evidence of entanglement was also found on beach-cast specimens of short and long-beaked common dolphins, bottlenose dolphins, Risso's dolphins, Pacific white-sided dolphins, killer whales, a Hubbs' beaked whale and a Cuvier's beaked whale (Heyning *et al.*, 1994). Total annual mortality for cetaceans was not estimated by CDFG due to insufficient sample size, but observed mortality is summarized in Table 2. Using data from the CDFG driftnet observation program and extrapolating to the 99% of sets that were unobserved, Heyning and Lewis (1990) provided a rough estimate that 441 rorqual whales were taken in driftnets between 1980–85 with an annual take of about 73 rorquals. If animals are small, they are brought aboard, but whales are usually cut out at the water line. Entangled cetaceans are usually dead, but one minke whale and one sperm whale were released alive. Table 2 provides observed and estimated total mortality from the 1990–93 NMFS Observer Program.

Table 2

Observed and estimated fishing effort and marine mammal mortality in California's drift gillnet fishery for swordfish and sharks from the 1980 to 1986 CDFG observer program (Miller *et al.*, 1983; Diamond *et al.*, 1987; Hanan *et al.*,1988; Hanan and Diamond, 1989; Konno, in press) and the 1990 to 1993 NMFS observer program (Lennert *et al.*, 1994; Perkins *et al.*, 1992; Julian, 1993; 1994). Missing data indicate no available estimates.

	Observation period								
From	4/80	4/83	4/84	4/85	4/86	7/90	1/91	1/92	1/93
To	3/83	3/84	3/85	3/86	3/87	12/90	12/91	12/92	12/93
Effort									
Est. no. net pulls	14,140	11,000	9,700	10,000	10,330	4,078	4,752	4,504	6,599
No. observed net pulls	226	71	44	66	0	181	470	595	728
% observed net pulls	1.6%	0.6%	0.5%	0.7%	0.0%	4.4%	9.9%	13.2%	11.0%
Observed marine mammal mortality									
Unid beaked whale	0	0	0	2	-	0	0	3	0
Common dolphin	0	0	3	7	-	9	44	47	28
Minke whale	0	0	1	0[1]	-	0	0	0	0
Northern right whale dolphin	0	0	0	1	-	0	7	15	7
Short-finned pilot whale	2	0	0	0	-	1	0	1	11
Pac. white-sided dolphin	1	0	0	0	-	3	5	3	2
Dall's porpoise	0	0	0	0	-	1	2	1	9
Risso's dolphin	-	-	-	-	-	0	5	5	4
Cuvier's beaked whale	-	-	-	-	-	0	0	6	3
Mesoplodont beaked whale	-	-	-	-	-	1	0	3	0
Bottlenose dolphin	-	-	-	-	-	0	0	3	0
Sperm whale	-	-	-	-	-	0	0	3	3[3]
Pygmy sperm whale	-	-	-	-	-	0	0	0	1
California sea lion	82	6	1	1	-	4	4	9	12
Harbor seal	0	0	0	1	-	1	0	0	0
Elephant seal	0	2	0	2	-	4	13	15	14
Steller sea lion	-	-	-	-	-	0	0	1	0
Estimated marine mammal mortality									
Unid. beaked whale	-	-	-	-	-	0	0	23	0
Common dolphin	-	-	-	-	-	203	373	356	207
Minke whale	-	-	-	-	-	0	0	0	0
Northern right whale dolphin	-	-	-	-	-	0	59	15	52
Short-finned pilot whale	-	-	-	-	-	23	0	8	81
Pac. white-sided dolphin	-	-	-	-	-	68	42	23	15
Dall's porpoise	-	-	-	-	-	23	17	8	67
Risso's dolphin	-	-	-	-	-	0	42	38	30
Cuvier's beaked whale	-	-	-	-	-	0	0	45	22
Mesoplodont beaked whale	-	-	-	-	-	23	0	23	0
Bottlenose dolphin	-	-	-	-	-	0	0	23	0
Sperm whale	-	-	-	-	-	0	0	23	22
Pygmy sperm whale	-	-	-	-	-	0	0	0	7
California sea lion	5,130[2]	917	232	157	129	90	34	68	89
Harbor seal	0	0	0	158	90	23	0	0	0
Elephant seal	-	-	-	-	-	90	110	114	103
Steller sea lion	-	-	-	-	-	0	0	8	0

[1] One minke whale was caught and released alive.
[2] 1980-82 California sea lion kill was extrapolated from observed mortality and given percentage of observed sets.
[3] One sperm whale was released alive.

Pinniped bycatches and other information

Pinniped mortality information is also given in Table 2. California sea lions and elephant seals were the most common pinnipeds taken. Populations of sea lions, harbor seals and elephant seals are growing in California, despite fishery mortality.

Discussion

Reliable population estimates are now available for most of the cetacean species that are taken in this fishery (Barlow, In press). The estimated annual take rates exceed 2% of the population for several species and may not be sustainable.

(B) California set net fisheries

In California, halibut fishing with gillnets increased dramatically in the 1970s and early 1980s (Methot, 1983; Barlow, 1987). These increases were accompanied by a concurrent increase in the rate at which harbor porpoises (Szczepaniak and Webber, 1985) and seabirds (Salzman, 1989) washed ashore in the vicinity of San Francisco. Similarly, a set net fishery for angel sharks developed in southern California in the 1970s and 1980s. CDFG began observing set gillnets in central and southern California and confirmed that marine mammals were being entangled in the halibut fishery, as well as in fisheries for sharks and white seabass (Miller *et al.*, 1983). The CDFG observer program was largely discontinued in the late 1980s and was supplanted in 1990 by a mandatory NMFS observation

program in the set net fisheries for halibut and angel sharks. Set net fisheries for white seabass, yellow tail, soupfin shark, white croaker, bonito and flying fish are not observed regularly.

Primary ports
The primary ports are San Diego, Oceanside, Dana Point, San Pedro, Port Hueneme, Ventura, Santa Barbara, Port San Luis, Morro Bay, Monterey, Moss Landing, Half Moon Bay, San Francisco and Bodega Bay.

Target species
The target species are halibut, angel shark and white seabass.

Area of operation
The area of operation comprises near-shore mainland and insular areas from the Russian River to the Mexican border, typically in waters less than 55m deep.

Vessels and crew
Vessels are 4–12m in length and made from wood or fiberglass. The fleet size is limited to 200 permits, 134 of which were active in 1993. Fish are typically kept on ice and are often landed each day. Crews consist of 1–3 US fishermen.

Gear specifications
Nets are monofilament, twisted monofilament or multifilament nylon with stretched mesh sizes of 20–21cm. Panels are typically 275–366m long by 20 meshes deep. Nets are floated with either a buoyant cork line or with 5cm corks every 1 or 2m. Nets are typically marked at each end with a float or with a pole and flag. Nets are hauled by hand or with a hydraulic net reel.

Operations
Trips range from 1 day (most common along the mainland) to 1 week (most common at the Channel Islands). Fishermen often fish 3–5 separate 1-panel nets. Nets are set in waters less than 91m and usually less than 55m deep. Nets are set along the bottom and are tended in the early morning. Net retrieval takes 1–2hrs. Soak times are usually 24–48hrs. Typical catches are 3–10 halibut or 10–20 angel sharks per net.

Economics and history
Ex-vessel prices range from $5/kg for halibut to $1/kg for angel sharks. Fish is sold domestically, either fresh or frozen. The net values of the landings were $2,750,000 for halibut and $2,600 for angel shark circa 1990. The set net fishery in California developed first for white seabass. This fish stock is now severely depleted in California (Methot, 1983). Set net fishing for halibut expanded in the 1970s and was followed by development of the angel shark fishery.

Total landings
Total landings in 1989 were 545 tonnes of halibut and 1 tonne of angel shark.

Effort data
In California, the number of net sets has decreased from approximately 39,000 annually in the mid-1980s to approximately 16,000 in recent years (Table 3). Much of this reduction in effort is attributed to area closures to protect marine mammals, sea birds and sport fisheries.

Interactions with cetaceans
Harbor porpoises, gray whales, Pacific white-sided dolphins, common dolphins and possibly bottlenose dolphins have been observed entangled in set nets in California. Harbor porpoise mortality in the central California halibut fishery was estimated as approximately 200–300 per year in 1983–87 and has averaged about 40 per year since 1987 (Table 3). Accurate estimates have not been made for 1989, but the minimum mortality was 53 harbor porpoises in this fishery: 38 observed deaths plus 15 stranded animals with gillnet marks (Jefferson *et al.*, 1994). One harbor porpoise was observed caught in a white croaker gillnet out of the 200 net-pulls that were observed off central California (Hanan, unpublished data). Earlier reports also mentioned the entanglement of six harbor porpoises in white seabass gillnets near Morro Bay, California. Although white seabass is no longer common in that area (Methot, 1983), Barlow (1987) speculates that harbor porpoises in central California could have been depleted by the large-scale seabass gillnet fishery in the 1950s. Gray whale mortality has been estimated as less than 10 per year, mostly occurring in southern California (Heyning and Dahlheim, In press). Heyning and Lewis (1990) document 65 records of the entanglement of baleen whales in southern California waters during the 1980s, most of which are attributed to gray whales entangled in this set net fishery. Gray whales appear most likely to be entangled in nets that are set at headlands during their northbound migration. Dead cetaceans are either brought aboard or are cut out of the nets at the water line. Live entangled gray whales typically take the net with them. Some gray whales have been freed by the removal of netting and attached lines.

Time and area closures have reduced the total level of fishing effort in the harbor porpoise range and presumably the level of incidental take. Current legislation will close waters inshore of 55m throughout the sea otter range, approximately from Waddell Creek to Point Sal. In California, a gillnet ballot initiative passed in November 1990 will result in a buy-out of set nets and the elimination of gillnet fishing within 3 n.miles of the mainland and 1 n.mile of any island in southern California by 1994. Preliminary data indicate that some fishing continues in deeper waters. Efforts have been made to reduce whale mortality by use of break-away panels, increased bridle strength and anchor weight, and decreased cork-line strength.

Local populations of harbor porpoises may have been reduced to less than 50% of their pre-fishery abundance in central California (Barlow, 1987; Barlow and Hanan, 1994). The gray whale population is continuing to increase (IWC, 1993; Buckland and Breiwick, In press).

Pinniped bycatches and other information
California sea lion mortality in this fishery has been approximately 2,000–4,000 per year and the harbor seal mortality has been 500–2,000 per year (Table 3). Populations of both species (and elephant seals) are growing in California despite this fishery mortality.

Discussion
Good information is available on the abundance and status of all species of cetaceans and pinnipeds in California waters. In fact, information on the impact of fishing mortality on marine mammal populations may be better for this fishery than for any other gillnet fishery.

Table 3

Observed and estimated fishing effort and marine mammal mortality in California's set gillnet fisheries for halibut and angel sharks from the 1983 to 1988 CDFG observer program (Diamond and Hanan, 1986; Hanan *et al.*, 1986; Hanan *et al.*, 1987; Hanan *et al.*, 1988; Hanan and Diamond, 1989; Konno, in press) and the 1990 to 1993 NMFS observer program (Lennert *et al.*, 1994; Perkins *et al.*, 1992; Julian, 1993; 1994). Missing data indicate no available estimates.

	Observation period								
From	4/83	4/84	4/85	4/86	4/87	7/90	1/91	1/92	1/93
To	3/84	3/85	3/86	3/87	3/88	12/90	12/91	12/92	12/93
Effort									
Est. no. net pulls	26,210	37,155	39,104	39,497	29,623	8,070	22,300	16,900	16,300
Effort in days	-	-	-	-	-	3,041	7,089	5,468	5,380
No. observed net pulls	962	1,723	1,499	2,107	978	406	2,231	2,155	2,641
% observed net pulls	3.7%	4.6%	3.8%	5.3%	3.3%	5.0%	10.0%	12.8%	16.2%
Observed marine mammal mortality									
Harbor porpoise	14	19	33	16	13	4	5	6	2
Common dolphin	-	-	-	-	-	0	0	2	0
California sea lion	76	69	84	90	174	67	149	340	239
Harbor seal	31	66	148	103	156	30	43	93	71
Northern elephant seal	-	-	-	-	-	13	3	7	11
Southern sea otters	-	-	-	-	-	3	0	0	0
Estimated marine mammal mortality									
Harbor porpoise	303	226	227	197	34	44	38	44	12
Common dolphin	-	-	-	-	-	0	0	17	0
California sea lion	3,427	2,244	2,207	4,288	2,722	847	1,858	3,255	1,984
Harbor seal	834	1,138	1,886	2,028	903	392	559	1,136	480
Northern elephant seal	-	-	-	-	-	144	26	51	71
Southern sea otters	-	-	-	-	-	33	0	0	0

(C) Washington gillnet fisheries for salmon

Gillnets are used to catch salmon in Washington state by both Native Americans and non-native commercial fishermen. By treaty, half the surplus salmon production is allocated to Native Americans. Set nets are used by the Makah tribe in western Washington (Gearin *et al.*, 1990; 1994). The incidental take of harbor porpoises in this fishery was recognized after unusually large numbers of porpoise were found dead on beaches of the Olympic National Park (Kajimura, 1990). In 1988–89, a cooperative study was initiated between NMFS and the Makah Tribal Fisheries Management Division to study the magnitude of harbor porpoise mortality in this fishery and the size of the affected populations (Kajimura, 1990; Gearin *et al.*, 1990; 1994). Another gillnet fishery for salmon by Native Americans takes place from Semiahmoo Bay, Washington. Incidental mortality of cetaceans has been recorded in this fishery (Baird and Guenther, 1994), but little information is available.

The non-native salmon allocation is divided among sport fishing and commercial fishing. The latter includes trolling, purse seining and gillnetting which have not been covered by observer programs.

Primary ports

The primary ports are Neah Bay, Sekiu and Semiahmoo Bay (Native Americans) and Seattle, Grays Harbor, and Willapa Bay (commercial).

Target species

The target species are chinook salmon (Makah tribe) and all salmon species (non-native commercial).

Area of operation

The area of the Makah fishery is along the northwest coast of Washington state in the Pacific Ocean and in the Strait of Juan de Fuca east to the Sekiu River and including Neah Bay. The non-native commercial fishery is in the Strait of Juan de Fuca and Puget Sound, Columbia River, Grays Harbor and Willapa Bay.

Vessels and crew

The Makah fishing vessels are small, 5–7m skiffs crewed by 1–3 US fishermen (Native Americans only). The current fleet size is 6–10 boats. In the non-native commercial fishery, approximately 600 vessels fish in the Columbia River, Grays Harbor and Willapa Bay, and, although 1,146 vessels were issued gillnet permits to fish in Puget Sound in 1990, the actual number fishing is somewhat less than this. The size of commercial vessels is probably similar to those in Prince Williams Sound, Alaska (see G below) given that many vessels there also fish in Puget Sound (Wynne, unpublished data).

Gear specifications

In the Makah fishery, monofilament and multifilament nylon nets are used with a stretch mesh size of 19–22cm and a maximum length of 183m. Nets are up to 100 meshes deep. In the non-native commercial fishery, nets are 230–550m long (typically 550m), 30–180 meshes deep and have mesh sizes of 13–22cm (net configurations vary with species and area).

Operations

In the Makah fishery, nets are set along the bottom in water depths of 11–18m and are anchored at both ends. Fishermen can fish a maximum of three 183m nets. The fishing season is from 1 May to 15 September with maximum effort in July and August. Nets are usually tended each day, but are typically not picked up or moved. Soak times can exceed 48hrs due to adverse weather. In the non-native fishery, driftnets are used.

Economics and history
In the 1950s, the Makah fishery was conducted primarily in Mukkaw Bay. The effort at that time was about 10 boats with as many as 6 nets per boat and catch rates were up to 75–100 fish per night. The fishery expanded in area in the 1970s.

The non-native fishery has declined consistently since 1974, when the number of gillnet licenses in Puget Sound peaked at approximately 2,000.

Total landings
In the Makah fishery, total landings were 6,404 and 1,690 chinook salmon, respectively for 1988 and 1989. For the non-native fishery in 1991, total landings from Puget Sound were 182,040 chum, 68,702 coho, 15,771 chinook, 174,147 pink and 417,526 sockeye salmon.

Effort data
The estimated effort in the Makah fishery was 2,600 net-days in 1988 and 1,342 net-days in 1989. There are no data for the non-native fishery.

Interactions with cetaceans
The most common cetacean/fishery interaction is with harbor porpoises. Gaskin (1984) reported that in 1972, Ken Balcomb found carcasses of 19 harbor porpoises (many with net marks) on the coast of Washington, possibly killed in a salmon gillnet fishery. An observer program was begun in 1988 to monitor marine mammal bycatch in the Makah fishery. Incidental take included at least 102 harbor porpoises in 1988, 23 in 1989 and 13 in 1990 (Gearin *et al.*, 1994). The take in 1988 was thought to be abnormally high. Studies of body temperature revealed that at least some harbor porpoises entangled during daylight hours. One minke whale was also taken in 1988. Harbor porpoises were used by Native Americans for subsistence purposes. A mandatory observer program is currently monitoring marine mammal mortality in the Makah fishery, but not in the non-native commercial fishery.

Less is known about cetacean mortality in the non-native gillnet fishery. Everitt *et al.* (1979) note Dall's porpoise captures in both salmon gillnets and seines in the San Juan Islands. Flaherty and Stark (1982) note one incident of harbor porpoise mortality in a gillnet in southern Puget Sound. Osborne *et al.* (1988) also note that both harbor and Dall's porpoises are killed in salmon gillnets in Puget Sound and the San Juan Islands. Ken Balcomb (pers. comm.) has noted an increase in harbor porpoise strandings coincident with the occurrence of salmon gillnet vessels in the San Juan Islands.

The population of harbor porpoises in Washington was estimated as 9,800 (SE 4,300) in 1984 (Barlow, 1988). Subsequent surveys of northern Washington (in the immediate area of the fishery) indicated a local abundance of only 634 harbor porpoises (Calambokidis *et al.*, 1993). Harbor porpoise stock structure in this area is not well understood.

Pinniped bycatches and other information
Fishermen reported that 24 harbor seals and 1 sea otter were also taken in 1989.

Discussion
The impact of fishery mortality on harbor porpoises in this area is likely to depend strongly on porpoise stock structure. If porpoise movement between the fishing areas and the southwestern coast of Washington is limited, incidental fishing mortality could severely deplete local harbor porpoise populations. There is a need for more information on porpoise stock structure and movement patterns and for updated estimates of porpoise abundance in surrounding areas.

(D) British Columbia driftnet fishery for salmon
The salmon driftnet fishery in British Columbia has been in operation for most of the century. Fishing occurs primarily in inshore waters. Levels of take of small cetaceans and one species of large whale have been estimated for this fishery by Stacey *et al.* (1990) and Baird *et al.* (In press), respectively. Prior to these recent estimates, evidence of marine mammal bycatch came from opportunistic observations or reports by fisheries officers or fishermen. No formal observation program has been undertaken.

Primary ports
The primary ports are Vancouver and Prince Rupert.

Target species
The primary target species are sockeye, chum, pink, coho and chinook salmon.

Area of operation
Gillnet fishing is permitted in inshore waters of British Columbia, in statistical reporting areas 1–29, which are shoreward of a so called 'surfline'. Regulations may vary between statistical areas.

Vessels and crew
Vessels range from 6–21m in length, with an average of 10.2m for gillnet vessels and 11.6m for gillnet/troll combination vessels. Both bowpicker and sternpicker designs are used. Fishing is controlled by a limited entry system. In 1989 there were 3,230 license holders for gillnet fishing, of which 2,540 held combination gillnet/troll licenses. Most license holders fish every season. Fish are kept in refrigerated seawater or on ice. The crew of 1–5 are Canadian.

Gear specifications
A multifilament nylon net is used with stretched mesh sizes of 10–22cm, with an average mesh of 13cm. Mesh size varies depending on the fish species and local regulations. Except for Area 20, regulations allow panel lengths between 135–375m and net depths of 60 meshes. In Area 20, the maximum size is 550m length and 90 meshes depth. Each vessel fishes only one panel. Floats are approximately 9 x 14cm and are tied to a mixed nylon and polypropylene cork line. Typically the cork line is tied every 1.2m to a 'weed' line, from which the net is hung. The weed line is 6mm polypropylene. The net is tied approximately every 20cm to the weed line. A lead line attached to the bottom of the net is usually about 55m longer than the net and consists of a lead core with a nylon cover, weighing approximately 1 pound per fathom (about 0.25kg per metre). During daylight all nets must be marked at both ends with a plain orange or colored iridescent buoy not less than 125cm in circumference. From one hour after sunset to one hour before sunrise, net ends must be marked with a lantern giving a steady white light. No flashing lights may be used.

Operations
Fishermen remain in attendance of their nets at all times. Fishing occurs from early June to mid September and from early October to the end of November. During this time, only a limited number of fishing openings will take place. Each opening is typically for a specific run of a specific species of salmon, and the length of an opening depends on the catch of that species and on the incidental catch of species which require protection, such as chinook salmon. Openings range from 12hrs to 4 days in length. Nets are typically set in waters less than 183m in depth and are suspended from the surface. Nets are not anchored; set nets are prohibited by regulations. Gillnets cannot be used to enclose an area. Fishing usually occurs from dusk to dawn and soak times vary between 1.5–5.0hrs. Fishing times depend on the length of the opening, the time of day that the opening begins and tidal conditions.

Economics and history
Salmon is used for both domestic consumption and export. Most of the catch is canned. Pearse (1982) reviews the history and management of fisheries on the BC coast. The fishery is presently a limited-entry fishery with a relatively constant number of permits. Between 1979–1988, gillnet catches of salmon have fluctuated between 21,100 and 26,130 tonnes. Total payments to fishermen have also fluctuated but have generally increased. Between 1951 and 1988, the percentage of the total salmon catch taken by gillnets has decreased relative to other gear types, from about 40% in the 1950s to about 25% in the 1980s. Over the same time, total salmon landings have remained relatively constant. It is not known if total gillnet effort has also decreased.

Total landings
In 1988, 19,204 tonnes of salmon were taken by gillnets, including 8,966 tonnes of chum and 7,591 tonnes of sockeye salmon. The salmon fishery (including all gear types) is Canada's most valuable fishery, with an annual landed catch value in excess of $275 million in recent years.

Effort data
In 1988, the fishing effort totalled 54,770 net-days. This effort was concentrated in the periods 26 June to 30 July (25,035 days fished), 31 July to 27 August (14,028 days fished) and 25 September to 29 October (10,738 days fished).

Interactions with cetaceans
Species known to have been caught in or involved in collisions with salmon gillnet gear include harbor porpoises, Dall's porpoises, Pacific white-sided dolphins, killer whales, gray whales and humpback whales (Pike and MacAskie, 1969; Goodman, 1984; Jefferson, 1987; Langelier *et al.*, 1990; M. Bigg, unpublished data; R. Baird, unpublished data). Stacey *et al.* (1990) estimated that at least 55 harbor porpoises, Dall's porpoises and Pacific white-sided dolphins collide with gillnets each year and that between 53–62% die as a result. However, numerous biases in the methods used to derive these estimates suggest that these estimates under-represent actual numbers of gear collisions and thus total mortality. Baird *et al.* (In press) estimate that 11 gray whales collide with gillnet gear each year and that 6.3% are killed. There are only two records of humpback whale entanglement in gillnets and the fate of those animals is not known. Cetaceans are generally discarded, but in responding to a questionnaire survey (Stacey *et al.*, 1990), one fisherman reported consuming caught porpoises.

Virtually nothing is known about the local populations of the two species which appear to be most frequently taken (harbor and Dall's porpoise) and thus evaluating fishery impacts is impossible. Cowan (1988) noted that harbor porpoise populations in British Columbia could be decreasing due to mortality in gillnet fisheries. Gaskin (1992) recommended to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) that the British Columbia population of harbor porpoises be listed as 'threatened', but the Committee did not so designate the population due to insufficient information. Populations are increasing for gray whales (Buckland and Breiwick, In press) and killer whales (Olesiuk *et al.*, 1990), so takes presumably are having a small impact.

Discussion
Research into bycatches in British Columbia has been limited but has shown the presence of some levels of incidental mortality. More research is needed to determine species taken, mortality level, areas of high catches and other details.

The salmon fishery is regulated by statistical area (and sub-areas), and the length and time of openings are also regulated. Since the abundance or density of small cetaceans probably varies along the coast, it may be possible to reduce bycatches in specific areas by closures or restriction of specific localized salmon fisheries. However, for such regulations to be feasible, additional detailed information on population size and movements is necessary.

(E) Western Canadian driftnet fishery for neon flying squid
This experimental fishery (now discontinued) was undertaken to evaluate the economic viability of using large-scale drift gillnets to catch flying squid off British Columbia (BC) and in adjacent international waters. Although an early report did not refer to marine mammal mortality (Bernard, 1981), later reports confirmed that marine mammals were caught each year (Jamieson and Heritage, 1987). The study concluded that commercially exploitable densities of flying squid did exist off BC, but that bycatch problems would probably have to be resolved before a commercial fishery could begin (Jamieson and Heritage, 1988).

Target species
The experimental fishery only targeted neon flying squid.

Area of operation
Fishing generally took place in Canadian and international waters from northern BC (approximately 54°N) to southern Oregon (approximately 42°N), between 50–300 miles off the BC coast and 200–300 miles off the US coast.

Vessels and crew
Five vessels were used, ranging from 22–55m: one Canadian tuna vessel, two Japanese squid vessels and two Canadian freezer blackcod trap vessels. Two vessels fished in 1980 and 1983, one in 1985, three in 1986, and two in 1987. Crews ranged from 7–27 and were Canadian and Japanese.

Gear specifications
Eight-gauge nylon monofilament nets were used with stretched mesh sizes of 11–12cm. On the Japanese vessels, panels were 48–50m long and 8.5m deep. On one of the

Canadian vessels, two panel lengths were used: 100 and 200m, both being 7.2m deep. The average net length fished by the Japanese vessels was about 45km and net lengths for the three Canadian vessels were about 19, 12 and 4km. Float information is only available for one of the Japanese vessels. It used 220g floats at approximately 1m intervals along a 5mm polypropylene float line. Radio buoys were set at the ends of each group of panels.

Operations
Fishing occurred from mid June through early September. The Japanese vessels remained in the fishing area the entire period, whereas the Canadian vessels left periodically to unload catches. Fishing occurred outside the 1,830m depth contour to minimize bycatch of salmon. On the Japanese vessels, 220–250 panels were set in calm weather and 110–125 panels in rough weather. Nets were suspended from the surface and were free to drift. Nets were pulled at first light after soak times of approximately 12hrs. The Japanese vessels could retrieve an average of 3.8km of net per hour. The Japanese vessels averaged 232kg of squid per km of net per night.

Economics and history
The fishery was concluded to be economically feasible but was discontinued largely due to the high levels of marine mammal bycatch found in the small experimental fishery.

Total landings
Squid landings in 1987 were greater than 1,500 tonnes (Jamieson and Heritage, 1988).

Effort data
Effort was reported as 1,474, 2,475, 4,307 and 4,417km net-nights in 1983, 1985, 1986 and 1987, respectively (Jamieson and Heritage, 1988).

Interactions with cetaceans
Species taken included Dall's porpoise, northern right-whale dolphin, Pacific white-sided dolphin, killer whale, short-finned pilot whale, an unidentified *Stenella* sp., and Cuvier's beaked whale. [Although Jamieson and Heritage (1988) note a single harbor porpoise taken, the great depth at which this would have occurred and the tentative nature of the identification given by the original observer (field notes provided by G.D. Heritage) lead us to conclude that it was not a harbor porpoise.] Cetaceans were not feeding on fish or squid in the net, but rather appeared to blunder into the net without detecting its presence (Jamieson and Heritage, 1988). From observer field notes provided by D. Heritage (Department of Fisheries and Oceans, Nanaimo, BC), animals were caught in all areas of the net. Those close to the cork line were occasionally alive and were released. Twenty individuals were released alive; 145 were caught and killed (Table 4). The mortality rate varied greatly with year and vessel, with a range of 0.03 to 0.001 cetaceans per km net-night and with a mean of 0.012 per km net-night. Typically, dead cetaceans would tear the net and fall out during net retrieval. Dead cetaceans were not utilized. Details on animals caught and released alive are presented by Baird and Stacey (1991; 1993) and Stacey and Baird (1991).

Jamieson and Heritage (1988) noted that one of the eight net groups operated by one of the Japanese vessels during 1987 had 20 consecutive tans (1km of net) with 2 meshes of hollow-core 3-thread filament woven into the 80-mesh deep net at meshes 39 and 40. The rationale was that air trapped inside the thread might improve detection of the net by marine mammals by presenting a stronger acoustic target. This net group was fished on 17 nights, but no information was presented on catches in that section of the net.

Table 4

Cetacean mortality in the British Columbia experimental squid fishery (from Jamieson and Heritage, 1988). Animals caught and released are not included.

Species	1983	1985	1986	1987
Dall's porpoise	3	1	33	58
Short-finned pilot whale	1	-	5	3
Pacific white-sided dolphin	-	1	3	16
Harbor porpoise	2	-	-	1
Northern right-whale dolphin	-	-	4	9
Killer whale	-	-	2	-
Cuvier's beaked whale	-	-	1	-
Stenella sp.	-	-	-	1
Unidentified	-	-	2	-
Total	6	2	50	87

Pinniped bycatches and other information
Two northern fur seals and one Steller sea lion were recorded killed in this fishery.

Discussion
If this fishery is ever started again, it is clear that the potential is great for significant impact on marine mammal populations. Any additional fishing of this type should be carefully monitored. Before this should be allowed, more information is needed on the size and status of the affected populations.

(F) Yakutat and southeastern Alaska gillnet fisheries for salmon
Gillnet fishing for salmon is allowed only with set nets in the Yakutat district and only with driftnets in the southeastern Alaska district.

Primary ports
The primary ports are Sitka, Ketchikan, Petersburg, Haines, Juneau and Yakutat.

Target species
All five species of Pacific salmon are targetted, with primarily sockeye and chum in southeastern Alaska and sockeye and coho in Yakutat.

Area of operation
Operations are carried out in inshore waters of southeastern Alaska and between Cape Yakataga and Cape Fairweather.

Vessels and crew
In southeastern Alaska, vessels are typically 7–11m with a crew of 1–3 US fishermen. In Yakutat, small skiffs are run by 1–2 US fishermen, but some nets are also operated from shore without use of boats.

Gear specifications
For southeastern Alaska driftnets, the maximum net length varies from district to district, but is between 388 to 550m. Maximum depth is 60 meshes for nets with less than 20cm mesh and 40 meshes for nets with 20cm or larger mesh. For Yakutat set nets, the maximum length varies

from 27m per net to 137m in aggregate for three nets. Maximum net depth is 45 meshes for nets with mesh size <20cm and 35 meshes for sizes >20cm.

Operations
Only driftnets are allowed in southeastern Alaska and only set nets are allowed in the Yakutat district. One net is fished by each vessel and the vessel must remain in attendance of the net. The drift gillnet season typically starts on the third Sunday in June and closes in late September or early October. Weekly fishing hours are set by emergency order, but typically last from Sunday through Wednesday and Sunday through Tuesday in northern and southern areas, respectively. Native Americans manage their own fisheries within 92 miles of the Annette Island Indian Reservation, where they use gillnets and purse seines. In the Yakutat area, seasons vary by district, but typically run in June through September, subject to emergency closures.

Economics and history
The value of landings varies annually and by species. Total earnings, in thousands of dollars, in 1987 and 1988 are given in Table 5.

Table 5

Total earnings ('000s$) in the Yakutat and southeastern Alaska fisheries for salmon, 1987 and 1988.

	Southeastern Alaska		Yakutat	
Species	1987	1988	1987	1988
Chinook	144	259	54	35
Sockeye	9,718	13,440	3,079	3,158
Coho	2,168	3,895	1,378	4,916
Pink	3,013	3,527	15	274
Chum	6,072	14,269	61	317
Total	$21,115	$35,390	$4,586	$8,701

Total landings
Yakutat landings were approximately 254,000 sockeye, 122,000 coho, 14,000 chum, 13,000 pink, and 1,750 chinook salmon for 1987 and 158,000 sockeye, 188,000 coho, 27,000 chum, 109,000 pink, and 870 chinook salmon for 1988.

Effort data
As in other Alaska salmon fisheries, effort is controlled by limited entry and by monitoring salmon escapement. There are 164 permanent permits in the Yakutat set net fishery and 468 permanent permits in the southeastern Alaska driftnet fishery. In Yakutat, the total number of permits fished in 1987 and 1988 were 154 and 159, respectively. For southeastern Alaska, the totals were 466 and 471, respectively.

Interactions with cetaceans
There have been no observer programs or other directed studies of marine mammal entanglement in gillnet fisheries in this part of Alaska. The NMFS Alaska Regional office in Juneau collects reports regarding marine mammal entanglement in gillnets and other fishing gear (NMFS, Alaska Region and Northwest Region, unpublished data). Since 1984, there have been 19 reports of humpback whale entanglement, of which 17 were in fishing gear (8 in gillnets, 4 in longlines or buoy lines, and 5 in unidentified gear). Eleven of these whales were freed by fishermen or volunteers, 1 freed itself, 1 died in a gillnet and 4 reports were unconfirmed with unknown outcome. The other two non-fishing entanglements were with abandoned logging gear and a boat anchor line. Six of the entanglements (including one death) occurred between 22 June and 22 July, 1987 in Upper Lynn Canal, south of Haines, Alaska. This anomalous situation probably resulted from an exceptionally dense aggregation of whale forage, probably sandlance, in an area of high gillnet effort. There were no reports of whale entanglement in Upper Lynn Canal in other years. In addition to humpback whales, one gray whale died in a stranding or entanglement incident at the mouth of the East Alsek River. The whale apparently followed schools of capelin over a sand bar at an extreme high tide and became entangled in set gillnets inside the sandbar. It was not clear whether the whale could have avoided stranding if it had not become entangled. There are anecdotal reports from individual fishermen of porpoise entanglements, probably both harbor and Dall's porpoises. Most may be released with little or no harm, but some may be killed. The opportunistic reports probably underestimate the total level of marine mammal entanglement.

In logbook reports submitted to NMFS for 1990 through 1992, fishermen reported 13 Dall's porpoise, 8 harbor porpoise, 1 Pacific white-sided dolphin and 8 unidentified cetaceans killed in the southeast Alaska driftnet fishery and no cetaceans in the Yakutat set net fishery (NMFS, unpublished data).

Pinniped bycatches and other information
Fishermen have reported one harbor seal, one sea otter and one northern elephant seal as being taken in gillnet fisheries in southeastern Alaska (NMFS, Alaska Region and Northwest Region, unpublished data). Previously, in response to harbor seal depredation of the salmon gillnet catch near the Stikine and Taku Rivers in southeastern Alaska during the 1940s and 1950s, resource managers hired seal hunters and levied bounties on seals (Imler and Sarber, 1947).

In 1990–92 NMFS logbooks, fishermen in southeastern Alaska reported 2 northern sea lions, 1 unidentified sea lion and 6 harbor seals killed in drift gillnets, and Yakutat fishermen reported, 12 harbor seals and 18 spotted seals killed in set gillnets (NMFS, unpublished data).

Discussion
There is a need for more information on cetacean entanglement in this fishery. There is no plan for an observer program to monitor marine mammal interactions in this fishery.

(G) Prince William Sound driftnet and setnet fisheries for salmon
The driftnet fishery includes areas from Prince William Sound to the Copper River Delta, Alaska. Marine mammal interactions with salmon driftnet fishermen on the Copper River Delta have existed for decades and have been relatively well documented. The setnet fishery occurs in western Prince William Sound.

Primary ports
The primary ports are Cordova, Whittier and Valdez, AK.

Target species
The target species are sockeye, chinook, chum, pink and coho salmon.

Area of operation
Operations take place in northwest Prince William Sound and the Copper/Bering River Delta.

Vessels and crew
Driftnet vessels are usually 7–11m long and made of fiberglass or aluminum. Both bowpicker and sternpicker designs are used. The crew is usually 1–2 US fishermen. Set nets are typically tended by small, open skiffs.

Gear specifications
In the driftnet fishery, multifilament nylon nets are used with stretched mesh sizes of 12–18cm. Vessels fish only one net panel which is a maximum of 275m long and is typically 90–240 meshes deep (8–27m). Late in the season when the sun is lower, beacons are required to mark the ends of the net during night sets. Driftnets are hauled with a net reel. Set nets are typically hauled and tended by hand.

Operations
Durations of fishing trips are dependent on Alaska Department of Fish and Game (ADF&G) openings (allowable fishing periods); openings are variable depending on the time of year and run strength, but may generally be from 12hrs to 7 days long. Typically there are less than 30 openings per season. Driftnets are fished at the surface in waters less than 366m (Prince William Sound) or less than 128m (Copper River Delta). Vessels are not allowed to anchor and must remain in attendance of their net. Nets may be set throughout the day, but fishing may be limited by tides in some areas. Soak times are typically 15 minutes to 5hrs. It may take 15–90 minutes to haul the net, depending on the catch. The catch is typically 0–1,000 fish per set. Set nets are hung from the surface, anchored at one end and set roughly perpendicular to shore.

Economics and history
Prices for landings vary annually and by species. In 1990, the average prices were $5.28/kg for sockeye salmon, $0.66/kg for pink salmon and 2.20/kg for coho salmon. The total ex-vessel value for the driftnet catch was $35.5 million in 1988. Fish are processed locally as fresh, frozen and canned salmon (and roe) and are shipped to domestic and foreign markets. Salmon originally released from hatcheries constitute 50–70% of the fish harvested in recent years.

Total landings
Combined landings for Prince William Sound and the Copper River Delta are given in Table 6.

Table 6

Combined landings (number of fish caught) for Prince William Sound and the Copper River Delta, 1988 and 1989.

Species	1988	1989
Chinook salmon	31,366	31,336
Sockeye salmon	724,619	1,171,335
Coho salmon	421,203	276,456
Pink salmon	1,562,221	705,431
Chum salmon	562,200	199,754
Total	3,304,609	2,384,312

Effort data
Effort in Alaskan commercial salmon fisheries is controlled by 'limited entry'. There are 550 permit holders for the Prince William Sound/Copper River driftnet fishery and 30 permit holders for the set net fishery. Of the driftnet permit holders, 519 reported landings in 1987 and 525 reported landings in 1988.

Interactions with cetaceans
Cetacean interactions in this fishery involve harbor porpoises, Dall's porpoises, killer whales and humpback whales. The larger cetaceans reportedly swim through the nets. There have been no documented deaths of large cetaceans. Porpoises get entangled in the net, but some 50% of harbor porpoises and 33% of Dall's porpoises are reportedly released alive (Matkin and Fay, 1980; Wynne, 1990; Wynne *et al.*, 1991; 1992). Harbor porpoises are generally not badly entangled and are easily rolled out of the net. Dall's porpoises are more severely entangled and often have to be cut from the gear. Porpoises are generally not brought aboard due to the limited size of the vessels. One entangled humpback whale calf was released when two vessels applied tension at each end of the net.

Twelve of 31 harbor porpoise carcasses examined from the Copper River Delta between 1988 and 1993 bore net marks indicating that they had been entangled (Wynne, 1990; Wynne *et al.*, 1991; 1992). The cause of death for the remaining specimens could not be determined. Matkin and Fay (1980) estimated that 58 harbor porpoises and 31 Dall's porpoises were killed in the salmon driftnet fishery in 1978. Based on dockside interviews in 1988, Wynne found no harbor porpoises taken in 67 trips, a rate that is not significantly different from that obtained by Matkin and Fay in 1978 (4 taken in 179 trips) ($p > 0.1$). Total marine mammal mortality was not estimated in the 1988 study due to clumped distributions and small sample sizes. A manditory observer program monitored marine mammal mortality in the Prince William Sound fisheries in 1990 (setnet and driftnet) and in 1991 (driftnet only). No marine mammal entanglements were observed during more than 300 hours of setnet monitoring. In 1990, 2 harbor porpoise entanglements (one dead, one released alive) were documented in 3,166 observed driftnet sets. The extrapolated mortality estimate was 8 harbor porpoise for the observed portion of the 1990 season (Wynne *et al.*, 1991). In 1991, 7 porpoise entanglements (4 dead, 3 released alive) were documented in 5,875 observed sets. Extrapolated across the driftnet fishery, an estimated 43 harbor porpoise died incidentally in this fishery in 1991 (Wynne *et al.*, 1992). In 1990–92 logbooks, fishermen also reported the catch of Dall's porpoise, white-sided dolphin and common dolphin in this fishery (NMFS, unpublished data).

Both harbor and Dall's porpoise are common in this area, but the impact of fishery interactions on their populations is unknown. In 1993, NMFS conducted aerial surveys to determine their abundance in this area, but estimates are not yet available.

Pinniped bycatches and other information
Matkin and Fay (1980) estimated total pinniped mortality as 516 harbor seals and 333 Steller sea lions (including both incidental and intentional take). Ten years later, Wynne (1990) found that the rate of intentional pinniped take was much reduced. Data from 1990 and 1991 observer programs indicate that pinniped interactions are frequent with driftnets on the Copper River Delta but are rarely

lethal. Lethal entanglements of 3 harbor seals and 1 Steller sea lion were recorded during 3,166 sets observed in 1991 for the Prince William Sound/Copper River Delta areas. Mean estimates of total pinniped mortality were 36 in 1990 and 27 in 1991 (Wynne *et al.*, 1991; 1992). In 1990–92 logbooks, fishermen also reported lethal entanglements of northern fur seals (2) and a sea otter.

Discussion
Entanglement and driftnet related cetacean mortality in this fishery appears limited to smaller species, primarily harbor porpoises. Although entanglement appears to be infrequent and is not necessarily fatal, assessment of its impact requires a better understanding of the populations' abundance, status and trends.

(H) Cook Inlet driftnet and set net fishery for salmon
Cook Inlet supports a large driftnet fishery and a set net fishery, both for salmon. Little is known about marine mammal entanglement in these fisheries.

Primary ports
The primary ports are Kenai, Kasilof, Homer and Ninilchik, Alaska.

Target species
The main target species is sockeye salmon (and to a lesser degree the other four species of Pacific salmon).

Area of operation
Driftnets are used in the central district of upper Cook Inlet, from the latitude of Anchor Point northward to the latitude of Boulder Point. Set nets are used along most of the shoreline of Cook Inlet.

Vessels and crew
Driftnet vessels range in length from 7–22m. Smaller vessels are typically made of aluminum and larger vessels of wood or steel. Crews range from 1 to 5 US citizens. Set net vessels are primarily small skiffs operated by 1–2 US fishermen.

Gear specifications
For driftnets, the maximum net size is 275m long by 45 meshes deep. The maximum mesh size is 15cm and typical size is 13cm. For set nets, the maximum length is 64m per net and with a maximum of 192m in aggregate. The maximum mesh size and net depth is the same as for driftnets in this area.

Operations
Only one driftnet is fished by each vessel and the vessel must remain in attendance of the net. The fishing season is from 25 June to September, but most fishing stops in mid-August. Typically there are only two 12-hour openings each week when fishing is allowed. The length and frequency of these openings can vary with the strength of the salmon run.

Economics and history
The value of landings varies annually and by species. Total earnings, in thousands of dollars, in 1987 and 1988 are given in Table 7.

Total landings
A total of 2,300,000 sockeye salmon was landed in 1990.

Table 7
Total earnings ('000s$) in the Cook Inlet driftnet and setnet fishery for salmon, 1987 and 1988.

	Drift gillnets		Set gillnets	
Species	1987	1988	1987	1988
Chinook	192	124	1,359	1,326
Sockeye	59,962	71,004	38,852	44,390
Coho	1,001	2,645	1,288	2,844
Pink	32	406	64	572
Chum	584	3,926	381	804
Total	$61,772	$78,103	$41,944	$49,936

Effort data
As in other Alaska salmon fisheries, effort is controlled by limited entry and by careful monitoring of salmon escapement. There are 560 permanent permits in the Cook Inlet driftnet fishery and 743 permanent permits in the set net fishery.

Interactions with cetaceans
There have been no studies of marine mammal entanglement in gillnet fisheries in Cook Inlet. White whales and harbor porpoises have been entangled in drift and set gillnets (NMFS, Alaska Region, unpublished data). In logbooks, fishermen reported 1 Dall's porpoise killed in gear in 1990 and none in 1991 (NMFS, unpublished data). The levels of mortality, release or overall take are not known.

Pinniped bycatches and other information
Earlier, pinniped conflicts led to bounties in the 1950s and an initial quantification of numbers of salmon damaged by pinnipeds (Imler and Sarber, 1947). Recently, incidental takes of harbor seals and Steller sea lions have been reported (NMFS, Alaska and Northwest Region, unpublished data). There were no pinnipeds reported killed in fishery logbooks for 1990 and 1991 (NMFS, unpublished data).

Discussion
Clearly there is a need for more information on cetacean entanglement in this fishery. The relatively small, geographically isolated stock of white whales is of particular concern. There is no plan for an observer program to monitor marine mammal interactions with this fishery.

(I) Kodiak, Alaska Peninsula and South Unimak driftnet and set net fisheries for salmon
Salmon gillnet fisheries exist around Kodiak Island (set nets) and along the Alaskan Peninsula (both set nets and driftnets).

Primary ports
The primary ports are Kodiak, King Cove, False Pass, Sand Point and Port Moller, Alaska.

Target species
The main target species is sockeye (and to a lesser degree chum and pink) salmon.

Area of operation
Gillnets are allowed in the region of Kodiak Island and along the northern shoreline of the Alaska Peninsula from the South Unimak area to Ugashik Bay. The South Unimak fishing zone is a sub-set of the Alaska Peninsula and includes coastal areas within 10 miles of Cape Lutke and along both sides of the Ikatan Peninsula, from Cape Pankof to Cape Lazaref.

Vessels and crew
Driftnet vessels are typically 9–14m in length and have crews of 3 US fishermen. Set net vessels are primarily small skiffs with 1–2 US fishermen.

Gear specifications
Drift gillnets are less than 366m in length and must have a stretched mesh size greater than 13cm. Set nets have a maximum length of 183m with an aggregate length of 275m (Kodiak area) and 92 to 366m (along different regions of the Alaska Peninsula).

Operations
Only set nets are allowed in the Kodiak region, only driftnets in the South Unimak area, and both set and driftnets along the Alaska Peninsula. The fishing season is open from early June to late October (Kodiak) or to September (Alaska Peninsula). The South Unimak fishery is limited to June and July. Fishing is subject to openings and closings by emergency order.

Economics and history
Value of landings varies annually and by species. No information on total landings is available. Total earnings, in thousands of dollars, in 1987 and 1988 are given in Table 8.

Table 8

Total earnings ('000s$) in the Kodiak, Alaska Peninsula and South Unimak driftnet and setnet fisheries for salmon, 1987 and 1988.

	Kodiak set gillnet	
Species	1987	1988
Chinook salmon	4	29
Sockeye salmon	5,638	12,428
Coho salmon	190	415
Pink salmon	914	6,678
Chum salmon	376	1,752
Total	$7,121	$21,303

	Alaska Peninsula (including South Unimak)			
	Drift gillnets		Set gillnets	
	1987	1988	1987	1988
Chinook	194	173	87	114
Sockeye	13,694	20,939	6,118	7,194
Coho	597	1,304	648	1,315
Pink	8	489	90	841
Chum	1,145	2,958	286	773
Total	$15,637	$25,864	$7,229	$10,238

Effort data
Effort in Alaskan commercial salmon fisheries is controlled by 'limited entry'. There are about 187 permanent permits in the Kodiak area and 158 permits for the Alaska Peninsula area. Anyone with an Alaska Peninsula permit can fish in South Unimak. The number of boats actually fishing in South Unimak may reach 140–150 in June and usually drops to 50 in July. Allowable fishing periods (openings) are variable depending on the time of year and run strength, but may generally be from 12–72hrs long.

Interactions with cetaceans
Previous records of entanglement exist for gray whales and harbor porpoises in the South Unimak or Alaska Peninsula (NMFS, Alaska Region, unpublished data). This fishery had a mandatory observer program in 1990. The extrapolated estimate of cetacean mortality in this driftnet fishery was 28 Dall's porpoises in 1990 (Wynne *et al.*, 1991). In 1990–92 logbooks, fishermen also indicated that harbor porpoises were taken in driftnet and setnet fisheries (NMFS, unpublished data).

Pinniped bycatches and other information
In observed sets in 1990, one Steller sea lion and two northern fur seals were briefly entangled, but each broke free unharmed (Wynne *et al.*, 1991). Fishermen's logbooks also indicate that harbor seals, spotted seals and sea otters were killed in setnet and driftnet fisheries in this area (NMFS, unpublished data).

Discussion
Little is know about marine mammal mortality in these fisheries. Except for the small area in the vicinity of South Unimak, there is no plan for an observer program.

(J) Alaskan trawl fishery for pollock and other groundfish
Although the Alaskan trawl fishery for groundfish does not use passive fishing gear and is therefore outside the intended purview of this report, this huge fishery generates massive quantities of lost and discarded net which then acts as passive fishing gear. Some direct marine mammal mortality occurs in addition to entanglement in discarded gear (Loughlin *et al.*, 1983).

Primary ports
The primary ports are Dutch Harbor, Kodiak and Akutan, Alaska.

Target species
The main target species are pollock (approximately 70% by weight), cod (approximately 10%) and various flatfish.

Area of operation
Operations take place in Bristol Bay and other regions in the Bering Sea, and in the Gulf of Alaska, including Shelikof Strait.

Vessels and crew
Trawling vessels are up to 92m long and are of steel construction. Larger vessels have on-board processing capabilities. Smaller vessels take their catch to factory ships or land it in Alaska. Currently most of the vessels are US owned and operated. The at-sea catcher-processor fleet produces frozen pollock filets. During the spawning season, roe is frozen and sent to Japan. The shore-based catcher vessels produce frozen filets and fish paste for *surimi*.

Gear specifications
Trawl nets have a mouth opening of approximately 92m by 69m.

Operations
Vessels use acoustic methods to find dense schools of pollock. Trawlings is conducted both in mid-water and on the bottom.

Economics and history
Since the 1930s, this fishery has evolved from (1) being primarily a Japanese far-seas fishery, to (2) being an international fishery with vessels from Japan, the former Soviet Union, Korea and Taiwan, to (3) being a US/Japanese joint venture, to (4) an entirely US fishery. It is currently the largest single-species fishery in the world. More than 20,000 residents of Alaska and Washington are employed in catching and processing pollock, and the total annual landings are worth approximately $200 million.

Total landings
The current quota on landings of Alaskan pollock is 2,200,000 tonnes. The actual US landings were 230,000, 590,000 and 1,100,000 tonnes for the years 1987, 1988 and 1989, respectively. These landings were worth $45 million, $95 million and $187 million, respectively. The joint-venture landings during the same time decreased from about 900,000 to 270,000 tonnes. In addition to this catch in the western North Pacific, the catch of pollock in the eastern North Pacific is about 3,000,000 tonnes (Northridge, 1984).

Effort data
Effort has increased substantially since the early 1980s. Total landings (joint-venture and US combined) increased from roughly 45,000 tonnes in 1981 to approximately 1,400,000 tonnes in 1988 and 1989.

Interactions with cetaceans
In the past, marine mammal take in the pollock trawl fishery was monitored only on foreign and joint-venture vessels. Prior to 1985, this included virtually all vessels. Cetaceans that have been observed taken between 1986 and 1988 (NMFS, unpublished data) include Dall's porpoises (20), killer whales (2), Pacific white-sided dolphins (3), harbor porpoises (3) and other unidentified cetaceans (18). There has been no evidence of cetacean entanglement in discarded netting, but it should be considered as a possible additional source of mortality.

Pinniped bycatches and other information
The direct catch of Steller sea lions has been observed in the trawl nets. Steller sea lion populations have been declining and this species is currently listed as threatened under the US Endangered Species Act. The cause of the decline is not known, but possible causes include resource depletion by overfishing, incidental mortality in trawl and gillnets, shooting, disease, predation, or combinations of the above. Of the pinnipeds, only Steller sea lions have been caught in substantial numbers in pollock trawls (Lowry *et al.*, 1989). The number of Steller sea lions caught and killed in groundfish trawls averaged 724 from 1978–81, 1,436 in 1982, 324 in 1983, and 355 in 1984 (Loughlin and Nelson, 1986). Direct catch in trawls has also been observed (NMFS, Alaska Fisheries Science Center) for California sea lions (1), northern fur seals (48), northern elephant seals (3), harbor seals (36), spotted seals (3), ringed seals (17), bearded seals (4) and walrus (76). Entanglement in discarded trawl net fragments may be an important factor in the decline of the Pribilof Islands population of fur seals (Fowler, 1982) and may account for an extra 15–20% mortality of juvenile fur seals (Fowler, 1985). Net fragments have also been seen on Steller sea lions (Loughlin *et al.*, 1986). Simultaneous with the development of the fishery was a precipitous decline in Steller sea lion populations in the Gulf of Alaska and Aleutian Islands, from 140,000 in 1960 to 25,000 in 1989 (Loughlin *et al.*, 1990). The direct Steller sea lion mortality is insufficient to explain the marked population decline; however, the effects of the fishery on sea lion prey abundance has been implicated as a potential cause of the decline.

Discussion
Discarded trawl nets and lines litter the beaches on many sites in the Aleutian Islands, Alaska (Merrell, 1985). Seventy-five beaches were examined on 21 Aleutian Islands in 1988–90 in a study on the impact of plastic debris on wildlife (A. Manville, unpublished data; Manville, 1990). Fishing-related debris was found to be the most prevalent form of plastic on the beaches. Fishing debris on these 75 beaches included 4,283kg of rope, 120kg of driftnet buoys, and 6,053kg of fishing net (95% of the net debris was from trawl nets). Although this beach survey found 3 Steller sea lions entangled in plastic debris, in all cases it was strapping bands and not fishing gear. Given the isolated nature of most of these islands, the large quantity of fishing-related debris found on these beaches and indications of the continued loss and/or discard of fishing-related gear, the potential for marine mammal entanglement in passive fishing debris is great. The danger is probably much greater for pinnipeds than for cetaceans.

US vessels are required to have mandatory observers on a subset of their trips. The observed incidental take in 1989 included 5 Steller sea lions, 1 Dall's porpoise and 1 ringed seal. These estimates have yet not been extrapolated to the entire US fleet. In the same year, the observer coverage on the joint-venture fleet was approximately 95% and the bycatch included 3 Steller sea lions, 1 fur seal and 1 unidentified marine mammal.

(K) Bristol Bay set net and driftnet fisheries for salmon
A large, intensive fishery for salmon occurs in the northeastern part of Bristol Bay.

Primary ports
The primary ports are Dillingham, Egegik and Naknek, Alaska.

Target species
The main target species is sockeye salmon, but coho, pink, chum and chinook salmon are also taken.

Area of operation
Operations take place principally in Nushagak and Kvichak Bays and adjacent coastal waters along the Alaska Peninsula.

Vessels and crew
Set net boats are small skiffs crewed by 1–2 US fishermen. Driftnet boats are limited to a maximum of 10m in length and are crewed by 2–4 US fishermen.

Gear specifications
Multifilament nylon gillnets are used with maximum stretch mesh of 11 to 17cm (depending on season). Maximum net length is 183m for set nets and 275m for driftnets. Maximum depth is limited to 29 meshes. Marker floats are required on the free end of the net.

Operations
Set nets are laid perpendicular to shore and are anchored at the seaward end. Some nets are set slightly offshore (<183m) and anchored at both ends. Driftnets must remain attached to the boat on one end with a buoy on the other, free end. All nets float at the surface. Soak times and durations of fishing periods are dependent on fishing conditions and current regulations.

Economics and history
This area has the largest run of sockeye salmon in Alaska and the fishery is consequently large. Most of the fish are frozen, but some are canned or sold fresh. Chinook salmon are important earlier in the year. Fish are sold to both domestic and foreign markets. Value of landings varies annually and by species. Total earnings, in thousands of dollars, in 1987 and 1988 are given in Table 9.

Table 9

Total earnings ('000s$) in the Bristol Bay setnet and driftnet fisheries for salmon, 1987 and 1988.

	Drift gillnets		Set gillnets	
Species	1987	1988	1987	1988
Chinook	1,402	699	372	237
Sockeye	115,696	168,098	18,015	24,920
Coho	134	1,101	193	1,041
Pink	-	782	-	424
Chum	2,643	2,340	332	387
Total	$119,875	$172,991	$18,912	$27,009

Total landings
Combined landings for set and driftnet fisheries were 16,048,000 sockeye, 69,000 coho, 1,510,000 chum and 77,000 chinook salmon for 1987; 14,010,000 sockeye, 187,000 coho, 1,475,000 chum, 922,000 pink and 45,000 chinook salmon for 1988. Total landings in 1989 were 80,557 tonnes for all salmon species.

Effort data
Effort in Alaskan commercial salmon fisheries is controlled by 'limited entry'. There are 943 permanent permit holders for the Bristol Bay set net fishery and 1,746 permanent permit holders for the Bristol Bay driftnet fishery. Allowable fishing periods (openings) are variable depending on the time of year and run strength, but may generally range from 12hrs to 7 days long. Fisheries are managed based on escapement goals, so after the desired escapement is achieved the fishery may be open continuously.

Interactions with cetaceans
A group of about 1,000–1,500 white whales occur in this area, some of which are incidentally caught in gillnets (Brooks, 1954; 1955; Frost *et al.*, 1984). There is no systematic program for measuring the level of take, but studies conducted in 1982–83 suggested that about 10–20 whales per year were killed. Most mortality seems to occur in the chinook salmon fishery which uses larger mesh sizes. Evidence indicates that the white whale population's distribution and abundance was largely the same in 1984 as it was 30 years earlier (Frost *et al.*, 1984). Some take of harbor porpoises is also likely in this fishery.

Non-lethal harassment was used from 1956–72 to displace the white whales which feed on sockeye salmon adults and smolt (Frost *et al.*, 1984). White whales are thought to consume less than 1% of the commercial catch of sockeye salmon and less than 5% of the total smolt production; however, they may consume up to 9% of the commercial catch of other salmon species (Frost *et al.*, 1984).

Fishermen logbooks for 1990–92 indicate that other species are occasionally killed, including the common dolphin, northern right whale dolphin and gray whale.

Pinniped bycatches and other information
Logbook data for 1990–92 show the deaths of 18 harbor seals and 1 spotted seal (NMFS, unpublished data).

Discussion
The group of white whales in Bristol Bay is usually considered to be a separate stock that numbers in excess of 1,000 animals. Although available data suggest that numbers have been stable and that incidental take has not affected the stock, there are suggestions that the level of take has increased since the 1950s. This warrants further study.

(L) Northern Alaska set net fisheries
Harbor porpoises are sometimes taken in gillnets that are set for salmon (and other fish) in Norton Sound, Kotzebue Sound and other areas north of Bristol Bay. Most fisheries interactions are likely to involve pinnipeds, including harbor, spotted, ringed and bearded seals, although there are no published records that describe this interaction.

Primary ports
The primary ports are Nome, Unalakleet, Golovin and Kotzebue, Alaska.

Target species
The main target species are coho, chum and chinook salmon.

Area of operation
Operations are primarily in coastal waters of Norton Sound and Kotzebue Sound.

Vessels and crew
The small skiffs used are crewed by 1–2 US fishermen.

Gear specifications
Mostly multifilament nylon gillnets are used. In Norton Sound, nets have a maximum stretch mesh of 11 or 15cm (depending on season). The maximum length is 183m. In Kotzebue Sound, there are no limitations on mesh size and nets are a maximum of 275m long. There are no restrictions on net depth. Floats are required on the free end of the net.

Operations
Nets are set perpendicular to shore and are anchored at the seaward end. All nets are floating at the surface. Soak times and durations of the fishing season depend on fishing conditions and current regulations.

Economics and history
Subsistence-caught fish are for personal use but may be bartered. Commercially-caught fish are sold to both domestic and foreign markets and may be sold fresh, canned, smoked or frozen. Price and ex-vessel value vary

considerably depending on run strength and market conditions. Value of landings varies annually and by species. Total earnings, in thousands of dollars, in 1987 and 1988 are given in Table 10.

Table 10

Total earnings ('000s$) in the northern Alaska setnet fisheries in 1987 and 1988.

Species	1987	1988
Chinook salmon	6,787	6,880
Sockeye salmon	1,706	2,134
Coho salmon	2,818	7,158
Pink salmon	1	69
Chum salmon	3,382	13,046
Total	$14,694	$29,287

Total landings
In 1989, catches of all salmon species amounted to 337 tonnes in Norton Sound and 989 tonnes in Kotzebue Sound.

Effort data
Effort in Alaskan commercial salmon fisheries is controlled by 'limited entry'. There were 1,952 permanent permit holders in 1987 for the Kuskokwim, Lower Yukon, Norton Sound, and Kotzebue management areas. Fishing periods (openings) are variable depending on the time of year and run strength, but may generally be from 12hrs to 7 days long. Harvests are continually monitored and fishing hours in particular areas are controlled by emergency order to achieve escapement goals.

Interactions with cetaceans
Harbor porpoises are occasionally entangled and drowned. ADF&G has recorded 7 instances during 1981–87 in the area from Nome to Unalakleet and 3 near Kotzebue in 1989–90. One harbor porpoise was even caught in a net set at Barrow (Hall and Bee, 1954). There is no formal program of monitoring and reporting.

Pinniped bycatches and other information
No pinniped bycatch has been reported, but some catch of spotted seals is likely. Any pinnipeds that are taken are likely to be used by Native American fishermen for subsistence purposes.

Discussion
The apparent level of take seems quite large considering the lack of a formal program for monitoring and the opportunistic nature of reports that have been received. Harbor porpoises probably occur in this area only during summer and fall since they would be excluded by sea ice during November-June. It is not known to which population these porpoises might belong.

(M) Driftnet fishery for salmon in eastern Russia
Gaskin (1984) reported that there were no records of harbor porpoise take from Korean waters, from the northern coast of China, or from gillnet operations in far-eastern Russian waters. Little mention was made of fishery/marine mammal interactions in Russian waters by Northridge (1984). Kornev (1994) mentions the entanglement and death of one right whale in a gillnet. There has been no specific research on problems of marine mammal mortality in fisheries of the east coast of the former USSR. Information provided in this review is based on one author's (VNB's) opportunistic observations, on data provided by researchers at the Kamchatka Department of the Pacific Institute of Fisheries and Oceanography, on information provided by inspectors of the Kamchatribvod Protective Service and on reports from the chiefs of Glavribvod and Kamchatribvod of the former USSR Department of Fisheries.

Primary ports
The primary ports are Petropavlovsk-Kamchatsky, Severo-Kurilsk, Vladivostok, Nakhodka, Preobrazhenye, and Hokkaido (Japan)

Target species
The main target species are pink and chum salmon, but all five Pacific species are caught.

Area of operation
Operations take place in the Sea of Okhotsk and the Bering Sea.

Vessels and crew
Driftnet fishing for salmon off eastern Russia is typically by Russian and Japanese fishermen (Kornev, 1994). In 1990, 2 larger (approx. 500 tonnes) and 6 smaller (100–120 tonnes, 40m, crew of 16–18) Japanese vessels participated in this fishery. That same year, 6 larger (800 tonnes, crew of 26) and 3 smaller (<100 tonnes, crew of 10–12) Russian vessels participated. In 1992–94 the number of small Japanese vessels increased to 30–40 per year.

Gear specifications
Nets are constructed of thin-vein, monofilament nylon mesh made in Japan or Taiwan. Panels are 45–50m long by 8–9m deep. Single nets (or 'oders') are made of 50–300 panels. A vessel typically fished 1 or 2 oders in 1990 and 4–7 oders in 1992–94. Each net is marked with lights and radio beacons.

Operations
Drift gillnet fishing for salmon in the eastern economic zone of Russia is conducted under a special research program of the Pacific Institute of Fisheries and Oceanography (PIFO) and, since 1992, as a commercial fishery. Research fishing operations occur from 20–25 July to 10–25 August, although sometimes it is carried into September. Commercial fishing occurs from 20 May to 20–25 July. Fishing takes place in the Sea of Okhotsk and the Bering Sea. Some additional fishing may take place in the northern Sea of Okhotsk and near the northern coast of Sakhalin Island, but information on that region is scarce. Typically nets are set after sunset and are hauled after sunrise or early the next day. Soak times are 9–12hrs.

Economics and history
Russian fishermen in 1990 received 23 rubles, 76 copecks ($30US: official rate, $2–3US: black market rate) per 100kg of cleaned salmon. Fish are cleaned immediately after being caught and are kept refrigerated on the vessel. Fish are sold to foreign and domestic markets.

Total landings
The 1990 landings for Russian vessels in the Bering Sea (in the former USSR economic zone) were 300 tonnes of salmon (approx. 100t pink and 195t chum). Total salmon

landings were down considerably from previous years. Record highs of 2,100 tonnes were recorded in 1988. The 1990 salmon landings from the Sea of Okhotsk and the Bering Sea were approximately 1,500 tonnes. The species composition of the catch varies with natural salmon cycles.

The Japanese driftnet fishery for salmon in the former Soviet economic zone was steady at 4–6,000 tonnes over the years 1987–90 in the region near the Okhotsk and Pacific coasts of the south Kuril Islands. A Soviet-Japanese joint venture firm (Pilenga GODO) fished with Japanese vessels in the Karaginsky Gulf in 1989 and in the Sea of Okhotsk near western Kamchatka in 1990. Total landings were 522 tonnes (and are included in the above 1,500 tonnes).

Effort data
The scientific gillnet fishery for salmon developed in 1986 and reached a peak in 1988. A commercial gillnet fishery in the Russian economic zone increased dramatically in 1992–94 with an agreement between Russia and Japan.

Interactions with cetaceans
In the research fishery, PIFO representatives and vessel captains report Dall's porpoises being caught in the scientific salmon gillnetting (G.E. Karmanov, A. N. Zaochny, M. T. Orlov, and V. A. Shniperov, pers. comm.). Porpoises were caught most frequently near the Kuril Islands, south to 51°N. Fishing in 1990 between 51°-51°30′N and 149°20′-155°50′E, G.E. Karmanov reported (pers. comm.) 8 Dall's porpoises entangled out of 2,295 panels of retrieved net (109.6km), of which 3 were released alive. Captains of two other vessels fishing in approximately the same area reported 20–25 Dall's porpoises killed per fishing season. Porpoises are caught much less frequently in the Karaginsky Gulf (Bering Sea, 58–60°N). In this area in 1990, PIFO natural resource observers saw no porpoises entangled in 5,000 panels of retrieved net. In the 1992–94 commercial fishery, several hundreds of Dall's porpoise were caught each year. Some harbor porpoise and unidentified whales were also caught. Porpoises are typically thrown back into the sea.

One entangled right whale (which died) was discovered on the Pacific side of Cape Lopatka in October 1989. It was caught in a fragment of green 6 x 6cm mesh gillnet with foam plastic floats (Kornev, 1994).

Pinniped bycatches and other information
Northern fur seals, ribbon seals, bearded seals and spotted seals were taken in the 1992–94 commercial fishery (probably less than 10 of each species per year).

Discussion
Fishery inspectors of the Kamchatribvod controlled fishery reported that a rather developed, unpermitted fishery existed in the Sea of Okhotsk and near the Pacific coast of the Kuril Islands prior to 1992. Each year, Russian patrol boats chased off Japanese, Korean and Taiwanese vessels in this area. This unpermitted fishery has been largely replaced by a permitted commercial fishery in 1992. This commercial fishery includes a bycatch observer program which is now providing needed information on marine mammal mortality.

(N) Eastern Russia coastal trap-net fishery for salmon
The vast majority of Russian-caught salmon on the east coast come from nearshore trap nets. These are passive nets that intercept salmon as they travel along the shore to their spawning river and guide the fish into a holding pen. Little information has been published regarding cetacean entanglement in this type of net, but it is considered very rare.

Target species
All five Pacific salmon species are taken.

Area of operation
Operations occur in near shore waters of the Russian Far East.

Gear specification
Trap nets are set with a wing net perpendicular to shore and leading to a trap or pen approximately 200–400m from shore.

Operations
Approximately 6–12 fishermen tend each trap net. Fish are transported to shore-based processing plants in special boats.

Total landings
The vast majority of Pacific salmon caught in Russian waters are caught in trap nets. Average landings in eastern Russian waters from 1987–90 were 131,000 tonnes per year, of which approximately 79,000 tonnes were caught on the Kamchatka peninsula.

Effort data
Annually in June-August, about 50 trap nets are set on the western (Okhotsk) coast of Kamchatka and about 50–80 are set on the eastern coast.

Interactions with cetaceans
Other than one reported narwhal entanglement (I.I. Muroshov, pers. comm.), interactions with cetaceans appear minimal in this fishery.

Pinniped bycatches and other information
Often spotted seals gather in groups of approximately 100 near the traps. Steller sea lions have also been reported. The trap itself is apparently not dangerous to pinnipeds, but fishermen often shoot at them, killing or wounding some.

Discussion
More details regarding the level of pinniped mortality by shooting are clearly needed. However, the available information suggests that this method of fishing appears to be effective at catching salmon without incidental entanglement of marine mammals.

(O) Other fisheries
There are many reports for the eastern North Pacific regarding marine mammals mortality in passive and active fishing gear in fisheries other than those mentioned above. Some of these fisheries are small and others have been discontinued. For completeness, we include all references we were able to find, without providing extensive details. The following list should not be considered complete.

In California, Scammon (1874) first documented the take of harbor porpoises in a beach seine in San Francisco. Although not strictly-speaking entangling gear, many short-finned pilot whales were thought to entangle and die (or were shot) in a market squid purse seine fishery in the California Channel Islands (Miller *et al.*, 1983; Seagers and Henderson, 1985; Heyning *et al.*, 1994).

In Oregon and Washington, significant pinniped mortality has been reported in the Columbia River salmon gillnet fishery (Beach *et al.*, 1985), but cetacean mortality does not seem important there. Scheffer and Slipp (1948) felt that fish nets were responsible for a large number of harbor porpoise deaths each year in Washington state. Harbor porpoises were also killed in trawl gear off Washington State (Leatherwood and Reeves, 1986).

In British Columbia, there are records of cetacean bycatch in several temporary experimental or now-discontinued fisheries. Cowan (1939) reported a minke whale caught in a salmon trap near Sooke, on the southern tip of Vancouver Island. Pike and MacAskie (1969) reported the deaths of three short-finned pilot whales in a gillnet during experimental fishing in international waters off BC and the entanglement of two killer whales in 'fishing gear'. Porpoises are occasionally killed in research fisheries currently being undertaken by the Canadian Department of Fisheries and Oceans; in 1990 a Dall's porpoise was killed in a surface trawl research fishery on salmon smolts and a harbor porpoise was killed in a monofilament sunken set gillnet used in a research fishery for dogfish shark (Baird, unpublished data). In addition to the salmon gillnet fishery described above, five current commercial fisheries are known to take cetaceans in BC. These include salmon seine, salmon troll, bottomfish trawl, shrimp trap, and crab trap fisheries (Le Boeuf, 1974; Baird *et al.*, In press), in the latter two, take involves large whales becoming entangled in lines associated with the traps. In 1990 a gray whale entangled and died in a pen used to hold herring in a herring roe fishery and in 1991 a gray whale was entangled in a herring set gillnet from this fishery (Baird *et al.*, In press).

Frequent marine mammal/fishery encounters have been reported for the salmon purse seine fishery in South Unimak, Alaska (Melteff and Rosenburg, 1984), but more recent investigations by the State indicate that this may no longer be the case (Anon., 1989). Elsewhere in Alaska, four humpback whales were reported to have entangled in buoy lines associated with longline and shrimp pot gear (Sease, pers. data). A killer whale entangled and drowned in a sablefish longline in 1988. Some Steller sea lions also were killed in association with longline fisheries in Alaska, but many probably were killed intentionallly to protect catch and gear. [Currently there is a ban on shooting at or within 100 yards of Steller sea lions throughout their range.] Gray whale mortality due to fisheries ranges from 8.7 to 25.8% of all stranded gray whales from the Alaska Peninsula to Baja California Norte (Heyning and Dahlheim, In press).

Several other passive-type fisheries are found in the waters of eastern Russia. Near western Kamchatka, approximately 10 Japanese vessels fished in 1990 used long-lines for cod, walleye pollack, and flatfish and use traps for crab. Approximately 5–6 Japanese vessels fish for halibut and large perch using bottom-set gillnets in international waters in the middle of the Sea of Okhotsk. In the latter fishery, 20–25cm mesh nets are set at extreme depths of 500–800m. One vessel typically sets 27km of net which is allowed to soak for 2–4 days. No information is available on cetacean mortality in any of these fisheries.

Crustacean trap fisheries occur in most coastal waters including California, Oregon, Washington, British Columbia, Alaska, the western Bering Sea (Russia), and the Sea of Okhotsk. Based on experience elsewhere, trap lines are likely to occasionally entangle and kill some whales. Four of the entangled gray whales mentioned by Heyning and Lewis (1990) were caught in crab or lobster traplines. In British Columbia, there is one record of a humpback whale becoming entangled in lines associated with prawn trap gear (Langelier *et al.*, 1990). In Russia, one gray whale has been seen with a part of a crab trap on its fluke (L.S. Bogoslovskaya, pers. comm.) and a spotted seal has been reported entangled in crab fishing gear.

DISCUSSION

Clearly there is insufficient information on the number of marine mammals that are taken incidentally in passive fishing nets and traps. For many fisheries, there is no information at all. In the case of California gillnet fisheries, for which we have the best data, it is still difficult to evaluate the significance of the observed mortality on the cetacean populations. In all areas, a larger effort is needed both to determine the number of animals killed in fisheries and to evaluate the significance of this mortality to the populations.

Recent US legislation that requires an observer program for certain fisheries is likely to fill many of the gaps in our knowledge about the level of marine mammal mortality in these fisheries. The resulting information will not be complete, however. The US program concentrates on fisheries with a high likelihood of taking marine mammals. Although vessel owners in other fisheries are required to report on levels of fishing effort and marine mammal interactions, there is no validation to ensure accurate reporting. For many fisheries without observer programs, there was no quantitative information on the levels of marine mammal catch. In this situation, a lack of information is perpetuating a continued lack of information. Some, perhaps low level of observation in all fisheries might be appropriate to better estimate the total level of cetacean mortality in US fisheries.

In Canada, the level of knowledge on fishery/marine mammal mortality is poor. The exception is the experimental squid fishery with its 100% observer program. Seldom has bycatch been adequately studied in experimental fisheries and seldom (as it was in this case) is bycatch a factor in deciding against continuing a potentially profitable fishery. In contrast, however, there is little direct information on cetacean mortality in the much larger drift gillnet fishery for salmon in BC. Most of the available information is from questionnaires, which are typically less reliable than direct observation. Some level of direct observation seems necessary in order to validate the level of incidental mortality that was estimated in the questionnaire survey.

In Russia, little information is available on the levels of incidental marine mammal mortality in fisheries. This report was based almost entirely on information for the Sea of Okhotsk and the Bering Sea. More information is needed regarding fisheries near Sakhalin Island and in the Sea of Japan. The largest and economically most important fishery, the trap-net fishery for salmon, appears to have little incidental marine mammal mortality. Driftnet fishing for salmon is, however, increasing rapidly. There is a need to continue studies of marine mammal/fishery interactions in eastern Russia and to expand the program of fishery observers.

It should be recognized that indirect methods of estimating marine mammal mortality in fisheries (including data from stranded animals, from dockside surveys and from questionnaires) are all likely to underestimate total marine mammal mortality. The biases are likely to be

different for each method. Stranding data are likely to underestimate takes from offshore fisheries more than inshore fisheries (Heyning *et al.*, 1994). Problems with questionnaires and dockside surveys are addressed by Lien *et al.* (1994). Indirect methods of estimating bycatch of marine mammals should not be considered as a substitute for direct observation.

Knowing the level of marine mammal mortality in fishing operations is an obvious first step in evaluating the significance of this mortality on the populations of marine mammals. Ideally, one would like to directly measure whether fishery mortality is adversely affecting populations. Data on population trends are rare for most marine mammal species. Populations appear to be increasing for California gray whales, killer whales in British Columbia, California sea lions, northern elephant seals and harbor seals in California, Oregon, Washington and British Columbia. The population of white whales in Bristol Bay appears stable. This type of information gives us some confidence that fisheries are not disadvantageous to these populations. In contrast, there are examples such as harbor seals, northern fur seals and Steller sea lions in Alaska where the populations are declining, but where the reasons for this are not understood and any possible relationship to gillnet entanglement is unclear. Unfortunately, trends in abundance are difficult and expensive to obtain, require long time series and may be difficult to interpret. Although it is anticipated that information on trends in harbor porpoise abundance in California will be available after 4 additional years of study (Forney *et al.*, 1991), this is one of the few cetacean populations for which this is likely. Trends are not always a practical approach to determining the significance of incidental marine mammal mortality in fisheries.

A more basic first step should be to estimate the size of the populations that are being affected by fishery mortality. A comparison between the estimated level of fishery mortality and the population size can quickly indicate whether fishery mortality is likely to be a problem for those populations. Most biologists would agree that incidental mortality rates of less than 1% per year are not likely to have an appreciable impact on a marine mammal population unless that population is suffering from additional factors that result in reduced productivity and/or survival. Similarly, most biologists would agree that incidental mortality rates greater than 4% per year for cetaceans or 10% per year for pinnipeds are not sustainable and could lead to catastrophic population declines. Between these values (1–4% for cetaceans, 1–10% for pinnipeds), there may be considerable difference of opinion as to the likely effect of incidental mortality. Using such a scheme, it is possible to classify fishery mortality on a population as being probably negligible, clearly too high, or potentially too high. Researchers and managers could then take action to reduce mortality where it is obviously too high and to gather adequate data in cases where we are unsure of the potential impact of a fishery on a marine mammal population.

RECOMMENDATIONS

(1) Baseline data on levels of marine mammal mortality for all fisheries based on direct observations and other appropriate methodology should be obtained. Fisheries that are found to have a significant level of marine mammal mortality should continue to be monitored. Countries which allow foreign vessels to fish in their waters may be able to require such an observation program as a condition for obtaining a fishing permit.

(2) Estimates of population size for species that are likely to be adversely affected by fishery mortality should be obtained. For most species, this will include determining stock boundaries, abundance and seasonal distribution. When possible, trends in abundance should be determined.

(3) Alternative fishing strategies that will minimize encounters with marine mammals (e.g. seasonal closures for gillnet fisheries) should be developed.

(4) Consideration should be given to the level of incidental marine mammal mortality when fishery management agencies decide the allocation of fish to various fishing methods. As an example, the use of trap nets for salmon could be allowed in place of using gillnets.

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Appendix 1

SCIENTIFIC AND COMMON NAMES

Marine Mammals	
Bearded seal	*Erignathus barbatus*
Bottlenose dolphin	*Tursiops truncatus*
California sea lion	*Zalophus californianus*
Common dolphin (short-beaked)	*Delphinus delphis*
Common dolphin (long-beaked)	*Delphinus capensis*
Cuvier's beaked whale	*Ziphius cavirostris*
Dall's porpoise	*Phocoenoides dalli*
Elephant seal	*Mirounga angustirostris*
Gray whale	*Eschrichtius robustus*
Harbor porpoise	*Phocoena phocoena*
Harbor seal	*Phoca vitulina*
Hubbs' beaked whale	*Mesoplodon carlhubbsi*
Humpback whale	*Megaptera novaeangliae*
Killer whale	*Orcinus orca*
Mesoplodont beaked whale	*Mesoplodon* spp.
Minke whale	*Balaenoptera acutorostrata*
Narwhal	*Monodon monoceros*
Northern fur seal	*Callorhinus ursinus*
Northern right whale dolphin	*Lissodelphis borealis*
Northern right whale	*Eubalaena glacialis*
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
Pygmy sperm whale	*Kogia breviceps*
Ringed seal	*Phoca hispida*
Risso's dolphin	*Grampus griseus*
Sea otter	*Enhydra lutris*
Short-finned pilot whale	*Globicephala macrorhynchus*
Sperm whale	*Physeter macrocephalus*
Spotted seal	*Phoca largha*
Stejneger's beaked whale	*Mesoplodon stejnegeri*
Steller or northern sea lion	*Eumetopias jubatus*
Walrus	*Odobenus rosmarus*
White whale	*Delphinapterus leucas*

Fishes	
Angel shark	*Squatina californica*
California halibut	*Paralichthys californicus*
Capelin	*Mallotus villosus*
Mako shark	*Isurus oxyrinchus*
Market squid	*Loligo opulescens*
Neon flying squid	*Ommastrephes bartramii*
Opah	*Lampris regius*
Pacific cod	*Gadus macrocephalus*
Pacific salmon	*Onchorhynchus* spp.
Chinook or king salmon	*O. tshawytscha*
Chum or dog salmon	*O. keta*
Coho or silver salmon	*O. kisutch*
Pink or humpback salmon	*O. gorbuscha*
Sockeye or red salmon	*O. nerka*
Swordfish	*Xiphias gladias*
Thresher shark	*Alopias vulpinus*
Walleye pollock	*Theragra chalcogramma*
White croaker	*Genyonemus lineatus*
White seabass	*Cynoscion nobilis*

Harbor Porpoise Interactions With a Chinook Salmon Set-Net Fishery in Washington State

Patrick J. Gearin[1], Sharon R. Melin[1], Robert L. DeLong[1], Hiroshi Kajimura[1] and Michael A. Johnson[2]

ABSTRACT

A cooperative study based on an agreement between the National Marine Fisheries Service and the Makah Indian Tribe was conducted during 1988–90 to assess the nature and magnitude of harbor porpoise (*Phocoena phocoena*) interactions in the Makah chinook salmon set-net fishery. The Makah set-net fishery operates annually along the northern coast of Washington State (USA) in the North Pacific Ocean and in the western Strait of Juan de Fuca from 1 May to 15 September. The fishery targets on chinook salmon (*Oncorhynchus tshawytscha*) using submerged gillnets up to 100 fathoms (200m) long. An observer program was conducted during the 1988–90 seasons and fishing effort was estimated. A total of 138 harbor porpoises was observed or reported taken incidentally during the three years of which 100 were collected and necropsied. Harbor porpoises were primarily taken during a one month period from mid-July to mid-August at the Spike Rock fishing grounds in the Pacific Ocean. The number of harbor porpoises observed or reported taken in the fishery declined dramatically during 1989 and 1990 due to low fishing effort. Of the harbor porpoises collected, 55 were males, 45 were females, 100 were aged and the reproductive condition of 99 was determined. The maximum estimated age (based on growth layer groups within the dentine) was five for females and eight for males. A large proportion (54%) of the aged porpoises were one and two years old. Most (63.6%) of the 99 animals examined were reproductively immature. Males were reproductively mature at age four with a body length of approximately 132cm. Females were reproductively mature at age three with a body length of approximately 155cm. The principal prey of both harbor porpoise and chinook salmon were Pacific herring (*Clupea harengus pallasi*), market squid (*Loligo opalescens*) and smelt (Family Osmeridae).

KEYWORDS: INCIDENTAL CAPTURE; NORTH PACIFIC; HARBOUR PORPOISE; BIOLOGICAL PARAMETERS; FEEDING; SQUID FISH; REPRODUCTION; SEXUAL DIMORPHISM

INTRODUCTION

This paper summarises a cooperative study assessing the nature and magnitude of harbor porpoise (*Phocoena phocoena*) fishery interactions in the Makah chinook salmon (*Oncorhynchus tshawytscha*) set-net fishery in Washington State (USA). The study was conducted from 1988–90 by the National Marine Mammal Laboratory (NMML) and the Makah Tribal Fisheries Management Division based on a cooperative agreement between the Makah Tribe and the National Marine Fisheries Service (NMFS) in 1988. This paper reports and updates the results of the 1988–89 studies reported in Kajimura (1990). A population assessment of harbor porpoises along the Washington State coast from aerial, shipboard and shore-based platforms is presented in Kajimura (1990) as well as more detailed information about the biology of the harbor porpoises collected during the fishery (Calambokidis, 1990; Gearin and Johnson, 1990; Gearin *et al.*, 1990; Melin *et al.*, 1990; Rugh and Melin, 1990; Turnock *et al.*, 1990).

In this paper we describe the Makah set-net fishery and the results of the observer programs conducted from 1988–90, report the incidental catches of harbor porpoises and other cetaceans taken in the fishery and present life history information on harbor porpoises collected during the fishery. We also discuss the measures that have been taken to reduce the incidental take of harbor porpoises and the potential impact of this fishery on the regional harbor porpoise population.

METHODS

Description of fishery

The Makah set-net fishery operates along the northern coast of Washington State in the Pacific Ocean and along the southwest coast of the Strait of Juan de Fuca (Fig. 1).

[1] *National Marine Mammal Laboratory, AFSC/NMFS, 7600 Sand Point Way NE, Seattle, WA 98115–0070, USA*
[2] *6411 Fremont Ave. N. Seattle, WA 98103, USA*

Tribal fishing grounds in Washington State were re-established under the Boldt decision of 1974 (*United States v. Washington*, 384 F. Supp. 312). The Makah tribe, like other northwest coastal Indian tribes, have a designated 'Usual' and 'Accustomed' (U and A) fishing area. The Makah tribal U and A area is shown in Fig. 1. The set-net fishery operates in a small portion of the U and A area corresponding to the Washington State Department of Fisheries commercial salmon statistical catch Areas 3, 4, 4A, 4B and 5 (Fig. 1). The fishery is open from 1 May to 15 September with peak landings of chinook salmon occurring in July and August.

The set-net fishing fleet consists of 6–10 boats, 16–24ft (5–8m) in length. Each fisherman is allowed three gillnets, 100 fathoms (183m) long. Nets are generally sunk to 6–10 fathoms (11–18m) and anchored at both ends with the lead line resting along the bottom. The nets are composed of mono– or polyfilament nylon ranging from 7.75–8.5 inch (19–22cm) stretch mesh and are up to 100 meshes deep. The set-nets are checked every 24 hours on average and remain in place for periods of up to several weeks. The nets are only pulled completely out of the water to be repaired, cleaned or moved to a new location.

Observer program

Observers rode on Makah set-net fishing boats and recorded data on the location and depth of nets, time of net retrieval, soak time, chinook salmon taken and the incidental catch of harbor porpoises and other marine mammals. Incidental catch data included date, time, location, net number, depth where taken, location of porpoise in the net and core body temperature of porpoise upon retrieval. Porpoises taken in the set-nets were assigned field numbers and transported to shore and necropsied.

Fishing effort estimates

Fishing effort is defined as net days fished where one net day (ND) equals a 100 fathom net set for 24 hours (Polacheck, 1989). Total fishing effort was calculated by multiplying the total number of 100-fathom nets by the total number of days set (a 50-fathom net was treated as 0.5 of a net).

Seasonal fishing effort estimates for 1988–90 were derived from three sources: the Makah fisheries sign-up forms; interviews with Makah set-netters; and direct observations made by observers during the fishery. Using these sources, the seasonal effort was estimated by month and area.

Determining incidental catches of harbor porpoises

Observed-plus-reported incidental catch

Fishermen were asked to report their catches of cetaceans to observers during the fishing season from May through August. Informal interviews were conducted with most of the Makah set-netters at the end of the fishery each year to obtain further information on fishing effort and data on incidental catches of harbor porpoises and other cetaceans. These interviews were helpful in reconstructing the seasonal fishing effort and in obtaining a record of incidental catches by area and time, where observations were minimal or not conducted. Observer data, previously reported porpoise catch data and interview data were combined to give the observed-plus-reported catch.

Rate of catch

The incidental catch rate (using observed-plus-reported catch data) of harbor porpoises was calculated for the Spike Rock fishing grounds during June through August 1988–90. The catch rate was defined as the catch of porpoises per unit of effort (CPUE). The rates for any stratum, such as month, are therefore the number of porpoises caught per net day fished. Rates for May at Spike Rock were not calculated as the absence of observer coverage would have meant that the values would not have been comparable to the other months.

Incidental catch estimates

Incidental catch estimates for harbor porpoises were calculated for the 1989 season by month and for the total season. The estimates were derived only from the numbers of incidentally caught porpoises that were observed by NMFS observers. Estimates for 1988 were not calculated because observer coverage was: (1) limited to one vessel; (2) only 3.1% of the total fishing effort and included observations of only six nets at Spike Rock; (3) limited to 14 days out of a 138-day season; and (4) confined to the period of the highest observed-plus-reported catches. An extrapolated estimate for 1988 using these data would thus be biased and invalid. No extrapolated estimates of incidental catch are reported for 1990 because observer coverage in the areas where porpoises were caught was near 80% and estimates would have only confirmed the accuracy of the observed-plus-reported catch data.

The 1989 harbor porpoise catch estimate was calculated for the Spike Rock area during June-August. This was the only area and period when porpoises were observed taken. The rates of incidental take of harbor porpoises during 1989 were calculated using two methods; a straight ratio estimate (T_i) and a bootstrap estimate (Diamond and Hanan, 1986).

The formula for the straight ratio estimate is

$$T_i = (t_i/n_i)\, S_i$$

where: i = area, T = total take, t = number observed taken, n = number of net days observed and S = estimated total number of net days.

The bootstrap estimate uses the computer generated resampling method described in Efron (1982). In

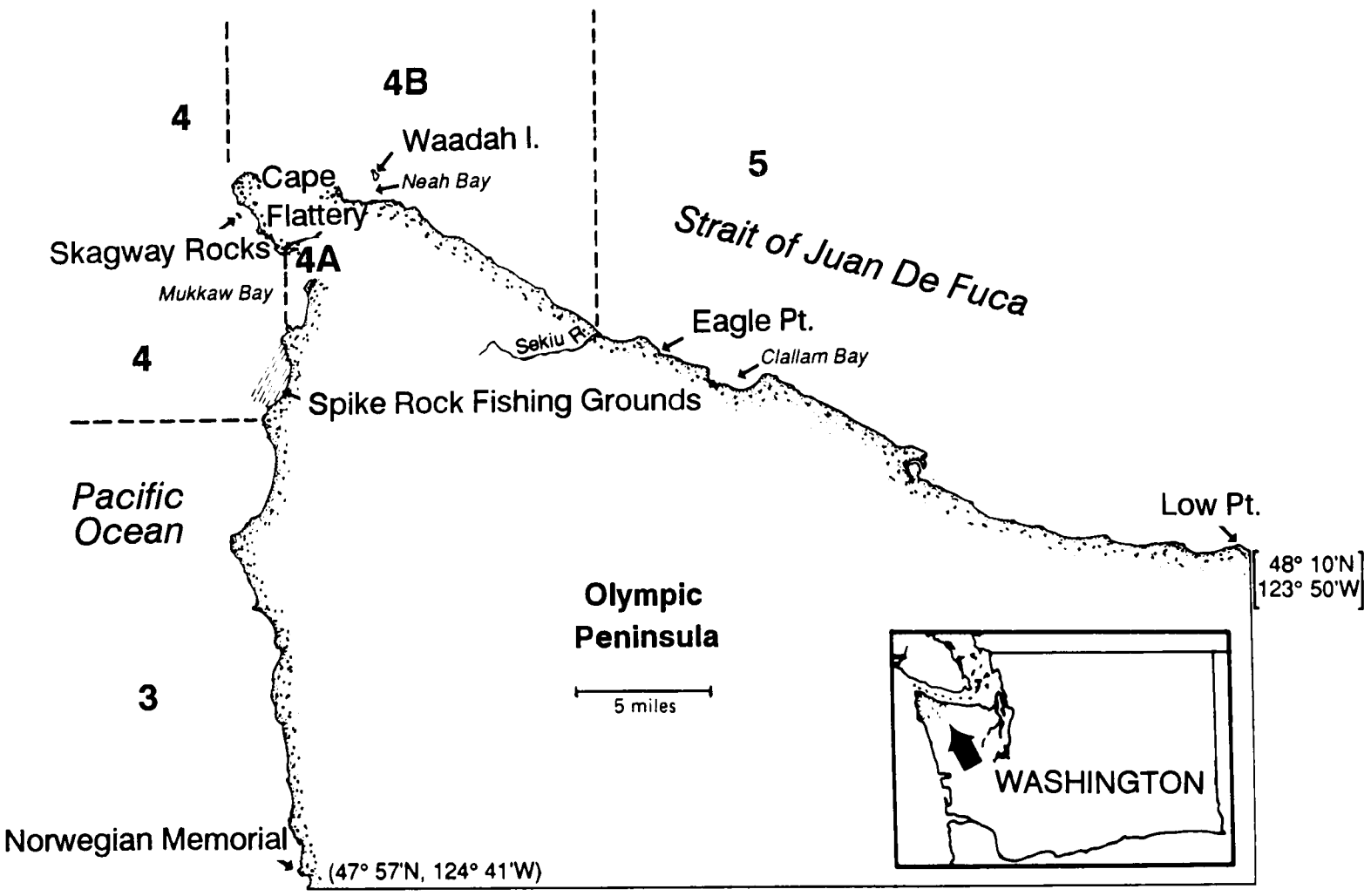

Fig. 1. Location of the Makah tribal Usual and Accustomed fishing grounds and the area of the Makah chinook salmon set-net fishery, showing the Washington Department of Fisheries statistical catch Areas 3, 4, 4A, 4B, 5 and Spike Rock.

calculating the bootstrap estimates, the following assumptions were made: (1) porpoise takes occurred only where observed (at Spike Rock); (2) porpoise takes occurred only in June-August (based on observed takes); and (3) porpoise takes were not necessarily evenly distributed in time (i.e. multiple takes could occur on the same day in the same net).

Life history parameters (collection and necropsy of specimens)

A total of 100 harbor porpoises incidentally caught in the set-net fishery from 1988 to 1990 were collected. Detailed necropsies were performed on all specimens. A brief summary of necropsy procedures is presented here and a more detailed description is provided in Melin *et al.* (1990).

Each animal was weighed, photographed and measured (47 straight line external measurements following Norris, 1961). For porpoises caught in 1988–89, rectal temperatures were taken when the animals were pulled on board the fishing vessels.

Tooth preparation and ageing techniques

Teeth were extracted from the middle of the lower jaw; they were stored in 70% ethyl alcohol for ageing (Gaskin and Blair, 1977; Perrin and Myrick, 1980; Hohn *et al.*, 1989). A growth layer group (GLG) is defined as a repeating or semi-repeating pattern of adjacent groups of incremental growth layers within the dentine or cementum (e.g. IWC, 1980). For the harbor porpoise, one GLG represents one year of age (Gaskin and Blair, 1977). Each tooth was cleaned, weighed and measured. The teeth were decalcified and stained following methods used for *Stenella attenuata* and *Stenella longirostris* (Myrick *et al.*, 1983) with several modifications (Melin *et al.*, 1990). Teeth were mounted on a freezing microtome and sectioned at 15–20 microns. Each tooth was read three times by three independent readers and twice by one reader. The average (modal) age for each tooth was determined for each reader. The ages were compared among readers. When readings did not agree, the tooth was read again by two readers who determined a final age estimate. The ages reported represent the maximum number of completed GLGs. The readings were done with a compound microscope at 40x and 100x magnifications with transmitted light. The cementum was also used as an index of age, but it did not help in determining the actual age estimate.

Reproductive organs

MALES

Both testes were removed, weighed and measured. The epididymis was removed from the left testis and the testis was reweighed. Fluid from each epididymis was examined for sperm. For each sample, the diameter for several seminiferous tubules ($n=10$) was measured in microns and the mean tubule diameter and standard deviation was calculated. Using the histological pattern of seminiferous tubules, four reproductive conditions representing different levels of testis activity were determined, two describing immature and two describing mature males. Reproductive conditions 1 and 2 represent reproductively immature males: (1) testes with very small tubules, no evidence of spermatogenesis and epididymal tubules that appear collapsed; (2) testes with small tubules with early signs of mitosis of the germinal epithelium but no evidence of spermatogenesis. Reproductive conditions 3 and 4 represent reproductively mature males: (3) testes with mitosis of the germinal epithelium, varying degrees of spermatogenesis but empty epididymal tubules and tubule diameters significantly larger than for 1 and 2; (4) testes with large tubules with mitosis of germinal epithelium, spermatogenesis, and spermatozoa within the lumen of the seminiferous tubules and epididymal tubules.

To account for possible differences in tubule diameters or germinal epithlium characteristics due to freezing before sampling for histological examination, specimens that had been frozen prior to histological sectioning and fresh specimens were examined and the results of tubule diameters and characteristics were compared. No differences were apparent and therefore the results were pooled.

FEMALES

Each female was checked for lactation by palpation or incision into the mammary gland before the reproductive tract was removed. The uterus and uterine horns were examined for signs of reproductive activity (i.e. thickened uterine walls, distended horns, embryos) and placed with ovaries attached in 10% buffered formalin. Following their preservation, both ovaries were weighed, measured and serially sectioned. The method of examination followed that of Miller *et al.* (1978).

Females were classified as mature if their ovaries had corpora lutea or corpora albicantia. Females without corpora were classified as immature.

Mature females were categorised as (1) post-partum and lactating (P/L), (2) post-partum and not lactating (P/NL) or (3) pregnant with fetus and colostrum in mammary glands (PR/C).

Stomach contents

Stomachs were examined from 100 harbor porpoises caught in the salmon set-nets during June through August, 1988–90. Ninety-seven porpoises examined were from the Point of the Arches area on the Spike Rock fishing grounds and three were from Skagway Rocks (Fig. 1). Stomachs were excised from porpoises during necropsy and examined. They were weighed with contents intact and then each compartment was examined. The pyloric and main stomach compartments were severed from the forestomach and opened along their length. The forestomach was weighed and each compartment was examined for contents and then rinsed over 3–4 nested metal sieves ranging from 4.75mm to 0.50mm in mesh size. The empty forestomach was then reweighed to obtain the prey content mass. If whole prey were recovered from the stomach, they were counted, weighed and measured. Standard length measurements were taken on whole fish and dorsal mantle lengths (DML) on whole squid. When vertebral columns were intact or partially intact, vertebral columns and vertebral segments were counted to obtain minimum number of prey present. Identification of whole fish prey was based on fish keys (Hart, 1973). Otoliths, fish skeletal remains and squid or squid beaks were identified using the reference collection at the NMML. Three indices of prey importance were used: *percent occurrence* calculated as a percentage of each prey type found in the total number of stomachs that had identifiable prey; *number of prey* determined by counting the fish otoliths, squid beaks, partial fish vertebral columns and whole prey found in the stomachs; and *size of prey*.

The stomachs of 50 chinook salmon caught in the Spike Rock area and in the same nets as harbor porpoises were collected during July 1988. The stomachs were excised,

placed in plastic bags and frozen. They were later thawed and weighed. Contents were then removed and weighed. Identification and measurement techniques of prey were the same as those used for harbor porpoise stomachs. Chinook salmon and harbor porpoise prey were compared by size of prey and percent occurrence.

RESULTS AND DISCUSSION

Observer coverage

Total observer coverage in 1988 was 80.7 ND (about 3.1% of the seasonal fishing effort) of which 76.6 ND were in the Spike Rock area and the remainder were in the Strait of Juan de Fuca (Table 1a). It was limited to one fishing vessel which generally fished six nets set at Spike Rock, and amounted to only 14 days out of the 138-day fishery, 11 of which were from 15–31 July.

Observer coverage for the 1989 fishery was 361.2 ND or 26.9% of the seasonal effort (Table 1b). It was evenly distributed by area except for a lack of coverage in Mukkaw Bay (fishing Area 4A). The most concentrated coverage was in July and August. Four of the eight fishing boats accepted observers for at least one trip during 1989. Observers covered 79 of 199 total chinook salmon landings (39.6%) and no chinook salmon landings were made on 17 of 96 observer trips.

Observer coverage for the 1990 season was 264.1 ND or 47.1% of the seasonal fishing effort (Table 1c). Four of the five fishing boats which operated during the 1990 season had observer coverage. Observers covered 56 of 143 chinook landings (39.1%).

Fishing effort estimates

The majority of Makah fishing effort during 1988–90 was in Area 4 near Spike Rock and Skagway Rocks and in Area 4B in the western portion of the Strait of Juan de Fuca from Clallam Bay to Cape Flattery (Fig. 1, Table 1). The fleet size ranged from 3 to 10. Effort by month and area was quite variable among years. Effort was highest in 1988 with an estimated 2,600 ND fished, compared to 1,342 in 1989 and 560 in 1990 (Table 1). This was due primarily to more effort in the Spike Rock area and the Strait of Juan de Fuca in 1988. Total fishing effort for the Spike Rock area was 1,312 ND in 1988, 241 ND in 1989 and 31.9 ND in 1990, the lower effort in 1989 and 1990 reflecting the scarcity of chinook salmon in the area. In contrast there was more effort in the Skagway Rocks area in 1989 than in 1988. During 1988 and 1990, several fishermen fished as far east as Clallam Bay in the Strait of Juan de Fuca whereas in 1989 the eastern limit was near Eagle Point.

Observed-plus-reported incidental catch

In 1988, 102 harbor porpoises were reported or observed taken (22 were observed by NMFS observers), of which 70 were collected. During 1989, 23 harbor porpoises were reported or observed taken (14 were observed by NMFS observers) of which 17 were collected. During 1990, all 13 harbor porpoises reported or observed incidentally taken were collected.

All but four harbor porpoises taken during the three years were taken in the Spike Rock area; three of those were taken at Skagway Rocks in 1990 and one in the Strait of Juan de Fuca near Waadah Island in July 1989. Thus, a total of 138 harbor porpoises were observed or reported to be taken between 1988 and 1990, of which 100 were collected.

Rate of catch

Table 2 gives estimated incidental catch rates of harbor porpoises at Spike Rock from 1988 to 1990. Although the observed-plus-reported catch varied among years, the combined catch rates were equal for 1988 and 1989. The rate for 1990 was the highest despite having the lowest actual catch. The lower number of total takes in 1989 and 1990 reflects the reduced fishing effort at Spike Rock during those years. During those seasons, few chinook salmon were caught there although the harbor porpoise CPUE was equal to or higher than the 1988 values (Table 2). The catch of harbor porpoises is thus primarily a function of fishing effort.

Table 1

Total and observed ( ) effort* during the Makah salmon set-net fishery (effort recorded in net days fished).

Month	Spike Rock		Skagway		Strait of Juan de Fuca		Mukkaw Bay		Total	
(a) 1988										
May	250	(0)	60	(0)	150	(0)	0	(0)	460	(0)
June	300	(0)	12	(0)	180	(0)	0	(0)	492	(0)
July	383	(71.6)	0	(0)	480	(0)	0	(0)	863	(71.6)
August	339	(5)	0	(0)	406	(4.1)	0	(0)	745	(09.1)
Sept.	40	(0)	0	(0)	0	(0)	0	(0)	40	(0)
Total	1,312	(76.6)	72	(0)	1,216	(4.1)	0	(0)	2,600	(80.7)
(b) 1989										
May	21	(0)	0	(0)	93.75	(0.10)	0	(0)	114.75	(0.10)
June	53	(09.98)	0	(0)	127.50	(6.06)	0	(0)	180.50	(16.04)
July	162	(65.5)	53	(42.2)	321.25	(82.85)	36.25	(0)	572.50	(190.55)
August	5	(04.04)	95	(44.15)	316.25	(106.29)	54.25	(0)	470.50	(154.48)
Sept.	0	(0)	0	(0)	0	(0)	3.75	(0)	3.75	(0)
Total	241	(79.52)	148	(86.35)	858.75	(195.30)	94.25	(0)	1,342.00	(361.17)
(c) 1990										
May	0	(0)	0	(0)	45.6	(0)	0	(0)	45.6	(0)
June	1.0	(0)	13.2	(10.8)	134.6	(52.3)	0	(0)	148.8	(63.1)
July	29.5	(27.7)	11.5	(07.86)	188.4	(101.0)	11.5	(07.89)	240.9	(144.5)
August	1.4	(01.4)	11.5	(06.16)	100.3	(42.8)	11.5	(06.14)	124.7	(56.5)
Total	31.9	(29.1)	36.2	(24.8)	468.9	(196.1)	23	(14.0)	560.0	(264.1)

* 1 net day = one 100 fathom net set for a 24-hour period.

In each season, the June CPUE values were considerably lower than for the other months, suggesting low harbor porpoise abundance in the Spike Rock area during June. Although we have no observer data for this area during May, we suspect that few if any animals are taken then; fishermen did not report any porpoises taken then from 1988–90.

Incidental catch estimates

No harbor porpoises were observed to have been taken during May and thus no estimates were made for that month. The straight ratio estimate of harbor porpoises caught during 1989 was 36.2 animals (Table 3), based on observed rates of take at Spike Rock. No estimate was made for the Strait of Juan de Fuca because observers saw none taken there. The bootstrap estimate for 1989 was 36.3 (SD 12.3) with a 95% confidence interval of 14–60. The estimates from both methods are in close agreement with the observed-plus-reported catch of 23 porpoises in 1989, which is within the range of the 95% confidence interval of 14–60 animals.

Incidental catch of other cetaceans

Two other species of cetaceans were involved in the Makah fishery from 1988–90; a minke whale (*Balaenoptera acutorostrata*) was reported taken at Spike Rock during July 1988 and a gray whale (*Eschrictius robustus*) was observed taken at Skagway Rocks during 1990. Both animals died in the nets.

Porpoise entanglement factors

The Spike Rock area is a shallow, sloping bay with a flat, sandy bottom. The fishable portion of the bay ranges from 6 to 16 fathoms (11–30m) in depth and extends 0.5 to 1 n.mile offshore. Incidental porpoise catches occurred at all depths fished although more were taken in the deeper areas (further offshore) in the Spike Rock area. The mean depth in the locations where porpoises were caught (n=52) was 10.3 fathoms (18.8m). Most porpoises were caught near the bottom or in the lower half of the net; of the 40 for which the location of the animal in the net was accurately determined, 23 (57.5%) were near the lead line, 16 (40%) were near the middle of the net and only one was closer to the surface near the cork line. This suggests that porpoises generally forage along the bottom or in deeper portions of the water column in the Spike Rock area.

All of the porpoises taken appeared to have entered the net head on (perpendicular to net) or at a slight angle. Most porpoises collected had 360° net marks around their heads where they may have been straining against the net and most animals appeared to have twisted after hitting the net, entangling themselves in several layers of web.

In 1988 and 1989, core body temperatures of 17 harbor porpoises were taken. These ranged from 11°-35°C (mean 18.6°C). Of an additional 16 porpoises from which temperatures were not taken but for which a general comment was made, 13 were still warm. The four porpoises taken on 28 July 1988 between 0730 and 2015 hrs were most likely taken after 1200 hrs since core temperatures were 25°, 23°, 35° and 34°C. These body temperatures suggest that at least some porpoises were entangled during daylight hours because many were still warm when the nets were checked in mid-morning or afternoon.

We observed 17 instances when more than one porpoise was entangled in the same net. Animals that were entangled at the same time were usually either females with calves or individuals of the same sex and age category. The greatest number of porpoises caught in a single set of one net was seven in 1988. However, in this case 48 hours had passed since the last check due to adverse weather.

No direct correlation was found between the CPUE of harbor porpoise and chinook salmon from those nets which caught harbor porpoise at the Spike Rock area in 1988 (r=0.277). However, the 1988 Spike Rock CPUE values for nets which caught harbor porpoises were significantly higher than for those which did not catch porpoises but were set on the same day (Mann-Whitney test; $p<0.001$). These results indicate that, although there was no direct correlation between the salmon and porpoise catch, the nets that caught porpoises contained significantly more salmon than those which did not. A probable explanation for these seemingly contradictory findings is that harbor porpoises and chinook salmon are attracted to the same areas where they feed on the same prey (see section on stomach contents).

Table 2

Incidental catch rates of harbor porpoises at Spike Rock during June through August, 1988-90.

Year/ month	No. of porpoise observed plus reported	Effort, net days	Rate of catch
1988			
June	2	300	0.006
July	65	383	0.169
August	35	339	0.103
Total	102	1,020	0.100
1989			
June	1	53	0.018
July	20	162	0.123
August	1	5	0.200
Total	22 *	220	0.100
1990			
June	0	1	0
July	9	29.5	0.305
August	1	1.4	0.714
Total	10	31.9	0.313

* 22 porpoises were observed and reported taken at Spike Rock and 1 was reported taken in the Strait of Juan de Fuca during 1989.

Table 3

Observed and estimated incidental catch of harbor porpoise at Spike Rock, May-August 1989. SR = straight ratio method.

Month	Number observed	Estimated catch SR	Estimated catch Bootstrap (SE)
May	0	0.00	0.00
June	1	5.31	5.3 (4.8)
July	12	29.68	29.7 (11.1)
August	1	1.24	1.3 (1.1)
Total	14	36.23	36.3 (12.3)
95% CI	-	-	14-60

Life history parameters

Sex ratio of specimens collected

Of the 100 harbor porpoises collected during the three seasons, 55 were males and 45 were females. The life history data for these are presented in Tables 4 and 5.

Table 4

Life history data for male harbor porpoises (n=55) taken in the Makah set-net fishery, June 1988 - August 1990. Mean seminiferous tubule diameter is the mean of 10 tubules. Reproductive status is calf (C), immature (I) or mature (M). Reproductive condition is immature with very small tubules (1), immature with evidence of mitosis but no spermatogenesis (2), mature with early spermatogenesis and no sperm in epididymal tubules (3), or mature with active spermatogenesis (4).

Specimen	Date	Total length (cm)	Weight (kg)	Age	Reprod. status	Reprod. condition	Specimen	Date	Total length (cm)	Weight (kg)	Age	Reprod. status	Reprod. condition
PJG081	16/07/88	82.0	9.5	<1	C	C	PJG089	17/07/88	133.9	37.0	2	I	1
PGJ083	16/07/88	86.5	9.5	<1	C	C	PJG096	28/07/88	134.8	47.0	6	M	4
HK09	03/08/88	92.8	13.0	<1	C	C	PJG117	20/06/90	135.5	33.5	2	I	1
HK010	02/08/88	98.0	16.0	<1	C	C	MAJ12	25/07/89	136.0	47.1	2	I	2
RLD959	13/08/88	107.4	27.0	1	I	1	MAJ022	24/06/90	136.1	38.0	2	I	1
PJG092	17/07/88	115.1	33.0	2	I	1	PJG071	14/07/88	136.4	41.5	5	M	4
HK006	03/08/88	115.6	29.5	1	I	1	MAJ18	25/07/89	136.7	42.0	4	M	3
PJG114	08/07/89	115.8	26.2	1	I	1	PJG078	15/07/88	137.7	46.0	3	M	3
PJG104	31/07/88	117.7	37.0	1	I	1	PJG088	16/07/88	139.4	43.0	3	I	2
PJG085	16/07/88	120.4	31.0	1	I	1	PJG108	07/06/89	140.0	48.0	5	I	1
PJG099	28/07/88	120.5	31.0	1	I	1	PJG091	17/07/88	140.5	52.0	5	M	4
PJG111	05/07/89	120.7	29.9	1	I	1	MEG006	02/08/90	140.7	44.5	5	M	4
PJG107	22/08/88	121.7	31.0	1	I	1	RLD960	13/08/88	141.5	44.0	5	M	4
PJG115	17/07/89	123.4	28.5	1	I	1	HK014	09/08/88	142.0	44.5	4	M	4
RLD958	13/08/88	124.0	39.0	1	I	1	PJG094	25/07/88	142.1	61.0	5	M	4
PJG119	22/07/90	124.2	33.7	1	I	1	HK015	10/08/88	144.0	45.0	5	M	4
PJG093	19/07/88	124.3	31.0	2	I	1	HK003	03/08/88	144.6	52.0	5	M	4
MAJ6	10/07/89	125.2	35.3	1	I	1	HK007	03/08/88	144.9	48.0	8	M	4
PJG070	14/07/88	125.6	34.0	1	I	1	RLD955	13/08/88	146.0	48.0	5	M	4
PJG087	16/07/88	126.4	32.0	1	I	1	PJG102	29/07/88	147.0	52.0	6	M	4
PJG100	28/07/88	126.7	31.0	1	I	1	PJG086	16/07/88	147.1	52.0	7	M	4
PJG109	05/07/89	128.0	36.7	2	I	1	HK016	10/08/88	147.5	50.0	7	M	4
HK020	09/08/88	128.5	35.0	1	I	1	PJG110	05/07/89	148.3	52.7	6	M	3
MAJ021	24/06/90	129.1	32.0	2	I	1	PJG106	19/08/88	148.5	44.0	4	M	3
PJG076	15/07/88	131.8	35.0	3	M	3	HK013	06/08/88	149.0	54.0	7	M	4
HK017	09/08/88	132.1	39.0	2	I	1	HK021	09/08/88	149.8	53.0	5	M	4
PJG105	31/07/88	133.2	48.0	8	M	4	HK004	03/08/88	155.4	55.0	8	M	4
HK002	03/08/88	133.5	39.5	3	I	1							

Table 5

Life history data for female harbor porpoises (n=45) taken in the Makah set-net fishery, June 1988-August 1990. For follicle diameter and corpora diameter, --- indicates not present. Reproductive status is immature (I) or mature (M). Reproductive condition is post-partum (P), pregnant (PR), lactating (L), not lactating (NL) and colostrum (C).

Specimen	Date	Total length (cm)	Weight (kg)	Age	Reprod. status	Reprod. condition	Specimen	Date	Total length (cm)	Weight (kg)	Age	Reprod. status	Reprod. condition
MAJ8	10/07/89	115.2	26.7	1	I	-----	MEG005	28/07/90	148.0	48.4	2	I	-----
PJG066	29/06/88	116.0	29.0	1	I	-----	MEG004	28/07/90	148.5	50.1	3	-	-----
PJG112	08/07/89	117.9	25.8	1	I	-----	PJG065	23/06/88	149.0	50.0	3	I	-----
HK018	09/08/88	119.5	36.0	2	I	-----	PJG074	15/07/88	149.2	50.0	2	I	-----
HK001	03/08/88	120.8	24.0	1	I	-----	PJG075	15/07/88	149.7	43.0	3	I	-----
RLD956	13/08/88	122.6	34.0	1	I	-----	HK012	06/08/88	152.0	49.0	3	I	-----
PJG118	07/03/90	124.0	30.0	1	I	-----	PJG077	15/07/88	152.3	59.0	3	I	-----
PJG090	17/07/88	125.9	38.0	1	I	-----	PJG103	30/07/88	152.4	49.5	3	I	-----
HK019	09/08/88	126.5	36.5	1	I	-----	PJG101	29/07/88	152.9	53.0	3	I	-----
MEG003	10/07/90	127.4	-----	1	I	-----	PJG079	15/07/88	154.8	70.0	4	M	PR/C
HK011	06/08/88	127.5	40.0	1	I	-----	PJG121	23/07/90	156.5	50.5	3	M	P/L
PJG069	08/07/88	128.0	37.0	1	I	-----	PJG097	28/07/88	157.8	62.0	3	M	P/L
PJG113	08/07/89	130.3	35.0	1	I	-----	PJG116	17/07/89	158.4	52.2	3	M	P/NL
RLD957	13/08/88	130.4	32.0	1	I	-----	HK005	03/08/88	159.5	60.0	4	M	P/NL
MAJ16	25/07/89	132.6	34.9	2	I	-----	PJG120	22/07/90	160.8	70.2	4	M	P/L
PJG072	14/07/88	135.7	40.5	2	I	-----	PJG080	16/07/88	161.0	-----	4	M	P/L
MAJ20	02/08/89	136.0	36.6	1	I	-----	MAJ17	20/07/89	161.4	56.6	4	M	P/NL
PG082	16/07/88	137.2	42.0	1	I	-----	PJG098	28/07/88	163.0	54.0	3	M	P/NL
PJG073	14/07/88	139.6	46.0	2	I	-----	MEG001	10/07/90	168.2	60.0	4	M	P/L
MAJ7	10/07/89	140.0	34.4	2	I	-----	HK008	03/08/88	170.4	63.0	5	M	P/L
MEG002	10/07/90	140.9	35.0	1	I	-----	PJG084	16/07/88	177.5	86.5	5	M	P/L
PJG067	06/07/88	142.0	49.0	4	I	-----	PJG095	25/07/88	177.7	77.0	5	M	P/L
PJG068	07/07/88	143.0	45.0	3	I	-----							

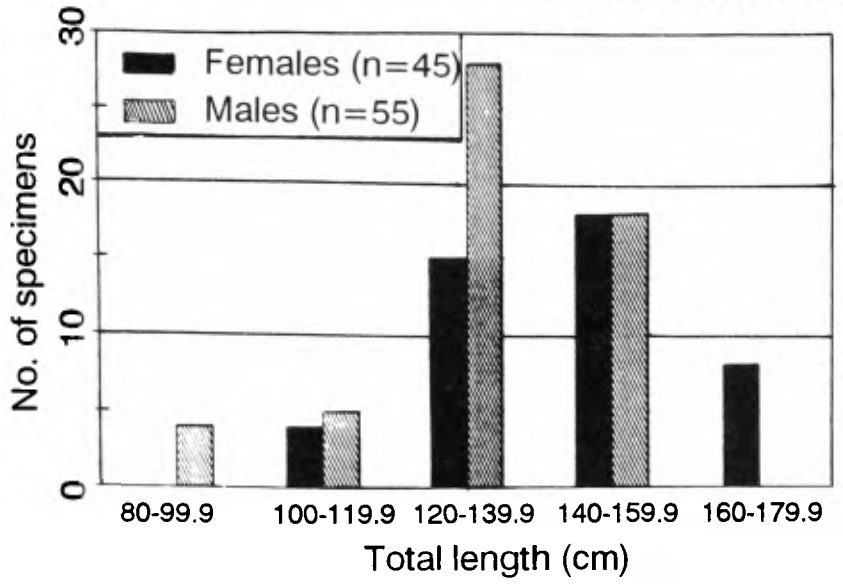

Fig. 2. Length distribution for female and male harbor porpoises collected during 1988–90.

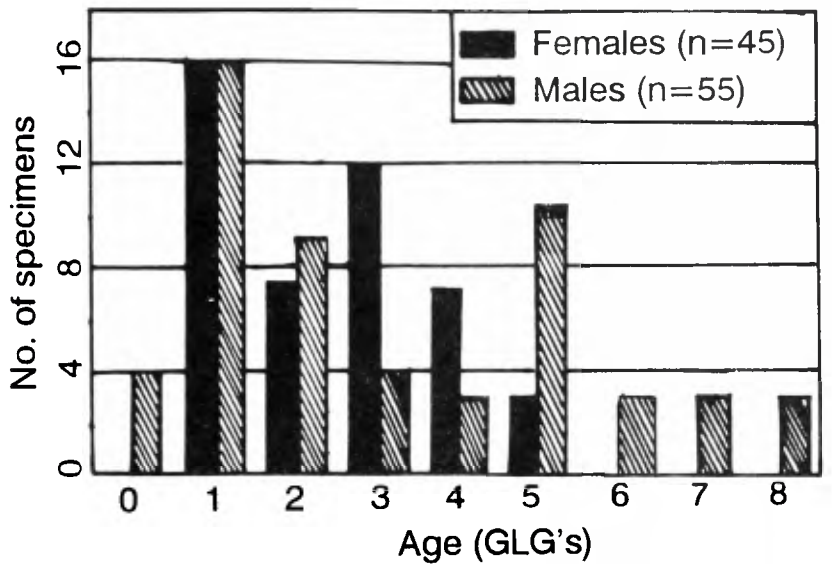

Fig. 3. Age distribution of female and male harbor porpoises collected during 1988–90.

Size and age of porpoises

The analyses of the mean length and weight distributions of sexually mature animals (Table 6, Fig. 2) showed that females were significantly longer and heavier than males (Mann-Whitney, $p<0.001$). Mature males had mean values of 143.0cm and 48.3kg while mature females had mean values of 163.6cm and 63.5kg (Table 6). Size dimorphism has been reported for other harbor porpoise populations (Möhl-Hansen, 1954; van Utrecht, 1978; Stuart, 1980; Gaskin *et al.*, 1984).

A large proportion of both sexes (48%) caught during 1988–90 were one and two year old animals (Fig. 3). There were more three year old females than males and no females over five years old. The absence of females over five years old may reflect a biassed sample given the small geographic area. Males ranged from newborn to eight years old, with 16% of the males being over five years old.

Table 6

Mean total lengths, body weights and ranges for 99 harbor porpoise collected from the Makah set-net fishery, July 1988-August 1990.

Reproductive class	n	Mean total length (cm)	Range (cm)	Mean body weight (kg)	Range (kg)
Immature females	31	134.9	115.2-152.9	39.9	24.0-59.0
Immature males	28	125.9	107.4-140.0	34.6	26.2-48.0
Mature females	13	163.6	154.8-177.7	63.5	50.5-86.5
Mature males	23	143.0	131.8-155.4	48.3	35.0-61.0
Calves	4	89.8	82.0-98.0	12.0	9.5-16.0

Gaskin and Blair (1977) and Read (1990a) reported the maximum age of porpoises in the Bay of Fundy at 10–13 years but suggested that most do not live beyond 7–8 years. Stuart (1980) reported a maximum age of 10 years in porpoises from the northeastern Pacific Ocean.

Reproductive condition

MALES

Four male calves were taken in the fishery in July and August. The mean total body length of calves (Table 6) was 89.8cm (SD=7.0cm). The mean seminiferous tubule diameters for three calves was 55.5μm (SD=15.79μm) and the mean paired testes weight was 12.6g (SD=6.3g).

Twenty-eight of 51 (54.9%) males (excluding calves) were immature and occurred in the fishery area throughout the collection period (Table 4). Immature males were 140cm or less in total body length (mean=125.9cm, SD=7.5cm) and were 5 years old or younger (Table 4). The mean seminiferous tubule diameter for immature males (reproductive classes 1 and 2) was 51.0μm (SD=14.9μm). This is similar to the results for mean tubule diameter for immature males in the Bay of Fundy (mean=48.0μm) (Gaskin *et al.*, 1984). The mean for paired testes weights was 142.7g (SD=237.9g).

Twenty-three males were mature (45.1%) and were present in the fishery area from 5 July through 19 August. Mature males (reproductive classes 3 and 4) were 3 years of age with a mean total body length of 143.0cm (SD=5.8cm) (Table 4). The mean seminiferous tubule diameter was 185.9μm (SD=31.4μm) and the mean of paired testes weights was 1742.1g (SD=1103.9g). The mean of the seminiferous tubule diameters for mature males in this study is greater than that reported for mature males in the Bay of Fundy population (mean=124.2μm) (Gaskin *et al.*, 1984). The differences in the range and mean tubule diameters are probably a reflection of individual variability but may also be due to the time of collection of each of the samples from the two populations relative to the reproductive cycle of animals in each population.

The seminiferous tubule diameter was significantly different for immature and mature males and increased with age (ANOVA $F=112.7$, $p<0.001$); Fig. 4). Based on

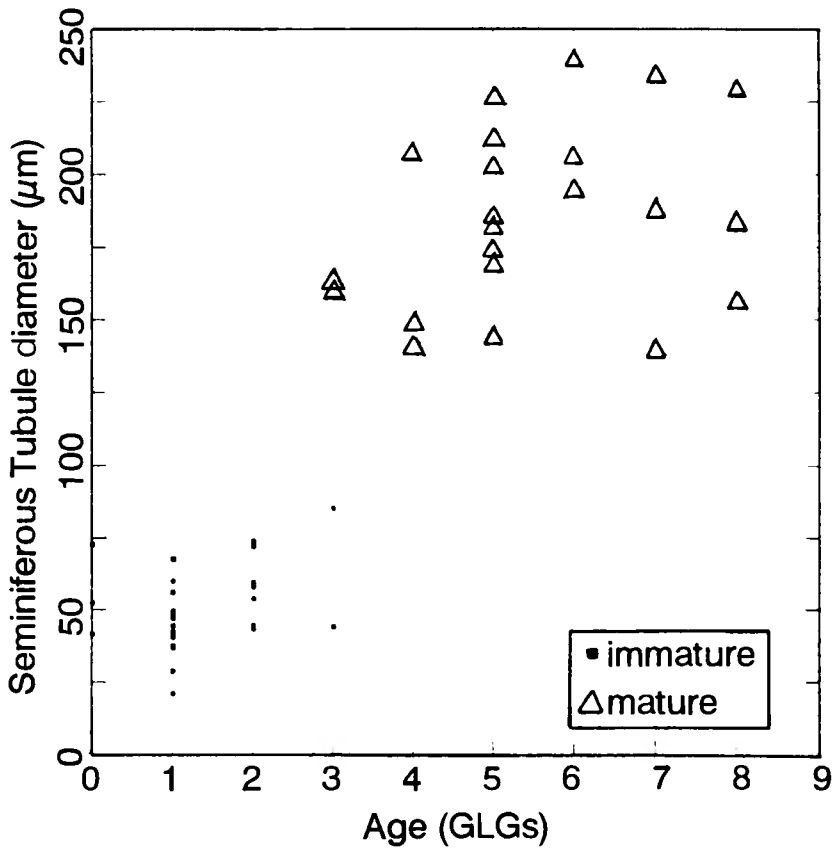

Fig. 4. Seminiferous tubule diameter versus age for male harbor porpoises collected during 1988–90.

histological evidence from the seminiferous tubules, the average age at attainment of sexual maturity was 3.5 years for this sample (DeMaster, 1978).

These values are similar to those estimated for the Bay of Fundy (Fisher and Harrison, 1970; Gaskin *et al.*, 1984; Read, 1990b) but the age is lower than that (5yrs) reported for porpoises from the North Sea (van Utrecht, 1978) and higher than that for animals in Danish waters (3yrs) reported by Clausen and Andersen (1988).

FEMALES

Immature females occurred in the fishery area from June through late August (Table 5). Thirty-one of 44 females (70.5%) (ovaries from one female were not collected) collected were reproductively immature (Table 5). Immature females were 4 years old or younger (Table 7) with a mean total body length of 134.9cm (SD=11.5cm).

Thirteen females were reproductively mature (29.5%) (Table 5). Mature females were 3 years old or older (Table 7) with a mean total body length of 163.6cm (SD=7.3cm). Eight of the mature females had recently given birth and were lactating and four females had recently given birth but were not lactating (Table 5). One female was pregnant with a full term fetus and producing colostrum.

The age at attainment of sexual maturity was 3.9 years for females in this sample (DeMaster, 1978).

Gaskin *et al.* (1984) and Fisher and Harrison (1970) found similar results for porpoises in the Bay of Fundy. Whereas van Utrecht (1978) reported 6 years (about 150cm) for North Sea females and Clausen and Andersen (1988) reported 3 years (140cm) for porpoises in Danish waters.

Although the sample size is small, 9 of the 13 sexually mature females had calves in the year of collection (based on presence of corpora lutea and lactation) yielding an estimated calving rate of 0.85 (calving rate = pregnancy rate).

Table 7

Occurrence of corpora (combined number of corpora lutea or corpora albicantia) in female harbor porpoise by age collected June 1988 - August 1990.

		Number of corpora					
Age	*n*	0	1	2	3	4	5
1	16	16	-	-	-	-	-
2	7	7	-	-	-	-	-
3	10	7	1	-	1	-	1
4	8	1	3	2	2	-	-
5	3	-	-	1	-	-	2

Stomach contents analysis

Of the 100 harbor porpoise stomachs collected in 1988–90, 94 contained identifiable prey, including four from calves that contained milk. The latter are excluded from the subsequent analyses. Although all compartments of each stomach were examined, only traces of bone or fish eye lenses were found in the main or pyloric compartments. Most food remains were found in the forestomachs (hereafter referred to as stomachs). Twenty-seven stomachs contained only trace amounts (less than 5.0g) of prey remains such as fish vertebrae, scales, eye lenses, otoliths or squid beaks. Three stomachs were completely empty.

Table 8

List of prey identified in harbor porpoise stomachs (n=96) from the 1988-90 Makah salmon set-net fishery.

Family or class	Common name	Scientific name
Clupeidae	Pacific herring	*Clupea harengus pallasi*
Osmeridae	Longfin smelt	*Spirinchus thaleichthys*
	Rainbow smelt	*Osmerus mordax*
	Capelin	*Mallotus villosus*
Gadidae	Pacific tomcod	*Microgadus proximus*
	Pacific hake	*Merluccius productus*
Salmonidae	Coho salmon	*Oncorhynchus kisutch*
Embiotocidae	Pile surfperch	*Damalichthys vacca*
Scorpaenidae	Yellowtail rockfish	*Sebastes flavidus*
Loliginidae	Market squid	*Loligo opalescens*
Crustacea	Shrimp	*Crangon alba*
	Isopoda	*Tecticeps pugettensis*

Prey identified

There is little published information on the food habits and foraging behaviour of harbor porpoises in the coastal waters of Washington State. Wilke and Kenyon (1952) reported a harbor porpoise collected near Port Townsend that had the remains of five Pacific herring (*Clupea harengus pallasi*) in its stomach. Scheffer (1953) examined the stomach of a stranded harbor porpoise (Twin Harbor Beach, WA) which contained 37 capelin (*Mallotus villosus*) and had suffocated due to a shad (*Alosa sapidissima*) lodged in its throat. Another harbor porpoise choked by a shad had been found dead on the same beach five years earlier (Scheffer and Slipp, 1948). Beach *et al.* (1985) reported the stomach contents of 10 harbor porpoise found dead on beaches near the Columbia River. Prey, including nine species of bony fishes and market squid (*Loligo opalescens*), was found in seven of the stomachs. One stomach also contained the remains of salmon. In our study (Table 8), six families and at least 9 species of bony fishes were identified from the stomachs as well as one species each of cephalopod (market squid), shrimp (*Crangon alba*) and isopods (*Tecticeps pugettensis*).

Percent occurrence (Table 9)

The dominant prey species for all years combined in order of percent occurrence were Pacific herring, smelt (Family Osmeridae), market squid, gadids and shrimp; Coho salmon (*Oncorhynchus kisutch*), rockfish (Family Scorpaenidae), surfperch (Family Embiotocidae) and isopods occurred in one stomach each. Some differences between years were apparent although the sample size was smaller in 1989–90 (Fig. 5). During 1988, Pacific herring was the dominant prey identified (78.7% of the stomachs) followed by market squid (37.7%) and smelt (32.8%) – whereas in 1989, smelt predominated (76.4%) followed by squid and gadids (64.7% each) and Pacific herring (52.9%). In 1990, Pacific herring was again the number one ranked prey (75.0%) followed by smelt (41.6%) and gadids (33.3%).

Number of prey (Table 10)

The 1988 stomachs contained 845 otoliths and 195 squid beaks. Smelt otoliths accounted for 57% of the total otoliths, followed by Pacific herring otoliths (32%) and gadids (10%). Of the 195 squid beaks recovered, 100 were upper beaks indicating that at least 100 individuals were represented.

Table 9

Percent occurrence of prey found in harbor porpoise stomachs collected from the Makah salmon set-net fishery, 1988 (n=61); 1989 (n=17) and 1990 (n=12).

	1988		1989		1990		Total	
Prey	No.	%	No.	%	No.	%	No.	%
Pacific herring	48	78.7	9	52.9	9	75.0	66	73.3
Osmeridae	20	32.8	13	76.4	5	41.6	38	42.2
Market squid	23	37.7	11	64.7	2	16.6	36	40.0
Gadidae	13	19.7	11	64.7	4	33.3	28	31.3
Shrimp	3	4.9	3	17.6	1	8.3	7	7.7
Coho salmon	1	1.6	0	0	0	0	1	1.1
Pile surfperch	1	1.6	0	0	0	0	1	1.1
Yellowtail rockfish	1	1.6	0	0	0	0	1	1.1
Isopoda	0	0	1	5.9	0	0	1	1.1

Table 10

Otoliths and squid beaks recovered from harbor porpoise stomachs collected during the 1988 Makah salmon set-net fishery 1988-90.

	1988		1989		1990	
Prey	No. of beaks or otoliths	%	No. of beaks or otoliths	%	No. of beaks or otoliths	%
Osmeridae	482	57.04	643	59.98	45	28.90
Pacific herring	269	31.83	40	3.73	86	55.10
Gadidae	88	10.41	389	36.29	25	16.00
Embiotocidae	3	0.36	0	0	0	0
Scorpaenidae	2	0.24	0	0	0	0
Salmonidae	1	0.12	0	0	0	0
Market squid	195 [1]		63 [2]		5 [3]	
Total	845	100.00	1,072	100.00	156	100.00

[1] 100 upper and 95 lower squid beaks were recovered. [2] 32 upper and 31 lower beaks were recovered. [3] 3 upper and 2 lower beaks were recovered.

During 1989, 1,072 otoliths were recovered of which Osmeridae accounted for 59.9% and Gadidae 36.2%. During 1990, 156 otoliths were recovered of which 55% were Pacific herring, 28.9% osmerids and 16% gadids.

For all years combined, fresh (with flesh still intact) or whole prey were recovered from 66 out of 96 stomachs (68.7%). Whole fish remains were recovered in 56 stomachs and whole squid in 22 stomachs. Eighteen stomachs contained both fish and squid. Pacific herring was the dominant prey numerically (203 were represented by the anatomical parts recovered) followed by smelt (135) and squid (54).

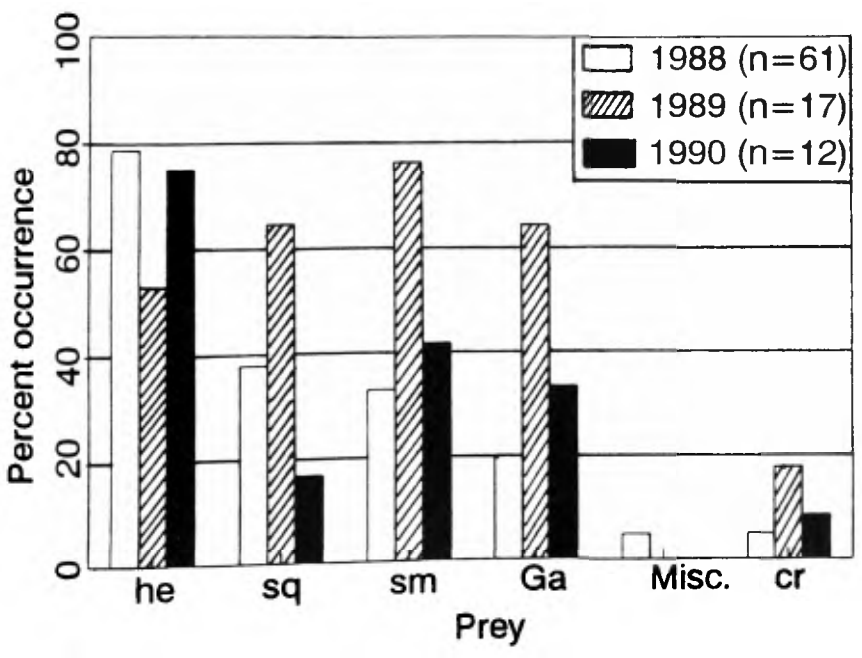

Fig. 5. Percent occurrence of major prey identified from harbor porpoise stomachs during 1988–90.

Size of prey

Harbor porpoises are known to feed on smaller, soft-bodied prey and rarely consume prey larger than 35cm in length (Rae, 1965; Jones, 1981; Recchia and Read, 1988).

The mean length of Pacific herring (n=15) found in porpoise stomachs in our study was 15.8cm (range 12–18cm). This length corresponds to juvenile herring in the 2–3 year old year classes with weights of approximately 70g apiece (Hart, 1973). The mean length of smelt (n=21) was 8.8cm (range 6–10.5cm) and based on otolith size, most appeared to be juveniles. The mean DML of market squid (n=28) was 8.53cm (range 6–10cm) and the mean mass was 8.97g (range 4–12g). Market squid of this size are juveniles of ages 6–15 months, with most probably 12 months old (Hixon, 1983). The size of a single coho salmon found in one stomach was an estimated 30–40cm long and probably a juvenile of about 1kg based on the sizes of the vertebrae and otolith. Most harbor porpoises appeared to be feeding on juvenile gadids as estimated by the relative size of the otoliths when compared to otoliths from known length fish from the NMML reference collection. Some gadid otoliths were minute (1mm or less in length) which would probably be from very young or even larval fish.

Sex and age differences

No major differences were found in stomach contents between males and females in terms of percent occurrence or numbers of prey consumed. Recchia and Read (1988) reported that pregnant or lactating harbor porpoises feed on the same prey but had a higher mass of contents in their stomachs than males or subadult animals. Our sample

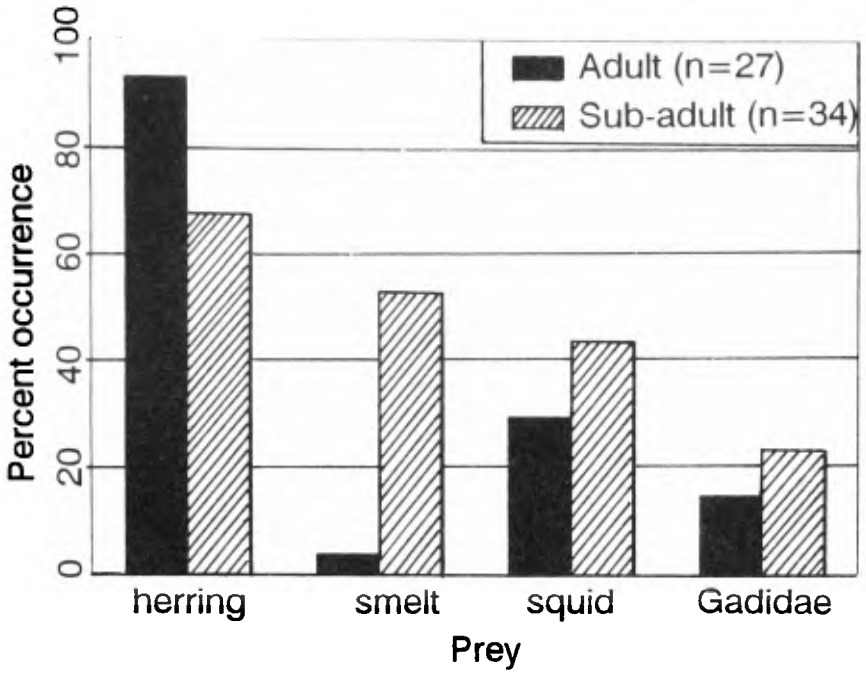

Fig. 6. Percent occurrence of major prey identified from adult and subadult harbor porpoise stomachs during 1988.

contained few lactating or pregnant females. However, one lactating female we examined had the largest mass of stomach contents (1,000g) and was the only individual which fed on salmon.

There were major differences in prey consumed by adults and subadults (reproductively mature vs. immature). Adult porpoises fed primarily on Pacific herring, with very few feeding on smelt (Fig. 6). Subadult porpoises fed on Pacific herring and over 60% fed on smelt. The numbers of fish otoliths and squid beaks recovered in porpoise stomachs were compared between adult and subadult porpoises during the 1988 season. Adult porpoises had significantly more Pacific herring otoliths in their stomachs than subadults (two sample t-test $p=0.052$) and significantly fewer smelt otoliths (two sample t-test $p=0.002$). There were no significant differences in the numbers of gadids consumed by adults and subadults based on otolith counts (t-test $p=0.44$). Subadult porpoise stomachs also contained significantly more squid beaks than adults (twosample t-test $p=0.023$).

Salmon stomachs

Information on the diet of adult chinook salmon from the northwest coast of Washington is scarce. However, northern anchovy (*Engraulis mordax*), Pacific herring, crab (*Cancer* sp.) and market squid have been recorded (Brodeur *et al.*, 1987). In British Columbia, Hart (1973) reported that they feed on Pacific herring, Pacific sand lance (*Ammodytes hexapterus*), pilchard (*Sardinops sagax*) and rockfish (Family Scorpaeniade).

Six of the 50 stomachs examined in this study were empty and the remainder contained identifiable prey. Pacific herring was the dominant prey of chinook salmon (found in 93.1% of the stomachs) followed by smelt (18.1%) and market squid (12.5%). No other prey were recovered. Numerically, herring were represented by 89 whole or partial fish followed by 23 smelt and 19 market squid.

Prey comparison

The prey taken by harbor porpoises and chinook salmon were compared using percent occurrence and the relative size of the prey consumed (Fig. 7). The three major prey items for both predators were Pacific herring, market squid and smelt. Pacific herring was the dominant prey for both species during the 1988 season, although it was found in a

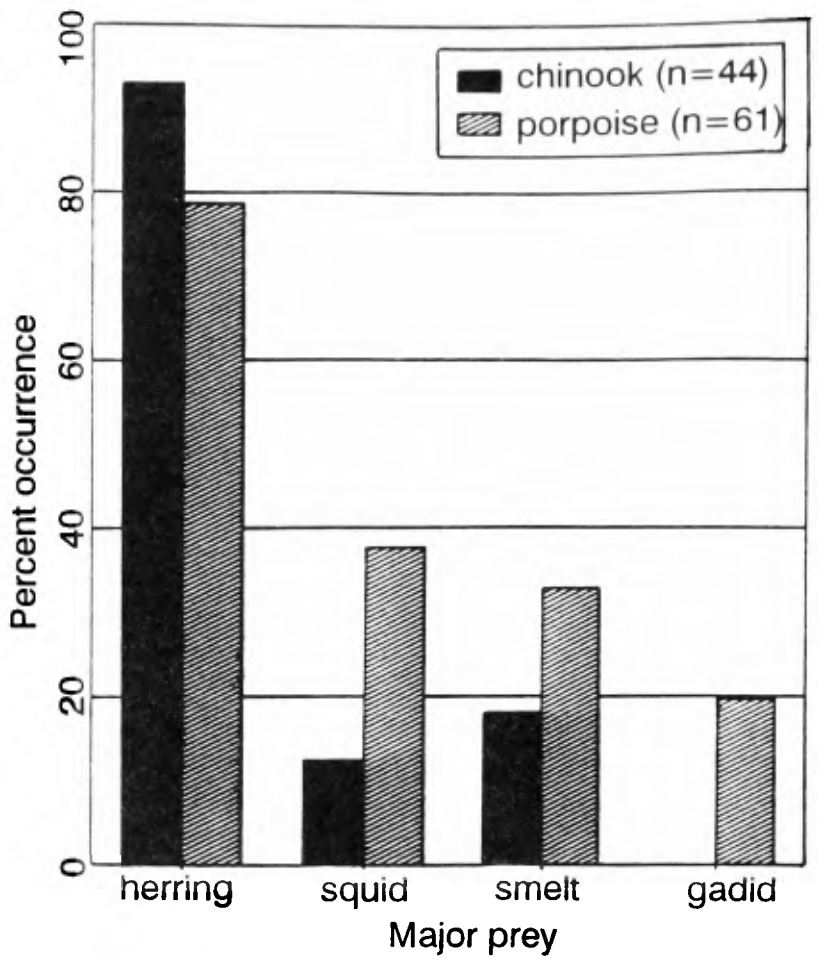

Fig. 7. Percent occurrence of major prey identified from harbor porpoise and chinook salmon stomachs during 1988.

greater percentage of chinook stomachs. Market squid and smelt were the second and third most prevalent prey in porpoise stomachs whereas the reverse was true for chinook salmon. Chinook salmon fed on significantly larger herring than did porpoises (Mann Whitney test $P < 0.00001$). The mean lengths of herring consumed were 20.8cm ($n=19$, range 19–23cm) for salmon and 15.86cm ($n=15$, range 12–18cm) for porpoises. Pacific herring of lengths between 19 and 23cm are adult fish 4–8 years old that weigh 85–183g (Hart, 1973). No chinook salmon stomachs were collected from the Spike Rock area in 1989; however, the several hundred chinook salmon stomachs examined from the Skagway Rocks area in 1989 contained primarily Pacific sand lance with few containing Pacific herring.

Measures to reduce porpoise catches

Individual fishermen took steps to reduce the level of incidental take of harbor porpoises during 1989 and 1990, primarily by reducing fishing effort in the Spike Rock area during July and August, the period of the highest rates of porpoise catches (Table 2). Effort was reduced by setting fewer nets and by decreasing the number of days the nets were in the water. Several nets were set for several days at a time at Spike Rock as indicator nets to see if chinook salmon were present. If only a few chinook salmon were caught, the nets were pulled out. After 1–2 weeks, the indicator nets were again set. By contrast in 1988 and previous years, nets were often left in place for several months at a time. During the 1988 fishing season, as many as 12 nets were in place at one time in the Spike Rock area, while only four nets were set in 1989 and two in 1990.

During 1990 fishermen also attempted to reduce the bycatch by setting nets in areas that had been low catch areas in previous years, i.e. in the southern inshore areas of the Spike Rock grounds. The effectiveness of this is questionable since the rates of porpoise catch were higher in 1990 than in 1988 or 1989.

Part of the reason for reduced fishing effort at Spike Rock during 1989–90 was related to low numbers of chinook salmon in the area. Fishing effort probably would have been greater in this area had chinook salmon been abundant.

CONCLUSIONS

The observations of the Makah salmon set-net fishery from 1988–90 demonstrate that the interactions between harbor porpoise and the fishery are limited to a small area and time span. Harbor porpoises were taken almost exclusively (97%, $n=138$) at the Spike Rock fishing grounds, which is a small fraction of the overall Makah set-net fishing grounds (Fig. 1). Similarly most (80%, $n=138$) of the porpoises taken from 1988–90 were caught between 14 July and 13 August. No harbor porpoises were reported or observed taken during May and only six were taken during June, despite the presence of nets set at Spike Rock during May and June of 1988 and 1989.

The low fishing effort at Spike Rock during 1989 and 1990 was partially a result of low numbers of chinook salmon in the area.

Both harbor porpoises and chinook salmon were actively foraging in the Spike Rock area and feeding on similar prey, although harbor porpoises appear to have a more diverse prey base. For both predators, Pacific herring was the principle prey species, although the salmon fed on significantly larger individuals. The results suggest that the reason for chinook salmon and harbor porpoises frequenting the Spike Rock area was correlated with prey availability, leaving both species susceptible to entanglement in gillnets.

The potential impact of the Makah set-net fishery on the regional harbor porpoise population is difficult to assess because little is known about the size, movements and discreteness of the population. If the animals in northern Washington coastal waters (estimated at about 900 individuals; Calambokidis et al., 1992) are viewed as a discrete group with little or no immigration, then the reported incidental catches for 1988–90 (102, 23, and 13) represent between 1.4% to 11.3% of the population. If the harbor porpoises in northern waters are part of a freely mixing population incorporating the entire Washington coast and the Swiftsure Bank area of Canada, the incidental catches would represent between 0.01% and 1.1% of the population estimate of about 13,000 (Calambokidis *et al.*, 1992).

A further factor to be considered in assessing the impact of incidental catches is that 63% of the mortality involved immature animals. In the short term this might suggest that the mortality will have less impact than if most or all of the mortality involved mature animals (e.g. see Chapman, 1987), but it has the potential of affecting future recruitment rates and thus remains a cause for concern. This is particulary true given the reproductive capacity of harbour porpoises. Most females give birth annually and only bear 4–5 calves in their lifetime (Gaskin *et al.*, 1984; Read, 1990a). Their apparently short life span limits reproductive flexibility, particularly with respect to any density-dependent response to high levels of mortality (Kasuya, 1976; 1985), further accentuating the need to resolve interactions.

It is clear that future research should concentrate on the refinement of population estimates and the delineation of boundaries of local populations (should they exist) or a demonstration of the continuity of harbor porpoise stocks along the Washington coast.

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A Note on Odontocete Mortality from Fishing Gear Entanglements off Southern California

John E. Heyning and Thomas D. Lewis

Section of Birds and Mammals, Natural History Museum of Los Angeles County, 900 Exposition Blvd., Los Angeles, CA 90007, USA

and

Charles D. Woodhouse

Section of Vertebrate Zoology, Santa Barbara Museum of Natural History, 2559 Puesta del Sol Road, Santa Barbara, CA 93105, USA

ABSTRACT

Strandings and sightings data of toothed whales entangled in fishing gear are documented for the Southern California Bight from 1975–90. Entanglements involve three fisheries: a nearshore set gillnet fishery; an offshore drift gillnet fishery; and a purse seine fishery for squid. Common dolphins were the most frequently entangled species south of Point Conception and harbor porpoises north of this point. For common dolphins, the majority of records were from the long-beaked species. Pilot whales were the most frequently documented takes prior to the 1982–83 El Niño event. Records of entanglement for other species include white-sided dolphins, Risso's dolphins and bottlenose dolphins with single records each for a killer whale, Cuvier's beaked whale and Hubb's beaked whale.

KEYWORDS: INCIDENTAL CAPTURE; NORTH PACIFIC; HARBOR PORPOISE; COMMON DOLPHINS; WHITE-SIDED DOLPHINS; RISSO'S DOLPHINS; BOTTLENOSE DOLPHINS; KILLER WHALE; CUVIER'S BEAKED WHALE; HUBB'S BEAKED WHALE; PILOT WHALE-LONG FINNED

INTRODUCTION

Twenty one species of odontocetes have been recorded off the coast of southern California (Leatherwood *et al.*, 1988). Although entanglements of baleen whales in fishing gear in this region have been summarised (Heyning and Lewis, 1990), there are few accounts documenting incidental kills of odontocetes (Norris and Prescott, 1961; Seagers and Henderson, 1985; Heyning, 1988; Bodkin and Jameson, 1991; Sinclair, 1992). In this report we summarise such data in order to determine which populations of odontocetes might be affected. Interactions in this region primarily involve three fisheries: the nearshore set gillnet fishery for sea bass and halibut; the offshore drift gillnet fishery for swordfish and shark; and the purse seine fishery for squid.

MATERIALS AND METHODS

Data on mortalities of toothed whales resulting from entanglement in fishing gear were gathered for southern California waters from the northern border of San Luis Obispo County to the Mexican border for the years 1975–90, inclusive. The data were obtained primarily from examinations of dead, stranded animals; only a few specimens were retrieved directly from nets. Specimens were normally included only if they bore direct marks such as net lacerations, knife cuts, or severed appendages (Hare and Mead, 1987) although some specimens were included if strong circumstantial evidence was present, such as apparently healthy animals whose stomachs were full of recently consumed food. Often several such animals in this condition were found dead within a small area over a short period of time. Common dolphin specimens were categorised into the long-beaked species (*Delphinus capensis*) (synonymous with *Delphinus bairdii*) and the short-beaked species (*Delphinus delphis*) based on the pigmentation and cranial criteria (Banks and Brownell, 1969; Evans, 1975, Evans, 1982; Heyning and Perrin, 1994).

RESULTS

We documented 69 fishery-related takes of odontocetes during the study period (Table 1). Of these, 44.9% (n=31) were of common dolphins (*Delphinus* spp.) with no detectable sex bias (15 males, 14 females). Sixteen specimens examined for reproductive condition included equal numbers of sexually mature and immature animals. Of the specimens identified to species, 19 were *D. capensis* and two were *D. delphis*.

Pilot whales (*Globicephala macrorhynchus*) were the next most frequently involved species (n=14) representing 20.3% of the total sample. With one exception, all takes of pilot whales occurred in 1980 or prior to this (Fig. 1).

Harbor porpoise (*Phocoena phocoena*) were the most frequently documented species killed in fishery operations north of Point Conception with 10 records. Most of the entangled harbor porpoises (8 of 9) were sexually immature.

Of the remaining records, bottlenose (*Tursiops truncatus*) and Risso's dolphins (*Grampus griseus*) were each represented by four records, white-sided dolphins (*Lagenorhynchus obliquidens*) by three records, and killer (*Orcinus orca*) and two species of beaked whales (*Mesoplodon carlhubbsi* and *Ziphius cavirostris*) each by single records. Records of fishery-related kills were lower in the summer months (Fig. 2).

Table 1

Records of odontocetes found dead due to interactions with fisheries in southern Californian waters. Entries followed by an 'E' indicate an estimated length. The long-beaked species of common dolphins are noted as *Delphinus capensis* and the short-beaked species as *D. delphis*. Institutional acronyms are LACM = Natural History Museum of Los Angeles County and SBMNH = Santa Barbara Museum of Natural History.

Source	Species	Sex	Length (cm)	Date	Locality	Comments
SBMNH 77-56	*Delphinus* sp.	F	144	1977/12/05	Ventura Co., Ventura Marina	Floating, crabpot line
LACM 72496	*Delphinuis delphis*	M	180E	1983/02/28	Orange Co., Huntingdon Beach	Stranding, flukes severed
LJH 106	*Delphinus* sp.	M	159	1983/08/22	San Diego Co., Carlsbad	Stranding, net marks
LJH 127	*Delphinus capensis*	M	215	1984/01/19	San Diego Co.	Stranding, flukes severed
DK 84-01	*Delphinus* sp.	M	201	1984/01/19	Orange Co., Dana Point	Floating, net marks
DK 84-04	*Delphinus capensis*	M	206	1984/03/09	Orange Co., Huntingdon Beach	Stranding, net marks
DK 85-02	*Delphinus capensis*	M	208	1985/03/03	Orange Co., San Clemente	Stranding, stomach full
DK 85-08	*Delphinus* sp.	M	180E	1985/04/18	Orange Co., San Clemente	Stranding, flukes severed
DK 85-12	*Delphinus* sp.	M	195	1985/05/18	Orange Co., Newport Beach	Stranding, stomach full
DK 85-13	*Delphinus capensis*	M	215	1985/05/31	Orange Co., Huntingdon Beach	Stranding, net marks
SBMNH 3407	*Delphinus* sp.	M	190	1985/11/27	Santa Barbara Co., Embarcadero	Stranding, flukes severed
HJB 26	*Delphinus capensis*	F	207	1986/02/11	San Diego Co., Cardiff	Stranding, net marks
HJB 29	*Delphinus capensis*	F	212E	1986/04/14	San Diego Co., Cardiff	Stranding, flukes severed
DK 86-06	*Delphinus* sp.	M	198	1986/04/21	Orange Co., Huntingdon Beach	Stranding, net marks
HJB 37	*Delphinus* sp.	M	193	1986/10/16	San Diego Co., San Diego Bay	Floating, line around tail
LACM 84258	*Delphinus capensis*	F	?	1986/12/13	San Luis Obispo Co., Morro Bay	Floating, flukes severed
SBMNH 3664	*Delphinus capensis*	F	218	1986/12/16	Santa Barbara Co., Coal Oil Pt.	Stranding, knife cuts
SBMNH 86-29	*Delphinus* sp.	?	182	1986/12/31	Santa Barbara Co., Gaviota	Stranding, knife cuts
LACM 84021	*Delphinus capensis*	F	211	1987/02/02	Los Angeles Co., Palos Verdes	Stranding, net marks
LACM 84092	*Delphinus capensis*	F	206	1987/02/15	Orange Co., Laguna Beach	Sranding, net marks
LACM 84040	*Delphinus capensis*	F	189	1987/03/04	Orange Co., San Clemente	Stranding, knife cuts
LACM 72595	*Delphinus capensis*	F	190	1987/03/08	Orange Co., Laguna Beach	Stranding, net marks
LACM 84130	*Delphinus capensis*	F	185E	1987/11/12	Los Angeles Co., Off L.A. Harbor	Stranding, flukes severed
LACM 84129	*Delphinus delphis*	F	175E	1988/05/10	Orange Co., Newport Beach	Stranding, flukes severed
LACM 84121	*Delphinus capensis*	F	195	1988/05/20	Los Angeles Co., Cabrillo Beach	Stranding, net marks
LACM 84100	*Delphinus capensis*	F	200E	1988/05/26	Orange Co., Newport Beach	Stranding, flukes severed
LACM 84184	*Delphinus capensis*	M	220E	1988/12/08	Los Angeles Co., San Pedro	Stranding, flukes severed
SBMNH 3959	*Delphinus* sp.	?	152	1989/03/05	Santa Cruz Island	Stranding, flukes severed
SBMNH 3893	*Delphinus capensis*	F	216	1989/03/22	Santa Barbara Co., Pt. Conception	Stranding, rope marks, bullets
LACM 84256	*Delphinus capensis*	M	198	1990/01/07	Los Angeles Co., Paradise Cove	In gillnet
SBMNH 3979	*Delphinus capensis*	M	228	1990/02/12	Santa Barabara Co., Goleta	Stranding, net marks
LACM 54182	*Globicephala macrorhynchus*	F	470E	1975/10/15	Los Angeles Co., Palos Verdes	Stranding, flukes severed
LACM 54749	*Globicephala macrorhynchus*	M	610	1977/11/07	Los Angeles Co., Palos Verdes	In purse seine net
LACM 54185	*Globicephala macrorhynchus*	F	433	1977/11/19	Los Angeles Co., Paradise Cove	Stranding, stomach full of squid
LACM 54184	*Globicephala macrorhynchus*	F	419	1977/11/19	Los Angeles Co., Paradise Cove	Stranding, stomach full of squid
SBMNH 77-53	*Globicephala macrorhynchus*	?	419	1977/11/22	Ventura Co., 5km S of Pt. Mugu	Stranding, circumstantial evidence
SBMNH 1637	*Globicephala macrorhynchus*	?	430E	1977/11/23	Ventura Co., La Jolla Beach	Stranding, stomach full of squid
WFS 1042	*Globicephala macrorhynchus*	?	500E	1980/01/22	Santa Catalina Island	Stranding
Seagers 1985	*Globicephala macrorhynchus*	?	?	1980/12/17	Santa Catalina Island	Floating, circumstantial evidence
Seagers 1985	*Globicephala macrorhynchus*	?	?	1980/12/17	Santa Catalina Island	Floating, circumstantial evidence
Seagers 1985	*Globicephala macrorhynchus*	?	?	1980/12/17	Santa Catalina Island	Floating, circumstantial evidence
Seagers 1985	*Globicephala macrorhynchus*	?	?	1980/12/17	Santa Catalina Island	Floating, circumstantial evidence
Seagers 1985	*Globicephala macrorhynchus*	?	?	1980/12/17	Santa Catalina Island	Floating, circumstantial evidence
Seagers 1985	*Globicephala macrorhynchus*	F	463	1980/12/19	Santa Catalina Island	Floating, stomach full of squid
LACM 84088	*Globicephala macrorhynchus*	?	250E	1988/03/24	San Clemente Island	Stranding, flukes severed
LACM 84174	*Grampus griseus*	M	229	1988/10/15	Orange Co., Crystal Cove	Stranding, stomach full of squid
LACM 84205	*Grampus griseus*	F	264	1988/10/17	Orange, Crystal Cove	Stranding, stomach full of squid
LACM 84201	*Grampus griseus*	F	314	1988/12/16	Los Angeles Co., L.A. Harbor	Stranding, stomach full of squid
LACM 84175	*Grampus griseus*	?	300E	1989/01/03	Los Angeles Co., Palos Verdes	Stranding, flukes severed
LACM 84053	*Lagenorhynchus obliquidens*	M	195	1981/05/16	Orange Co., Boisa Chica	Stranding, trammel net marks
LACM 84114	*Lagenorhynchus oliquidens*	M	232	1988/04/27	Orange Co., Huntingdon Beach	Stranding, circumstantial
LACM 84133	*Lagenorhynchus obliquidens*	?	201	1988/04/30	Orange Co., Huntingdon Bch.	Stranding, stomach full
LACM 72550	*Orcinus orca*	F	260	1985/04/21	Orange Co., Bolsa Chica	Stranding, net marks
WFP 520	*Tursiops truncatus*	M	300E	1976/06/28	San Diego Co., Cardiff	Stranding, flukes severed
LJH 6	*Tursiops truncatus*	F	236	1981/11/14	San Diego Co., La Jolla	Stranding, net marks
DK 85-19	*Tursiops truncatus*	M	218E	1985/10/05	Orange Co., Boisa Chica	Stranding, flukes severed
LACM 84285	*Tursiops truncatus*	F	272	1990/08/13	San Diego Co., La Jolla	Stranding, knife cuts
LACM 72588	*Phocoena phocoena*	M	100	1976/07/29	San Luis Obispo Co., Oceano	Stranding, net marks
SBMNH 1380	*Phocoena phocoena*	?	151	1977/03/01	San Luis Obispo Co., Ocean Beach	Stranding, probable gunshot
LACM 84016	*Phocoena phoecoena*	M	133	1983/08/13	San Luis Obispo Co., Pt. Estero	In monofilament gillnet
LACM 72541	*Phocoena phocoena*	M	133	1983/09/24	San Luis Obispo Co., Pt. Estero	In nylon trammel net
LACM 72563	*Phocoena phocoena*	F	138	1983/09/27	San Luis Obispo Co., Morro Bay	In monofilament gillnet
LACM 72540	*Phocoena phocoena*	F	135	1984/01/25	San Luis Obispo Co., Morro Bay	In monofilament gillnet
LACM 72536	*Phocoena phocoena*	M	124	1984/03/03	San Luis Obispo Co., Morro Bay	In monofilament gillnet
LACM 72539	*Phocoena phocoena*	M	121	1984/04/27	San Luis Obispo Co., Cayucos	In monofilament gillnet
LACM 72538	*Phocoena phocoena*	M	124	1985/04/27	San Luis Obispo Co., Off Cayucos	In monofilament gillnet
RLB 1006	*Phocoena phocoena*	F	184	1987/01/26	San Luis Obispo Co., Estero Bay	In monofilament gillnet
LACM 84018	*Mesopolodon carlhubbsi*	F	256	1986/06/04	Orange Co., San Clemente	Stranding, net marks
USNM 550122	*Ziphius cavirostris*	M	526	1980/11/20	San Diego Co., La Jolla	Stranding, knife cuts

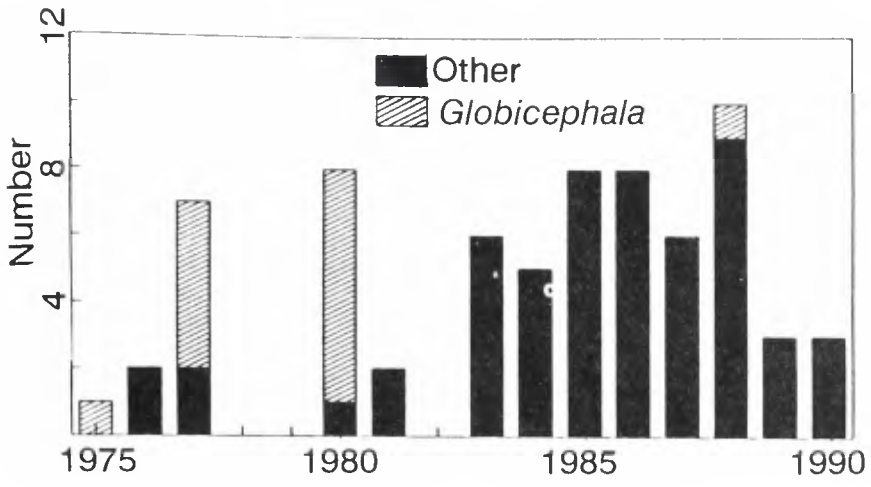

Fig. 1. Records of odontocete mortalities from fisheries interactions by year from 1975 through 1990.

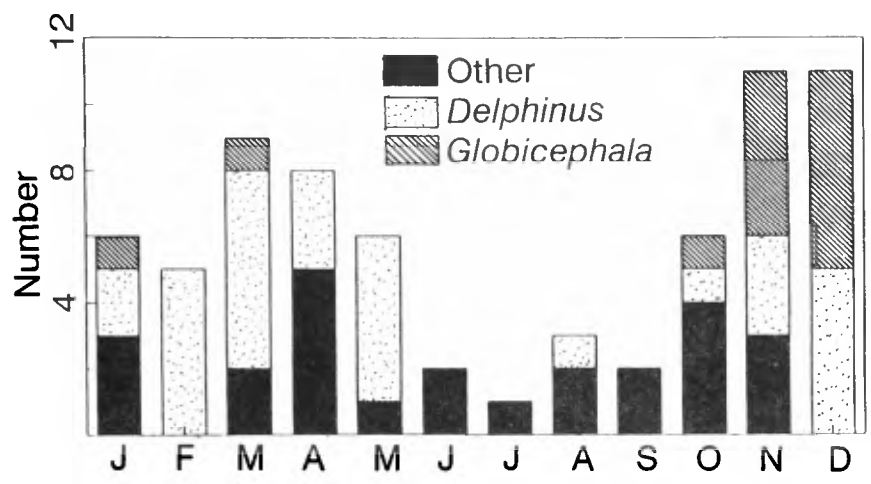

Fig. 2. Records of odontocete mortalities from interactions with fisheries by month.

DISCUSSION

Reports of fishery takes increased through the study period (Fig. 1), particularly if the takes of pilot whales are excluded. This apparent rise may result from an increase in fishing activities, an increase in the documentation of fishery-related mortalities or a combination of both.

Our stranding data greatly underestimate entanglements in fisheries, especially offshore drift gillnets, because cetacean carcasses typically do not drift significant distances shoreward (Heyning and Lewis, 1990; Bishop, 1985; Bodkin and Jameson, 1991). Data from stranded animals also are difficult to interpret because they represent an unknown percentage of the entanglements that actually occur (Seagers *et al.*, 1986) and carcass retrieval effort is difficult to quantify.

Absolute abundance estimates have only recently been available for most odontocete species in Californian waters (Barlow *et al.*, 1993). Common dolphins are the most abundant cetacean species in southern California waters (Evans, 1975; Leatherwood and Walker, 1979), although few surveys to date have distinguished between the two species. The long-beaked species is the most frequently entangled common dolphin based on strandings, but the population level of this species is unknown.

White-sided dolphins are also abundant in southern California waters (Leatherwood and Walker, 1979; Leatherwood *et al.*, 1984) but absolute abundance estimates for southern Californian waters are not available. In the eastern North Pacific, there are two putative stocks of white-sided dolphins; a larger, southern form and a smaller, northern form (Walker *et al.*, 1986). These two forms overlap in the Southern California Bight. Although this species represents only three specimens in our data, it is rarely found in waters shallower than about 40m (Leatherwood *et al.*, 1984). It is thus more susceptible to entanglements in offshore drift gillnets where catches have been documented by fisheries observers (Diamond *et al.*, 1987).

Prior to the 1982–83 El Niño event, pilot whales were abundant during the winter in the waters surrounding the Channel Islands. Although there are potential problems with the previous abundance estimates (A. Hohn, pers. comm.), it is likely that the number of pilot whales in southern California waters ranged from several hundred to a few thousand animals during the winter months prior to 1983. The reasons for the decreased sightings of pilot whales in this region since 1983 are unknown. There have been no studies to determine the structure of pilot whale stocks in the eastern North Pacific. We believe that most of the pilot whales in our data were killed in purse seine operations for squid. One specimen was recovered directly from such a vessel. During November 1977 and December 1980, several pilot whales were found dead within a small area (Table 1). All animals examined (Seagers and Henderson, 1985; Sinclair, 1992) had stomachs full of market squid (*Loligo opalescens*) and commercial squid boats were reported to have been working those areas at that time. The high number of dead animals reported prior to 1981, when documentation of fishery-related kills was low, suggests that the absolute number of pilot whales killed may have been significant.

Harbor porpoises in California currently may be at 30–97% of carrying capacity due to fisheries-related mortalities (Barlow and Hanan, 1994). Our finding that more sexually immature animals are represented in our sample is corroborated by the much larger sample of incidentally killed California harbor porpoise studied by Hohn and Brownell (1990).

Although no quantifiable data are available, the numbers of Risso's dolphin sightings have increased noticeably over the past 15 years (pers. obs.). There is no information on the presence of distinct stocks of Risso's dolphins in the North Pacific. We believe that Risso's dolphins are killed primarily in purse seine operations for squid; as with pilot whales, these stranded animals have stomachs filled with fresh market squid (*L. opalescens*). We have often heard reports of squid boats working the region on nights prior to the discovery of dead animals.

Bottlenose dolphins off southern California have been classified into offshore and inshore types (Walker, 1981). Abundance estimates are only available for the inshore type, with a population in southern Californian waters ranging from 173 to 240 animals (Hansen, 1990). With such a low population level, if this represents a discrete stock, it would be susceptible to impact even from low numbers of annual takes.

For the beaked whales (Ziphiidae), virtually nothing is known of population levels or the status of stocks. The same is true of the status of killer whales in southern Californian waters but, based on infrequent sightings, we assume that the numbers probably do not exceed the very low hundreds.

Limited data from observers placed on offshore drift gillnet boats indicates that both species of common dolphins are the most frequently taken species south of Pt. Conception (Diamond *et al.*, 1987). North of Pt. Conception *P. phocoena* is the most frequently entangled cetacean species in nearshore set gillnets fishing for either white seabass, halibut, or white croaker (Barlow, 1987).

However, both the observer and our stranding data sets are based on small sample sizes and more data are needed to assess the impact of these takes on local populations.

CONCLUSIONS

It is difficult to assess the potential impacts of entanglements for two reasons: (1) the limited quantifiable data on the population size and structure of most cetacean species; and (2) the limited data on the numbers of animals of the various species that are killed in fishing gear annually. We believe that management agencies should invoke the concept of Diamond (1988), who stated that conservation efforts should be directed not only towards endangered species, but also to populations for which the status is unknown but may be depleted. It is clear that more data are needed.

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SC/42/O 1

A Note on the Death of a Right Whale (*Eubalaena glacialis*) off Cape Lopatka (Kamchatka)

S.I. Kornev

KAMCHATRYBVOD, Partizanskaya 9, Petropavlovsk-Kamchatskiy, 683000, USSR

ABSTRACT

This note reports the death of a 12.15m male right whale due to its entanglement in a gillnet off the southern tip of the Kamchatka peninsula. The animal was found stranded on the beach near Cape Lopatka

KEYWORDS: NORTH PACIFIC; RIGHT WHALE; INCIDENTAL CAPTURE; FISHERIES

In 1985, a sea otter observation station was set up by KAMCHATRYBVOD on Cape Lopatka (on the southern tip of Kamchatka). In addition to the major task of monitoring sea otters, observations of marine mammals occurring in the area were made. This included recording stranded animals. Between 1985 and 1989 the carcasses of 8 Dall's porpoise (*Phocoenoides dalli*), 1 fin whale (*Balaenoptera physalus*), 1 killer whale (*Orcinus orca*) and 1 right whale (*Eubalaena glacialis*) were discovered. In most cases the state of decomposition of the animal made it difficult to determine the cause of death.

However, for the right whale specimen the cause of death was identified. The whale, a 12.15m male, was found on the Pacific coast of Cape Lopatka at 1630hrs local time on 16 October 1989 (Fig. 1), apparently soon after it had died. It was examined and some measurements were taken at low tide (Table 1). The body was covered in cyamids and was bleeding from the mouth and the caudal peduncle. A 20m long salmon net was tightly wrapped around the caudal peduncle. The deep wounds visible (Fig. 2) show that the whale must have dragged the net for a long period.

The green net had a 6 x 6cm stretched mesh size, with foam plastic floats and no weights. Its design and the light yellow band fixing the floats suggested that it was manufactured abroad (probably in Japan or Taiwan). In 1988, the USSR fishery guard had detained three fishing

Table 1

Measurements of the right whale found dead on Cape Lopatka on 16 October 1989.

Body length	Length of lower jaw	Median length of flipper	Width of flipper	Fore-edge length of fluke	Width of fluke
12.15m	3.28m	2.17m	1.39m	2.45m	1.43m



Fig. 1. General view of the right whale. This and the other photos were taken 4–5 days after the whale was thrown by a storm onto the beach.



Fig. 2. Right whale in the shallows.



Fig. 3. Fishing net wrapped around the tail.

vessels belonging to Taiwan in the coastal waters of the Kuril Islands. The vessels were engaged in illegal fishing using nets similar to that found on the whale. Barlow *et al.* (1994) reviewed incidental mortality of cetaceans in fishing gear in coastal Pacific waters and noted that vessels from a number of countries, including Taiwan, Japan and the Democratic People's Republic of Korea fish in these waters.

This is the first record of this species in Kamchatkan waters for many years; the species is thought heavily depleted, numbering at best in the low hundreds (Berzin and Doroshenko, 1982). Any human-induced mortality is thus of concern.

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Harbor Porpoise Mortality in the Monterey Bay Halibut Gillnet Fishery, 1989

Thomas A. Jefferson[1], Barbara E. Curry[1] and Nancy A. Black

Moss Landing Marine Laboratories, PO Box 450, Moss Landing, CA 95039, USA

ABSTRACT

Harbor porpoises (*Phocoena phocoena*) have been killed in gillnets set for halibut in central California since at least 1969. In the Monterey Bay area (Pigeon Pt. to Pt. Sur), past estimates of mortality have ranged from 25–55/yr. In the spring of 1989, many dead harbor porpoises began washing ashore with evidence of gillnet entanglement. Observer records from the California Department of Fish and Game and stranding data indicated that a minimum of 53 harbor porpoises were killed in Monterey Bay gillnets in 1989, and it is likely that the total number killed in this area was several hundred. Two-thirds of the specimens were immature. If Monterey Bay harbor porpoises form a resident population, such high takes in the future threaten to decimate the population. We recommend closing the fishery or setting quotas and monitoring the kill with approximation of 100% observer coverage.

KEYWORDS: INCIDENTAL CAPTURE; MANAGEMENT; FISHERIES; HARBOUR PORPOISE; NORTH PACIFIC

INTRODUCTION

Harbor porpoises (*Phocoena phocoena*) are killed in entangling nets[2] throughout their range in the temperate waters of the Northern Hemisphere (IWC, 1994). In central California, such mortality occurs as a result of fishing for halibut with bottom-set gillnets and trammel nets (descriptions in Scofield, 1951; Ueber, 1988), and has occurred since at least 1969 (Barlow, 1987). Until 1980, there was no systematic monitoring of the fishery, but in that year some monitoring was begun by Moss Landing Marine Laboratories (MLML) and California Department of Fish and Game (CDFG) personnel (Miller *et al.*, 1983; Keating, 1986). Since 1983/84, CDFG has been systematically monitoring incidental mortality in this fishery and producing annual estimates of mortality of harbor porpoises and other by-catch species (Diamond and Hanan, 1986; Hanan *et al.*, 1986; 1987; Hanan and Diamond, 1989). These estimates for the 1983/84 to 1986/87 seasons have ranged from approximately 200–300 porpoises per year for the central coast, from Bodega Head to Pt. Conception.

Beginning in mid-February 1989, a much higher than normal number of harbor porpoises started washing up on Monterey Bay beaches, most with evidence of gillnet entanglement. CDFG observer data, which began in mid-March, confirmed that higher than usual levels of porpoise mortality were occurring in the Bay. There was a great deal of pressure put on CDFG to reduce the high kills. Before a ban on gillnet sets in waters shallower than 40 fathoms (73m), covering most of Monterey Bay, was put into effect on 15 April, a total of at least 34 porpoise deaths related to gillnets had been documented in the area.

This paper examines 1989 harbor porpoise gillnet-caused mortality in the Monterey Bay area and presents general information that may help in managing this situation in the future. In addition, it provides recommendations for management.

[1] Present address: *Marine Mammal Research Program, c/o Department of Wildlife and Fisheries Sciences, 210 Nagle Hall, Texas A&M University, College Station, TX 77843, USA.*

[2] Entangling nets include setnets, driftnets, and trammel nets. In this paper, the term 'gillnet' is used loosely to refer to any type of entangling gear.

MATERIALS AND METHODS

The Monterey Bay study area extends from Pigeon Pt. to Pt. Sur, and was divided into four regions of comparable size for analysis (Fig. 1). Materials were of two types: stranding records and gillnet observer data. Stranded cetaceans in the Monterey Bay area were reported to Moss Landing Marine Laboratories (MLML), and Long Marine Laboratory, University of California, Santa Cruz (LML), both participants in the California Marine Mammal Stranding Network (Seagars and Jozwiak, 1991). Personnel from MLML and LML responded to stranding reports and examined the carcasses. When possible, the carcass was collected for more detailed scientific study. Each porpoise was examined for evidence of gillnet entanglement, such as cuts and depressions along the head, flippers, dorsal fin, or flukes (Hare and Mead, 1987). Standard data, including photos, morphometrics, and tissue samples for analysis of reproduction, feeding habits and pollutant levels, were collected on site or at the lab during necropsies.

Gillnet observation data were kindly provided by C.W. Haugen, CDFG. Information on set location, water depth and by-catch was collected by CDFG observers, either from a shore-based observation platform (uncommon in Monterey Bay), from a research vessel that pulled alongside a gillnetter during net retrieval, or from on-board the fishing vessel. When possible, CDFG observers attempted to secure incidentally-taken porpoises, which were then examined by MLML or LML biologists. Samples and data were then forwarded to the Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service (NMFS), for life history analysis.

RESULTS

Harbor porpoise take in 1989

Table 1 shows the total minimum number of harbor porpoises known to be taken in the Monterey Bay gillnets in 1989. The total of 53 porpoises was computed by adding the number of takes observed by CDFG to the number of strandings with gillnet markings that could be excluded from the observed gillnet takes.

A reliable estimate of take is not possible without knowing the number of gillnet sets (fishing effort) in the

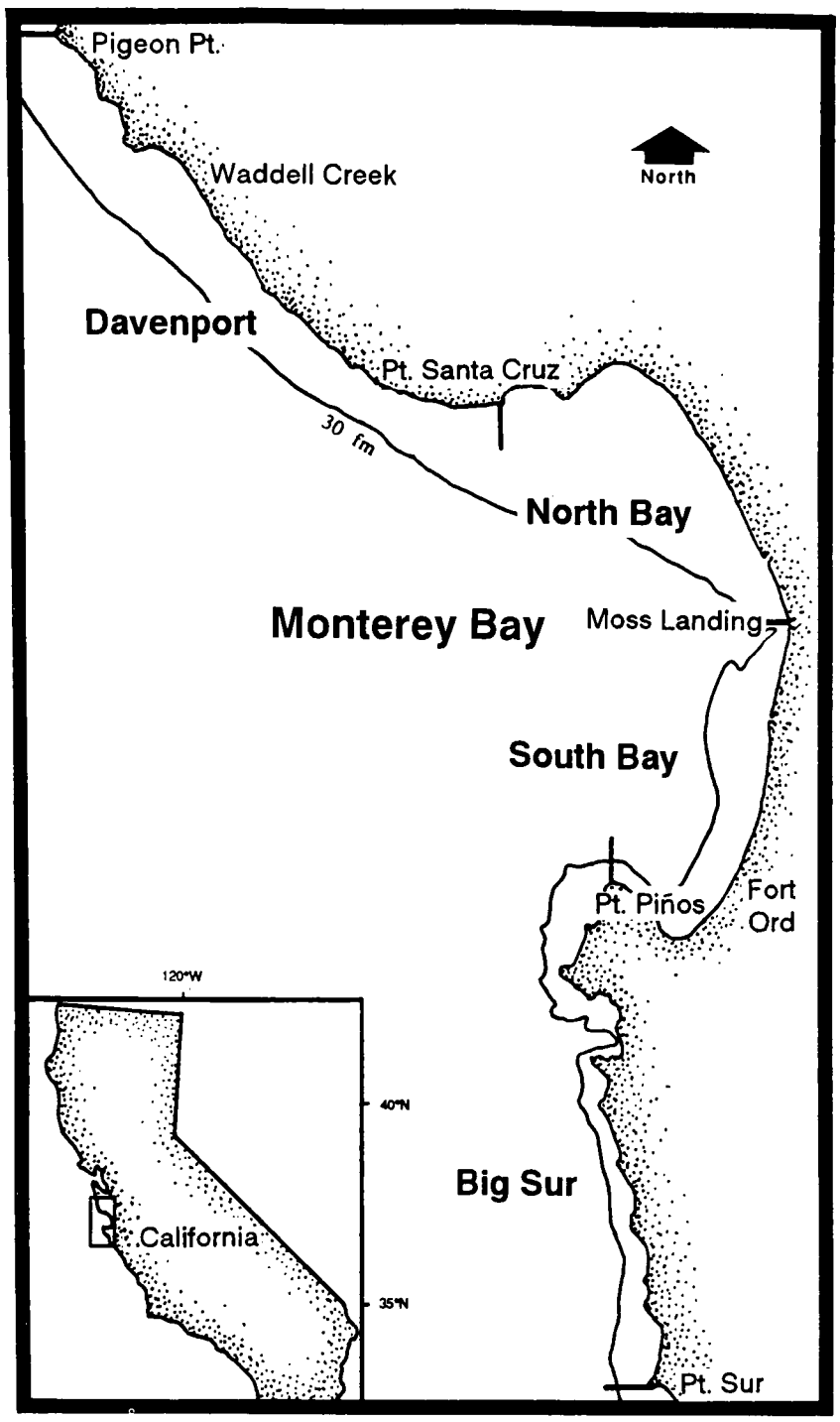

Fig. 1. Map of the study area, showing the four subareas and place names mentioned in the text. Inset shows location of Monterey Bay in central California.

Table 1

Summary of numbers of strandings and observed takes of harbor porpoises in 1989 in Monterey Bay, and an estimate of the minimum number taken in the halibut fishery.

Dates	Gillnet markins on strandings			Observed takes		Minimum taken
	Yes	No	?	Specimen	No	
15 Feb - 15 Apr.	14	1	5	4	16[1]	34
16 Apr. - 1 Sept.	1	1	3	3	1[2]	5
2 Sept. - 31 Dec.	0	0	0	5	9	14
					Total	53

[1] Six of these were slashed and sunk and 10 others were taken after the last stranding was recovered, so these 16 animals cannot be duplicates of the 14 stranded with gillnet markings.
[2] This animal cannot be a duplicate of the stranding during this period with gillnet markings, because the stranding, which was freshly dead (< 2 weeks), was found 3½ weeks after the last observed take.

Monterey Bay area in 1989. Fishing effort is estimated by CDFG, by combining data from fishing logs completed by the fishermen, with landing receipts or 'pink tickets', and CDFG observer data (see Diamond and Hanan, 1986). Not all of this information is available, so fishing effort is not known for 1989.

Data are available, however, for four previous years. Assuming that fishing effort in 1989 was within this range, the total number of harbor porpoises killed in the Monterey Bay area alone is possibly several hundred, many times higher than the estimates of 25–55 for previous years (Table 2).

Table 2

Estimated number of sets and estimated harbor porpoise take in Monterey Bay for 1989 and previous years compared.

Year	Est. no. sets (% observed)	Estimated mortality	Take rate	Source
1983/84	517 (4%)	45-47	0.091	Diamond and Hanan, 1986
1984/85	1,606 (7.8%)	25-26	0.016	Hanan *et al.*, 1986
1985/86	1,255 (3.9%)	55	0.041	Hanan *et al.*, 1987
1986/87	896 (3.9%)	26	0.029	Hanan and Diamond, 1989
1989	-	180-560[1]	0.349	CDFG, unpubl. data

[1] Based on range of estimated number of sets for 1983/84 to 1986/87.

Take rate in 1989

In 1989, CDFG observers saw 38 harbor porpoises taken in 109 observed sets, for a take rate of 0.35 ± SD 0.738 porpoises/set. This is much higher than the take rate of 0.02–0.10 observed in past years in the same area (Table 2).

Take rate between the four regions, and take rate between four depth categories (15–18, 19–22, 23–26 and 27–30 fathoms), were examined and no significant differences were found ($Chi^2=4.346$, df=3, $p>0.05$; $Chi^2=1.706$, df=3, $p>0.05$; respectively). There were no observed sets in water depths greater than 30 fathoms (55m).

A closure of waters shallower than 40 fathoms (73m), between Waddell Creek and Fort Ord, was in effect from 15 April to 1 September. During the closure, most of the fishing was still in less than 40 fathoms, south of Fort Ord. There was a significantly lower take rate during the closure (Fig. 2; $Chi^2=9.296$, df=1, $p<0.01$).

Biological observations

Of the 28 gillnet-caught porpoises examined by MLML or LML biologists, 16 (57.1%) were females (Table 3). This difference from parity was not statistically significant ($Chi^2=0.571$, df=1, $p>0.05$).

There was a preponderance of immature animals among the incidentally-taken porpoises. Based on Hohn and Brownell's (1990) information on lengths at sexual maturity for central California harbor porpoises ('best' averages: 140cm for males and 152cm for females[3]), 4 of 12

[3] Hohn and Brownell computed 152cm as the most representative length at sexual maturity for females in their sample (excluding one outlier). Male sexual maturity could not be determined with certainty until testes were examined histologically, but testis weight increased rapidly at 140cm, and this currently represents the 'best' length at sexual maturity.

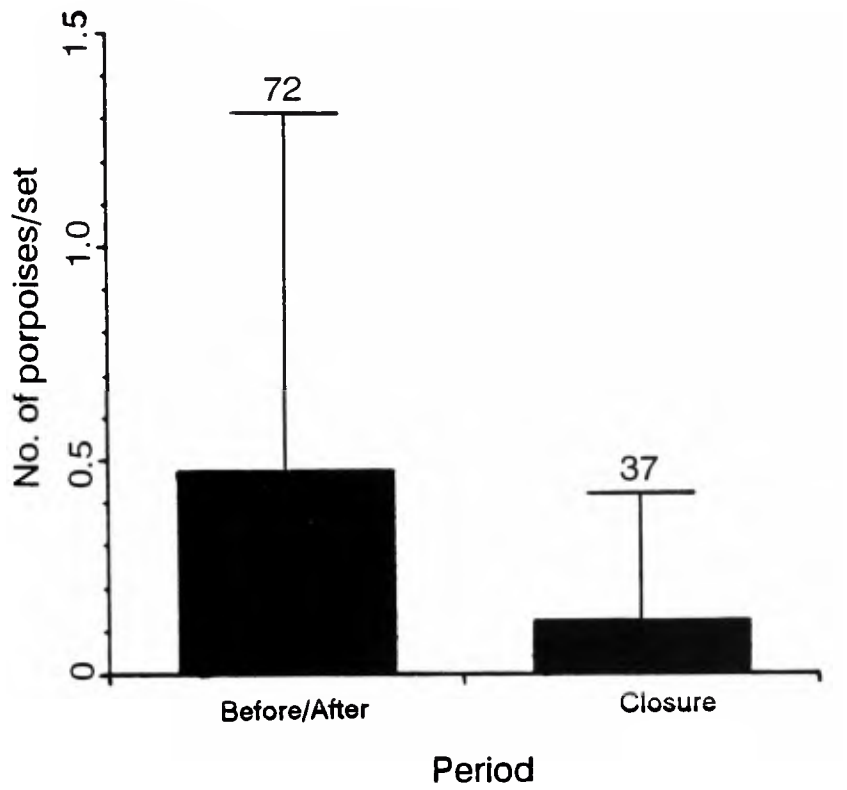

Fig. 2. Mean number of porpoises taken per set by period. The closure was in effect from 15 April to 1 September 1989, and prohibited sets in waters shallower than 40 fathoms north of Fort Ord. Bars are standard deviations and numbers are sample sizes (no. of sets).

(33.3%) males and 5 of 16 (31.1%) females were sexually mature. There were no newborn calves, but at least three of the females were pregnant.

DISCUSSION

Status of population and effect of take

The population structure of Monterey Bay harbor porpoises is not known (see review of status of central California harbor porpoises by Barlow, 1987; Barlow and Forney, 1993; Barlow and Hanan, 1994). The only evidence directly relating to population structure is from the work of Calambokidis and Barlow (1991), who compared PCB/DDE pollutant ratios from animals along the west coast of the United States. The variances and ranges of 13 Monterey Bay animals differed from those of animals from adjacent waters (two from Morro Bay to the south, and eight from around San Francisco Bay to the north). So, despite uncertainty resulting from very small sample sizes, the evidence indicates that Monterey Bay may contain a resident population of harbor porpoises, or at least that there is little movement of porpoises to the surrounding coastal areas.

Since 1984, NMFS and CDFG have conducted aerial and ship surveys for the purpose of estimating harbor porpoise abundance in California (Barlow, 1988; Barlow *et al.*, 1988; Forney *et al.*, 1991). Ship survey estimates are currently considered more accurate (see Kraus *et al.*, 1983), however aerial surveys have generally produced estimates similar to those from ship surveys. 'Best estimates' from these surveys are approximately 14,300 harbor porpoises for central and northern California and 1,460 (CV=0.61) for the Monterey Bay area (Barlow, 1988). If the Monterey Bay abundance estimate is correct, then our 1989 minimum take (53 porpoises) represents 3.6% of the population. This is probably unsustainable, and the estimated take of several hundred porpoises would be certainly unsustainable (see Woodley and Read, 1991). However, a more recent abundance estimate, based on aerial surveys, is somewhat higher, 1,948 (CV=0.28) (Barlow and Forney, 1993).

The 1989 fishing year was unusual because of the temporal and spatial distribution of fishing effort. This may be the reason for the high take in that year. However, such unusual years could quickly damage a small resident

Table 3

Harbor porpoise specimens obtained and examined that were either observed taken in gillnets or stranded with gillnet markings, Monterey Bay, 1989. [1] Stranding or capture. [2] NB = North Bay; SB = South Bay and D = Davenport.

Date	Specimen #	S or C[1]	Length (cm)	Sex	Location[2]	Date	Specimen #	S or C[1]	Length (cm)	Sex	Location[2]
15 Feb.	TAJ 181	S	134	F	NB (Pajaro Dunes)	04 Apr.	NAB 011	C	158	F	NB (Santa Cruz)
18 Feb.	EJD 007	S	155	F	NB (ML Beach	05 Apr.	NAB 012	S	132	F	SB (Marina)
22 Feb.	BEC 89-1	S	129	F	NB (Seascape)	13 Apr.	TAJ 1283	C	131	M	SB (Marina)
28 Feb.	EJD 008	S	135	M	SB (Marina)	13 Apr.	TAJ 184	C	178	F	SB (Marina)
05 Mar.	EJD 009	S	147	F	NB (Seacliff)	10 May	GAW 89-8	S	128	M	NB (Rio del Mar)
16 Mar.	NAB 005	S	139	F	SB (Marina)	10 Aug.	TRK 109	C	129	M	SB (Seaside)
16 Mar.	TRK 108	S	138	F	SB (Marina)	12 Aug.	EJD 020	C	125	M	SB (Seaside)
16 Mar.	EJD 010	S	150	M	SB (Marina)	18 Aug.	EJD 021	C	130	M	SB (South Fort Ord)
25 Mar.	EJD 011	S	151	F	SB (Salinas River)	22 Sept.	EJD 022	C	127	M	NB (Soquel Point)
29 Mar.	NAB 007	S	145	F	NB (Sunset Beach)	07 Oct.	EJD 024	C	138	F	SB (North Fort Ord)
29 Mar.	NAB 008	S	136	F	NB (Sunset Beach)	07 Oct.	EJD 025	C	120	M	SB (North Fort Ord)
29 Mar.	NAB 009	S	156	F	NB (Sunset Beach)	15 Oct.	NAB 013	C	150	F	D (Davenport)
03 Apr.	EJD 012	S	147	M	SB (Marina)	15 Oct.	NAB 014	C	122	F	D (Davenport)
04 Apr.	NAB 010	C	170	F	NB (Santa Cruz)						

population, such as that presumed to exist in Montery Bay. Due to funding limitations, CDFG's observer effort has been extremely low in the past (see Table 2). In 1989, eight harbor porpoises with gillnet marks were recovered from Monterey Bay beaches before CDFG was able to begin net retrieval observations.

Barlow (1987) and Barlow and Hanan (1994) suggested that past levels of harbor porpoise setnet mortality have resulted in reduction of central California stock(s), possibly to levels below Optimum Sustainable Population (OSP). They further suggested use of the '2 percent rule' for maximum allowable take in this case. The high level of take in 1989 (>3.6% of the best population estimate) warrants serious concern for the future of harbor porpoises in Monterey Bay (and possibly the rest of the central California coast). Despite a great deal of uncertainty, the best available information suggests that the 1989 levels of take are too high for assured survival of the population.

RECOMMENDATIONS

Considering the current problems involved in management of harbor porpoise populations, we recommended one of the following two options:

(1) eliminating mortality by closing the Monterey Bay halibut setnet fishery until such time that effective methods of reducing or eliminating porpoise take in gillnets are discovered and implemented [the passage of proposition 132 (SB 2,563 1990, Chapter 884) effectively did so – see Wild, 1990 – but there is a move to overturn this legislation]; or

(2) if accurate estimates of abundance are available, monitoring the fishery with a goal of 100% observer coverage to eliminate uncertainty in estimating take (minimum acceptable coverage should be 35%, see Barlow, 1989), and observing the '2% rule' for maximum allowable take in any one year (with a quicker response to close the fishery than occurred in 1989, if required).

The main hindrance to sound management of central California harbor porpoise population(s) is the uncertainty involved in determining population status and in estimating incidental take and stock size. If the fishery is to continue, these shortcomings should be addressed immediately.

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Estimates of Incidental Marine Mammal Bycatch in California Gillnet Fisheries for July through December, 1990

Cleridy Lennert and Susan Kruse

Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, PO Box 271, La Jolla, CA 92038, USA

Marilyn Beeson

California Department of Fish and Game, 330 Golden Shore, Suite 50, Long Beach, CA 90802, USA

Jay Barlow

Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, PO Box 271, La Jolla, CA 92038, USA

ABSTRACT

Data are reported on marine mammal mortality collected from California's gillnet fisheries for California halibut and Pacific angel shark (set net) and swordfish and pelagic sharks (driftnet) during the first six months of a three-year mortality assessment program. NOAA Fisheries (NMFS) observer-technicians collected information on species composition, mortality and life history data from entangled cetaceans, pinnipeds and sea otters. Four harbor porpoises, three southern sea otters, 13 elephant seals, 30 harbor seals, 67 California sea lions, one unidentified otariid, and two unidentified pinnipeds were observed killed in the set net fisheries. Estimated total incidental mortality for these species during the six month period was: harbor porpoises (central California), 44 (SE=25); southern sea otters (central California), 33 (SE=18); elephant seals (central California), 144 (SE=58); harbor seals, 392 (SE=83); and California sea lions, 847 (SE=134). Nine common dolphins, three Pacific white-sided dolphins, one short-finned pilot whale, one Dall's porpoise, one mesoplodont beaked whale, four elephant seals, one harbor seal, two California sea lions and two unidentified otariids were observed killed in the driftnet fishery. Estimated total incidental mortality for these species during the six month period was: common dolphins, 203 (SE=82); Pacific white-sided dolphins, 68 (SE=38); short-finned pilot whales, 23 (SE=22); mesoplodont beaked whales, 23 (SE=22); Dall's porpoise, 23 (SE=22); elephant seals, 90 (SE=43); harbor seals, 23 (SE=22); and California sea lions, 90 (SE=62). Biological data including total length, sex, reproductive condition and age were collected from a subset of animals. Sex and length data were collected for some animals; age and reproductive condition have not been determined for most.

KEYWORDS: NORTH PACIFIC; INCIDENTAL CAPTURE; HARBOUR PORPOISE; COMMON DOLPHIN; PACIFIC WHITE-SIDED DOLPHIN; PILOT WHALE – SHORT-FINNED; DALL'S PORPOISE; BEAKED WHALES

INTRODUCTION

During the late 1970s and early 1980s there was a rapid expansion in the use of entanglement nets (driftnet, set net, multi-panel and trammel nets) in coastal California waters (Herrick and Hanan, 1988). The incidental kill of non-target species (including marine mammals) by these nets has become a focus of concern for state and national environmental and legislative bodies.

In the United States, marine mammals are managed under the Marine Mammal Protection Act (MMPA). Prior to amendments of the MMPA in 1988, incidental take of marine mammals in commercial fisheries was allowed if populations could be proven to be within a range of Optimal Sustainable Population levels (OSP). OSP has been defined operationally as the range of population sizes between carrying capacity and the maximum net productivity level. However, for most fisheries-affected marine mammal species, adequate information on abundance and population parameters that would allow estimation of status relative to OSP is unavailable. In 1988, amendments to the MMPA enacted a temporary exemption program for five years. In the interim, collection of statistically reliable data on the status of marine mammal stocks and total incidental mortalities has been congressionally mandated (United States Federal Register, 1989). These data are expected to be made available to the Congress prior to the scheduled re-authorisation hearings in 1994.

In order to facilitate monitoring incidental mortality and its impact on marine mammal populations, the exemption program classifies commercial fisheries into three categories according to expected levels of incidental mortality: Category I (frequent take of marine mammals incidental to fishing activities), Category II (occasional take of marine mammals) and Category III (rare or infrequent take of marine mammals) (United States Federal Register, 1989). All vessel operators are required to submit annual reports of incidental takes of marine mammals. Since 1990, Category I operators have been required to take NMFS observer-technicians onboard and allow them to collect information on the species and number of marine mammals taken. When possible, observers collect detailed biological information on entangled animals that are brought onboard. These data will be used to verify the adequacy of the vessel self-reporting program established under the MMPA amendments, as well as to provide a foundation for marine mammal management policy.

In this report, data are presented on marine mammal mortality collected from Category I gillnet fisheries in California including (1) a set net fishery for California halibut, (2) a set net fishery for Pacific angel shark, and (3) a driftnet fishery for sharks and swordfish (see Barlow *et al.*, 1994 for detailed synopses of each fishery). Set net fisheries in southern California (the Mexican border north to Point Conception) comprise year-round fisheries for California halibut (*Paralichthys californicus*) (effort peaks in spring and fall), and angel shark (*Squatina californica*) (Collins *et al.*, 1985; 1986). Category I set net fisheries off central California (Pt. Conception to Bodega Bay) include those for halibut (taken from May to October, with a

summer peak), shark (November through February), and flounder (*Pleuronectiformes*) (March and April) (Wild, 1986; 1987; Herrick and Hanan, 1988). However, most California halibut and Pacific angel shark fishing effort in central California is concentrated between Point Conception and Monterey Bay. Coastal set net fisheries are not allowed in northern California (north of Bodega Bay).

California's driftnet fishery extends from the California-Mexico border in the south, to the Oregon border in the north, and beyond 200 miles offshore (Herrick and Hanan, 1988). Initially, common thresher (*Alopias vulpinus*) and short-fin mako (*Isurus rinchus*) sharks were the target species. In the last decade, swordfish (*Xiphias gladius*) has replaced sharks as the primary target species (Herrick and Hanan, 1988). Fishing is regulated by restricted seasons designated by distance from shore (California Department of Fish and Game, 1990). Within 75 n.miles of the coast, the driftnet fishery is active from 15 July to 31 January. Between 75 and 200 n.miles offshore, the fishery is open from 15 April through 31 January.

Prior to 1990, data on the composition of the incidental kill of marine mammals by California gillnet fisheries were collected by the California Department of Fish and Game (CDFG). These data, obtained from both set net and driftnet fisheries, have been summarised by Herrick and Hanan (1988) and Barlow *et al.* (1994). In this report, we present results of the first six months of a three-year study of incidental marine mammal mortality in California's Category I gillnet fisheries.

METHODS

Data collection

Data summarised herein were collected by NOAA Fisheries observer-technicians primarily from onboard commercial gillnet vessels. Observers collected data on net characteristics, target species, fishing operations, marine mammals interacting with fishing operations and bycatch composition. Tally data collected by observers included number and species of marine mammals incidentally entangled during fishing operations, each animal's location in the net, its condition at the time of net pull (i.e., dead, alive or injured) and if possible, its sex. Following procedures described by Perrin *et al.* (1976), observers collected life history data from a subset of individuals incidentally killed during fishing operations. As time permitted, observers also recorded length measurements and dispositions of various species of fish caught in the net. These data were edited in several stages prior to analysis.

In accordance with 1988 MMPA amendments, the targeted level of sampling coverage was 20% of the fishing activity, measured in terms of trips. A trip was defined as any period of active fishing terminated by a port call. Sampling methods differed between driftnet and set net fisheries. Safety considerations prohibited the placement of observers on some set net and driftnet vessels.

Set net

For the set net fishery, six port stations were established. Stations were staffed with a port coordinator, responsible for monitoring vessel activity, and one or more observers, depending on the anticipated level of fishing activity (determined from earlier CDFG programs). Port stations were established at San Diego, Los Angeles (San Pedro), Ventura, Santa Barbara, Morro Bay and Monterey. At the end of each day, a subset of 20% of those vessels which had nets actively fishing was selected. Vessel selection (i.e., trip selection) was done randomly whenever possible. However, sporadic fishing activity and limited cooperation of fishers with local regulating agencies often influenced observer placement (see Discussion). Selected vessels were obligated to permit observers to board and to collect data during net retrieval. Whenever possible, fishers were notified of their obligation to carry an observer after their nets had been set so as to minimise the influence of the observer program on fishing behaviour. Observers generally boarded vessels at the dock. However, in the Morro Bay area, a chartered vessel was occasionally used to observe fishing activity of vessels that were otherwise unobservable due to safety concerns. Information regarding the platform of observation and the time of fisher contact relative to net set (prior– or post–notification of observation) was recorded for each observed trip.

Driftnet

The driftnet fishery observer program was headquartered in San Diego where a staff of several observers and a port coordinator monitored fleet movements from San Diego to Eureka. Prior to the opening of the swordfish season, each active (and observable) driftnet vessel was assigned a first trip to carry an observer. This first trip was selected randomly from the first five trips the vessel was expected to make during the fishing season. On this and every subsequent fifth trip, the vessel would be obligated to carry an observer. Periodic contact between fishers and NMFS personnel established each vessel's fishing status.

Analyses/mortality

Simple descriptive statistics (e.g., mean, variance, and correlation coefficient) and scatter plots were used to screen the data for potential relationships between marine mammal mortality and various physical characteristics of the fisheries for the purpose of post-stratifying the data. Variables considered to potentially affect marine mammal mortality included water depth, soak time (number of hours the net is submerged), length of net and mesh size (driftnets only). Due to a paucity of observed marine mammal mortality for the driftnet fishery, post-stratification of the driftnet data was not deemed appropriate. However, simple correlation coefficients were still estimated.

Correlations between marine mammal mortality (summarised by trip) and variables representing measures of fishing effort (e.g., number of sets or soak time) were examined to try to determine a measure of effort most appropriate for calculating mortality rates for different species of marine mammals. Details of the methods used to post-stratify the data (set net) and to estimate total incidental mortality follow.

Set net

Gillnet fishers often participate in more than one fishery at a time. To separate halibut and angel shark data from circumstantial data collected for other set net fisheries, data were grouped by target species and mesh size. Analysis of set net data was restricted to sets with mesh size (stretched-mesh measurement) ≥8ins (20cm) and target species involving California halibut or Pacific angel shark. No attempt was made to analyse data for halibut and angel shark sets separately because the many similarities

between the two fisheries (e.g., mesh size and fishing locations) often made the assignment of target species arbitrary.

POST-STRATIFICATION

Pinniped entanglement data from central California were used to try to determine if prior-notification of set net fishers of their obligation to carry an observer (notification before nets were set) affected the rate of pinniped take. Data from central California were used because they represented the highest percentage of non-zero mortality sets, as well as the highest frequency of prior-notification of fishers. It was assumed that biases in pinniped mortality due to prior-notification would not be species specific; that is, results were assumed to be relevant for sets involving cetaceans as well. A test of the effect of prior-notification on observed pinniped mortality was formulated as a multiple regression problem. It was assumed that variability in the natural logarithm of pinniped mortality (K) could be described by a linear combination of various explanatory variables. To better identify variation in the mortality data resulting from prior-notification, several other factors potentially affecting pinniped mortality were included in the model. These factors included soak time, length of net, water depth, and a 'port effect' – included to account for any regional differences between Monterey and Morro Bay. Occasionally, net characteristics (e.g., suspender length or net material) changed along the length of a net. In such cases, the net's characteristics were described by section, but mortality was tallied for the net as a whole. A 'gear effect' was included in the model to account for differences in mortality between nets with only one set of characteristics (one section) and nets with multiple sections. The natural logarithm transformation was used to stabilise the variance and to make the data more nearly normal. The addition of 1 (i.e., K+1) ensured that the logarithm function (denoted 'ln') was defined for sets with zero mortality. The resulting model (with intercept term β_0) was

$$\mu_j = \beta_0+\beta_1X_{1j}+\beta_2X_{2j}+\beta_3X_{3j}+\beta_4X_{4j}+\beta_5X_{5j}+\beta_6X_{6j} \quad (j=1, \ldots, 129),$$

where

μ_j = mean log (pinniped mortality plus 1) for the jth set
(μ_j = $E(\ln(k_j+1))$, $\ln(k_j+1) \sim$ (indep.) $N(\mu_j, \sigma^2)$),
X_{1j} = soak time (hours) for the jth set,
X_{2j} = length of net (fathoms) for the jth set,
X_{3j} = water depth (fathoms) for the jth set,
X_{4j} = categorical variable indicating a port effect (X_4=1 if the observer's port station for the jth set was Monterey, and X_4= 0 otherwise),
X_{5j} = categorical variable indicating a prior-notification effect (X_5=1 if the set net vessel for the jth set was notified of observation responsibilities prior to setting the nets, X_5=0 otherwise),
X_{6j} = categorical variable indicating a gear effect (X_6=1 if the net for the jth set was made up of multiple pieces with different characteristics, X_6=0 otherwise).

Parameter estimates were obtained using ordinary least squares. A test of the hypothesis that there was no prior-notification effect is equivalent to a test of the hypothesis that β_5=0. Test statistics for this hypothesis and a test of the overall significance of the model (i.e., a test of the hypothesis that all coefficients except the intercept are zero) were based on the usual F statistic (e.g., Draper and Smith, 1981).

Density differences of California sea lions and harbor seals between central and southern California (south of Point Conception, Channel Islands excluded) were considered as a potentially important factor affecting incidental take rates of these species in the set net fishery. Due to the large number of zero-mortality sets (particularly in southern California, see Discussion), the assumption of normally distributed errors made for the previous model was considered inappropriate here. Therefore, we chose to model the natural logarithm of the odds of taking at least one marine mammal as a linear combination of various explanatory variables, where the number of sets involving positive mortality (Y) is assumed to follow a binomial distribution (i.e., a logistic model for the probability of taking at least one marine mammal (p), where $Y \sim B(p,n)$, n assumed fixed). A test of the hypothesis that there was no areal effect on mortality of these species was formulated in terms of a test of an areal effect on the odds ratio. The odds ratio is defined as the probability of at least one marine mammal mortality in a set divided by the probability of no marine mammal mortality in a set (p/(1-p)). To evaluate the odds ratio binomial observations were constructed by grouping the mortality data into two categories: zero-mortality sets and non-zero mortality sets. Because of the limited number of non-zero mortality observations available, our choice of a logistic model restricted the number of explanatory variables that could be considered. Next to area, soak time was considered to be one of the more important factors likely to affect mortality. A soak time effect was included in the model to account for the potential affect of longer soak times on the odds ratio. Soak time was treated as a categorical variable because of the limited data available. The resulting model (with grand mean μ) was

$$\ln [p_i/(1-p_i)] = \mu+ \alpha X_{1i} + \beta X_{2i}, \ (i=1,\ldots,4),$$

where

p_i = probability of taking at least one marine mammal in a set for the ith binomial observation $y_i \sim B(p_i,n_i)$ (i.e., $p_i = (\exp(\mu+\alpha X_{1i}+\beta X_{2i}))/(1+\exp(\mu+\alpha X_{1i}+\beta X_{2i}))$),
X_{1i} = categorical variable indicating a soak time effect (X_1=1 if odds ratio is for sets with soak times $\geq$ 27 hours, X_1=0 otherwise), and
X_{2i} = categorical variable indicating an areal effect (X_2=1 if odds ratio is for sets made in central California, X_2=0 otherwise).

Parameter estimates were obtained by maximising the log likelihood of the parameters given the data, using the technique of iteratively reweighted least squares. A test of the hypothesis that there was no areal effect is equivalent to a test of the hypothesis that β=0. A test statistic for this hypothesis was constructed as the difference in deviances (a measure of discrepancy formed from the logarithm of a ratio of likelihoods) between models fit with and without the parameter of interest (McCullagh and Nelder, 1983). A similar statistic was constructed to test for a soak time effect. Adequacy of the model was assessed using a chi-square goodness of fit test (McCullagh and Nelder, 1983).

MORTALITY ESTIMATION

Because total fishing effort was measured in days, total mortality (M) for each species was estimated as

$$\hat{M} = D \cdot \hat{f}_d,$$

where D = total number of fishing days (assumed known), $\hat{f}_d$ = estimated mortality/day = $(\Sigma_i k_i)/(\Sigma_i d_i)$, k_i=total

mortality for trip i, d_i=number of days for trip i and i=1,...,n where n=number of observed trips. The variance of total mortality was estimated as

$$\hat{\sigma}^2_M = D^2 \cdot \hat{\sigma}^2_r,$$

where $\hat{\sigma}^2_r$ = estimated variance of $\hat{f}_d$.

Observers collected data on every set made during a trip. As a result, trips represented clusters consisting of one or more sets. For the purpose of computing variance estimates, each trip was considered a data unit, assumed to be independent (and identically distributed). In addition, observed trips were assumed to be the result of a simple random sample.

Except for two trips from southern California, no other multi-day set net trips were observed. For single-day trips, the sampling unit, a trip, was equivalent to a day. Because of the predominance of single-day trips, $\hat{f}_d$ was assumed to be equivalent to a mean per unit estimator. In this case, an estimate of the variance of $\hat{f}_d$ is given by

$$\hat{\sigma}^2_r = (fpc/n)\ (1/(n-1))\ \Sigma_i(r_i-\bar{r})^2,$$

where r_i=kill on day (trip) i, $\bar{r}$=average kill per trip ($(1/n)\ \Sigma_i r_i$) (in this case, $\hat{f}_d=\bar{r}$), n=number of observed trips, and fpc=finite population correction factor (=1–f, f=sampling fraction). In order to calculate the finite population correction factor, it was assumed that the sampling fraction of trips was equivalent to the sampling fraction of days because the total number of trips was unknown.

Driftnet

MORTALITY ESTIMATION

For the driftnet fishery, $\hat{f}_d$ was equivalent to mortality per set, since driftnet vessels make only one set per twenty-four hour period. (Typically, the net is set in the late afternoon or early evening and pulled the following morning.) Because driftnet trips often last more than one day, the number of days per trip was itself random and $\hat{f}_d$ had to be treated as a ratio estimator (e.g. Cochran, 1977). An estimate of the variance of $\hat{f}_d$ was obtained by the linearisation (or delta) method (e.g., Efron, 1982),

$$\hat{\sigma}^2_r = (fpc/n)(1/\bar{d}^2)(\hat{f}_d^2\ \hat{\sigma}^2_d + \hat{\sigma}^2_k - 2\hat{f}_d\hat{\rho}\hat{\sigma}_d\hat{\sigma}_k),$$

where fpc and n are defined as above, $\bar{d}$ is the average number of days per trip, $\hat{\sigma}^2_d$ is an estimate of the variance of the number of days per trip ($= (1/(n-1))\ \Sigma_i(d_i - \bar{d})^2$), $\hat{\sigma}^2_k$ is the estimate of the variance of mortality per trip calculated in the same manner as σ^2_d, and $\hat{\rho}$ is the estimated correlation coefficient between mortality per trip and number of days per trip.

Analysis/Fishing effort

Estimates of the total fishing effort for July through December 1990 were made in order to estimate total marine mammal take during this time period. A unit of effort was defined as one boat having retrieved a minimum of one net on a given day (i.e., one day of fishing effort). Retrieval of more than one net was counted as one unit of effort if the nets were retrieved on the same day, and the target species were the same.

The primary source of effort data was the commercial gillnet fishers' daily fishing logs. Fishing logs are required by state law and are submitted monthly to the CDFG. The gillnet logs specify the area fished by CDFG block number (numbered rectangular quadrants (Appendices 1a and b)), type of gear fished, number of sets made, and the species of fish caught. Although most fishers complete logs for each net set, some fishing activity goes undocumented. To account for fishing effort not recorded in the gillnet logs, data from landing receipts of fish sales were incorporated into the total effort estimate. Landing receipts from licensed fish dealers are required by state law for each boat landing fish. Data collected by NMFS observers were used to verify gillnet log entries and to help identify fishing activity associated with landing receipts.

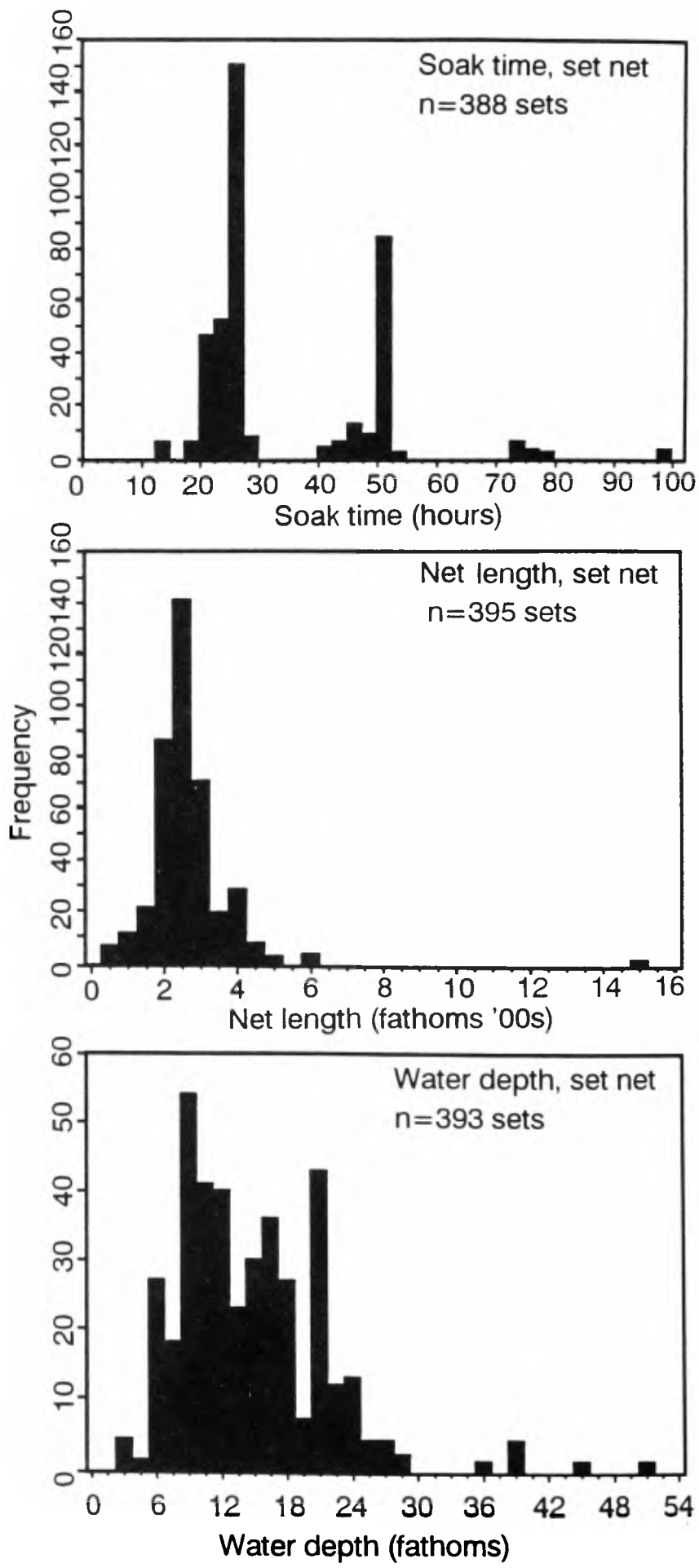

Fig. 1. Frequency distributions of soak time (hrs.), net length (fathoms), and water depth (fathoms) by set for the set net fishery, 1990.

Computer programs developed by the CDFG were used to verify target species against catch and gear data, and then to combine gillnet log data with landing receipt and observer data. One unit (a day) of fishing effort was tallied for each date which had a log entry, and/or an observation. Landing receipts that lacked corresponding log or observer entries three days before or after the landing date were also counted as one day of effort (it was assumed that the associated fishing effort was unlogged). The number of days fished per boat was tallied for each target species in a given area (CDFG block).

RESULTS

Set net

A total of 153 trips involving 406 sets were observed for the halibut and angel shark fisheries between mid-July and December 31 1990. A total of 60 trips involving 140 sets was observed in the central California area. Fifty-eight percent of the observed nets were single panel trammel nets; the remainder were non-trammelled set nets. Ninety-eight percent of the observed nets were constructed of monofilament material (single fiber nylon); the rest were constructed of multi-filament twine (nylon and other material). Ninety-nine percent of all observed halibut and angel shark nets had a mesh size of 8.5in (21.59cm). Partial observations were made on 10 sets, generally as a result of observations made from another vessel. Nine of these sets occurred in the Morro Bay area. The average number of sets per trip was 2.7 (SD=1.3). The average number of soak-hours per set was 31 (SD=13.82, n=388). The average net length was 253 fathoms (SD=103.8, n=395), and the average water depth per set was 14.1 fathoms (SD=6.59, n=393). Frequency distributions are presented in Fig. 1.

Scatter plots did not reveal any obvious relationships between marine mammal mortality and soak time, net length, or water depth. With the exception of the estimated by-set correlation between soak time and California sea lion mortality (central California, 0.42), estimated by-set correlations between marine mammal mortality (by species) and soak time were all less than 0.4 in absolute value. No preferable measure of fishing effort was evident for predicting marine mammal mortality, although weak relationships between California sea lion mortality and soak time and elephant seal mortality and soak time (estimated by-trip correlation coefficients were 0.32 and 0.31 (central California), respectively) were found.

Observed mortality

Total observed set net mortality was four harbor porpoises (*Phocoena phocoena*), three southern sea otters (*Enhydra lutris* subsp.) and 113 pinnipeds, including 67 California sea lions (*Zalophus californianus*), 30 harbor seals (*Phoca vitulina*), 13 northern elephant seals (*Mirounga angustirostris*), one unidentified otariid and two unidentified pinnipeds. Biological data collected from one harbor porpoise are summarised in Table 1. Otter and pinniped data are summarised in Table 2. The locations of observed sets and associated cetacean mortality are shown in Figs 2 and 3, sea otter mortality is shown in Fig. 3, and pinniped mortalities are displayed in Figs 4 and 5.

An additional 35 sets involving stretched-mesh sizes between 6.0 ins (15.2cm) and 6.5 ins (16.5cm), and target species other than halibut or angel shark were coincidentally observed. One harbor porpoise mortality was observed in a 6.25in (15.9cm) mesh net in the Monterey Bay area.

Table 1

Composition and life history of cetaceans incidentally killed in California Category I gillnet fisheries: July through December, 1990. Length is in centimeters. Maturity codes: U = unknown, analyses pending, M = sexually mature, P = pregnant. Comment codes: * = maturity and age determination pending, ** = age determination pending.

Map Code	Species	Location (N/W)	Sex	Length	Maturity	Comments
Driftnet						
1	*Delphinus delphis*	32°27.9 117°58.9	M	190	U	*
2		37°01.0 122°51.0	F	169	P	**
3		35°53.2 122°10.9	M	168	U	*
4		34°38.1 121°25.6	M	164	-	
4		34°38.1 121°25.6	F	163	P	**
5		32°34.5 117°29.2	M	153	U	*
6		31°59.0 118°08.1	M	-	M	**
7		32°49.2 120°02.1	M	-	-	
4		34°38.1 121°25.6	M	-	-	
8	*Lagenorhynchus obliquidens*	35°04.0 121°16.0	M	188	U	*
9		36°54.8 122°05.6	M	180	U	*
10		34°02.3 122°36.4	F	-	-	
11	*Globicephala macrorhynchus*	35°53.0 122°10.6	-	--		
12	*Phocoenoides dalli*	40°20.6 125°49.1	-	-	-	
13	*Mesoplodon* spp.	34°18.8 122°38.0	F	-	-	
Setnet						
S1	*Phocoena phocoena*	35°19.6 120°53.2	F	152	-	
S2		36°42.8 121°50.4	-	-	-	
S2		36°42.8 121°50.4	-	-	-	
S3		37°00.5 122°14.5	-	-	-	

Table 2

Summary of pinniped life history information collected from California Category 1 gillnet fisheries: July through December, 1990. Sex: M = male, F = female, U = unknown. Length: K = known, E = estimated, U = unknown. Age/maturity: A = age material collected, M = reproductive material collected.

	No.	Sex	Length	Age/maturity
Setnet				
Z. californianus	24	8F,3M,13U	12K,10E,2U	1A,1M
P. vitulina	19	4F,3M,12U	8K,8E,3U	3A,2M
M. angirostris	9	9U	2K,7E	-
E. lutris	2	2M	2K	2A,2M
Driftnet				
Z. californianus	2	1F,1M	2K	1A,1M
P. vitulina	1	1F	1K	1A,1M
M. angirostris	4	1F,2M,1U	3K,1U	1A,1M

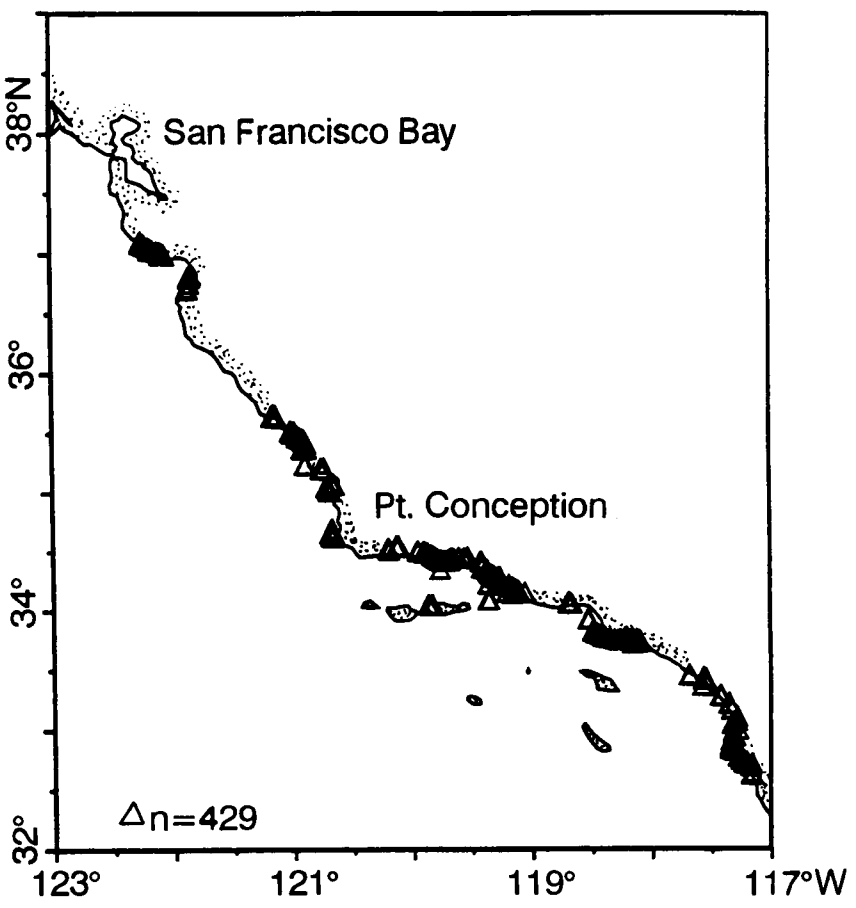

Fig. 2. Locations of observed sets (n=429) for the set net fishery, 1990.

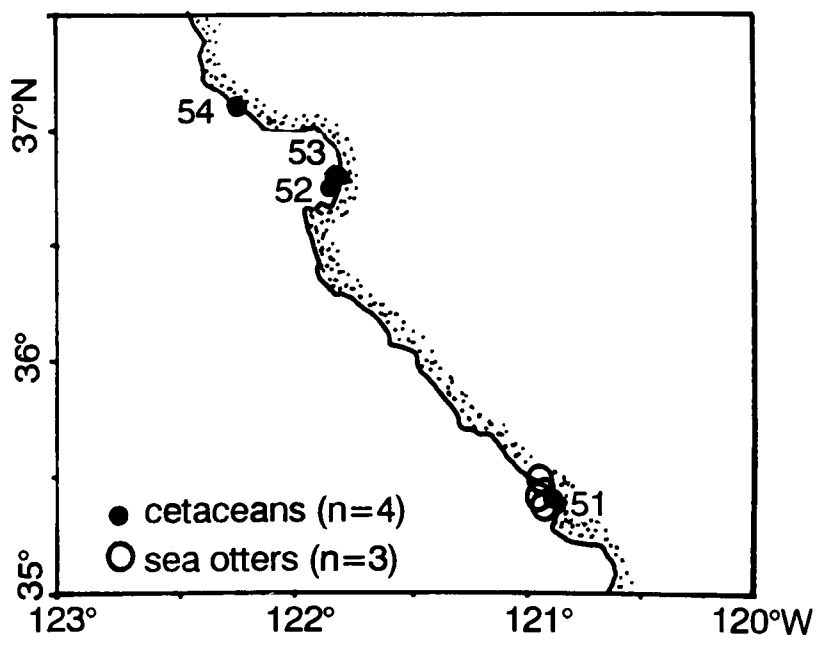

Fig. 3. Locations of observed cetacean and sea otter mortality by set: set net fishery: 1990. n=number of sets. Numbers next to filled circles refer to map codes given in Table 1.

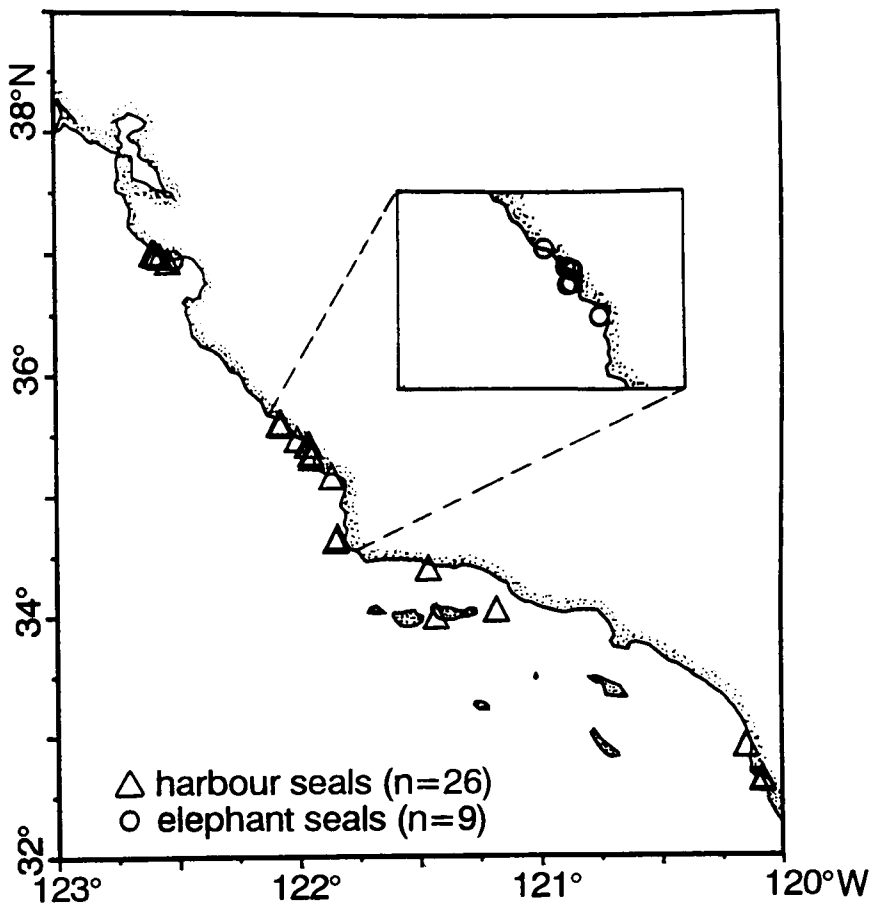

Fig. 4. Locations of observed harbor and elephant seal mortality by set: set net fishery: 1990.

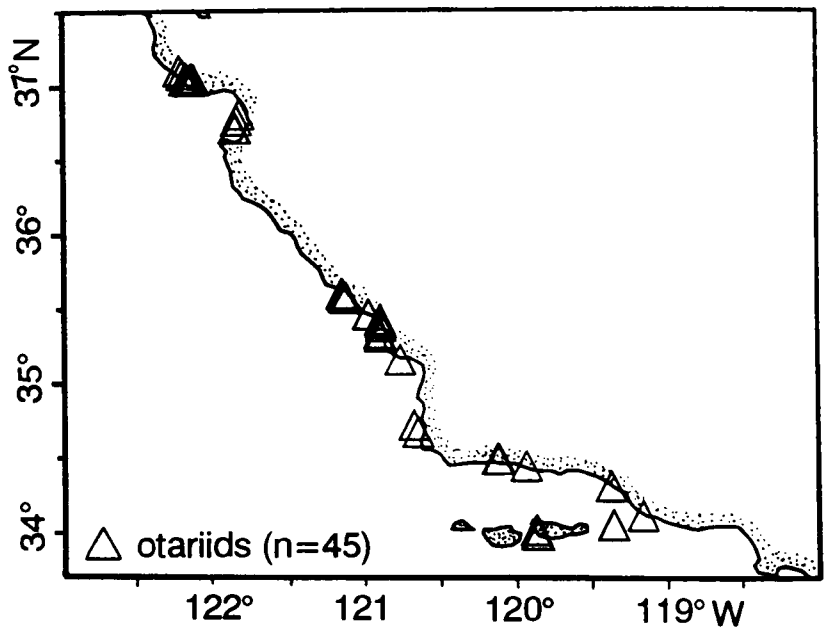

Fig. 5. Locations of observed otariid mortality (California sea lions and unidentified otariids combined by set): set net fishery: 1990.

Post-stratification

We were unable to detect an effect of prior-notification on pinniped mortality ($p = 0.36$); however the linear model proposed was significant ($p < 0.005$, $R^2=0.21$). The significance of this model was due largely to the coefficient for soak time which was significantly different from zero ($p < 0.005$). All other coefficients were not significantly different from zero ($p > 0.10$ for individual tests of each coefficient). A plot of residuals versus predicted values suggested that the natural logarithm transformation helped to stabilise the variance; however, a normal probability plot of the residuals showed some degree of skewness with respect to a normal distribution. Following these results, the data were not stratified by prior– versus post-notification.

Table 3

1990 (July through December) kill statistics for marine mammals involved with California Category I gillnet fisheries. Numbers in parentheses indicate standard errors; σ_b is the bootstrap estimate of the standard error. The drift-net and set-net (southern California) take rates for California sea lions includes unidentified otariids. CC = Central California, SC = Southern California, CI = Channel Islands.

Species	Observed killed	Kill/day	Total kill
Setnet			
Phocoena phocoena (central California)	4	0.067 (0.0382)	44 (25)
Enhydra lutris (central California)	3	0.05 (0.0269)	33 (18)
Zalophis californianus	67	CC=0.90 (0.1589) SC=0.055 (0.0279) CI=0.75 (0.3202)	847 (134)
Phoca vitulina	30	CC=0.400 (0.1013) SC=0.044 (0.0211) CI=0.167 (0.0868)	392 (83)
Mirounga angustirostris (central California)	13	0.217 (0.0876)	144 (58)
Driftnet			
Delphinus delphis	9	0.05 (0.0202) (σ_b=0.0207)	203 (82)
Lagenorhynchus obliquidens	3	0.017 (0.0093) (σ_b=0.0092)	68 (38)
Globicephala macrorhynchus	1	0.006 (0.0053) (σ_b=0.0052)	23 (22)
Phocoenoides dalli	1	0.006 (0.0053) (σ_b=0.0049)	23 (22)
Mesoplodon spp.	1	0.006 (0.0054) (σ_b=0.0053)	23 (22)
Mirounga angustirostris	4	0.022 (0.0106) (σ_b=0.0105)	90 (43)
Z. californianus	2	0.022 (0.0153) (σ_b=0.0155)	90 (62)
P. vitulina	1	0.006 (0.0053) (σ_b=0.0051)	23 (22)

The postulated areal effect on the mortality odds ratio for California sea lions and harbor seals was found to be significant (change in deviance=38.6 (d.f.=1), $p < 0.005$); however, the soak time effect was not significantly different from zero (change in deviance=3.4 (d.f.=1), p=0.07). There was no indication of a significant lack of fit for this model (goodness of fit test, chi-square, p=0.22), although one cell described by the logistic model involved less than five sets. Following these results, California sea lion mortality and harbor seal mortality were stratified by area (central California (Morro Bay and Monterey), and mainland California south of Pt. Conception), but not by soak time.

Mortality rates

In accordance with observed data and the known distributions of harbor porpoise and sea otters, estimates of the take rates for these animals in set nets were based on data from central California (Monterey and Morro Bay areas). Estimated take rates for elephant seals were also based on central California data as that was the only area where incidental mortality was observed. Cetacean and pinniped mortality rates are given in Table 3. The estimated mortality rate for California sea lions in southern California was based on observed mortality of both California sea lions and a single unidentified otariid.

The incidental take of marine mammals at the Channel Islands was estimated separately due to historical treatment of these data (Hanan *et al.*, 1988; Hanan and Diamond, 1989). No tests for significant differences between island and mainland rates were done. There were a total of 14 sets (three trips) observed near the Channel Islands (Fig. 2). Incidental marine mammal take associated with these three trips was nine California sea lions, two harbor seals, and one unidentified pinniped (one trip lasting 10 days accounted for 10 of the 14 sets and 10 of the 12 mortalities). Estimated standard errors for California sea lion and harbor seal mortality were obtained from variance estimates for take rates in each of the three areal strata (central California (c), mainland southern California (s), and Channel Islands (i)) according to the formula for variance of a sum (assuming covariance terms are zero): $\hat{\sigma}^2_M = D^2_c\hat{\sigma}^2_{rc} + D^2_s\hat{\sigma}^2_{rs} + D^2_i\hat{\sigma}^2_{ri}$.

Effort and total mortality

Observer placement at the six port stations began in mid-July, with the exception of the Los Angeles office, which was staffed by mid-September. Observer coverage was considerably lower than the targeted level of 20%; an estimated five to six percent of all set net fishing effort was observed between July and December 31, 1990. Observer coverage for central California was slightly better than for southern California; an estimated 10% of all fishing effort was observed. Coverage of the set net fisheries was not uniform because some boats were 'unobservable' due to safety considerations. The fraction of unobservable vessels differed by area. In particular, very few observations were made on vessels fishing near the Channel Islands or on vessels making multi-day trips from the Morro Bay area. It is estimated that one or more observations were made on 33% of all active vessels between July and September 30, increasing to 40% between October 1 and December 31. (Active vessels were defined as those vessels for which the CDFG had some record of fishing activity for halibut or angel shark).

The total number of days fished for the halibut and angel shark fisheries during July through December 1990, was estimated at 3,041. Fishing effort tallies for central California were estimated as the sum of effort within CDFG blocks 500 to 650. Fishing effort for the Channel Islands was estimated as the sum of effort in CDFG blocks 684–690, 707–713,760–762, 765, 806, 807, 813, 814, 829, 849, 850, and 867. Fishing effort for mainland southern California was estimated as the sum of effort from all blocks south of Point Conception (block numbers greater than 650) with the exception of effort in blocks included in the Channel Islands tally (Appendices 1a and b). Total

fishing effort for the Monterey and Morro Bay areas was estimated at 664 days; effort for mainland southern California was estimated at 2,206 days. Total fishing effort for the Channel Islands was estimated at 171 days with 98% of the effort occurring around the northern islands. No variance estimate was available for total fishing effort. Under the assumption that kill rates on unobserved trips were the same as kill rates on observed trips, these measures of total fishing effort were used to estimate total take of marine mammals in the set net fishery between July and December for each species for which observed incidentally take occurred (Table 3).

Driftnet

A total of 54 trips involving 181 sets were observed between late July and December 31, 1990. Seventy four percent of the observed sets involved nets made of multifilament twine (nylon and other material); the remainder were made of twisted monofilament material. There was only one partial observation (an estimated 80% of the net retrieval was observed). The average soak time per set was 12.1 hours (SD=2.45, n=180). Average net length and mesh size (stretched measurement) per set were 973.5 fathoms (SD=37.14, n=180), and 20.7 inches (SD=1.54, n=180), respectively. Average water depth per set was 1206.3 fathoms (SD=651.56, n=168). Frequency distributions are given in Fig. 6. The average number of sets (or equivalently days) per trip was 3.35 (SD=2.048).

Estimated by-set correlations of mortality with soak time, net length, water depth and mesh size were close to zero. Similarly, estimated by-trip correlations between marine mammal mortality and number of days, soak time, length of net and number of sets were low and approximately equivalent (less than 0.2 in absolute value). No preferable measure of fishing effort for predicting marine mammal mortality was evident for either cetaceans or pinnipeds.

Observed mortality

Fifteen cetaceans and nine pinnipeds were observed killed in driftnets. Cetacean species incidentally taken included nine common dolphins (*Delphinus delphis*), three Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), one short-finned pilot whale (*Globicephala macrorhynchus*), one Dall's porpoise (*Phocoenoides dalli*), and a single, unidentified mesoplodont beaked whale (*Mesoplodon* spp.). Life history data were available for 13 of these animals (Table 1). Incidental pinniped take included four northern elephant seals, two California sea lions, a single harbor seal, and two unidentified otariids. Pinniped life history data are summarised in Table 2. The locations of observed driftnet sets are shown in Fig. 7. Locations of sets involving cetaceans and pinniped mortality are displayed in Fig. 8.

Mortality rates

Mortality per day (equivalently mortality per set) for the driftnet fishery was calculated for each species of marine mammal incidentally taken by the fishery (Table 3). The estimated take rate of California sea lions was based on observed mortality of both California sea lions and unidentified otariids (two animals).

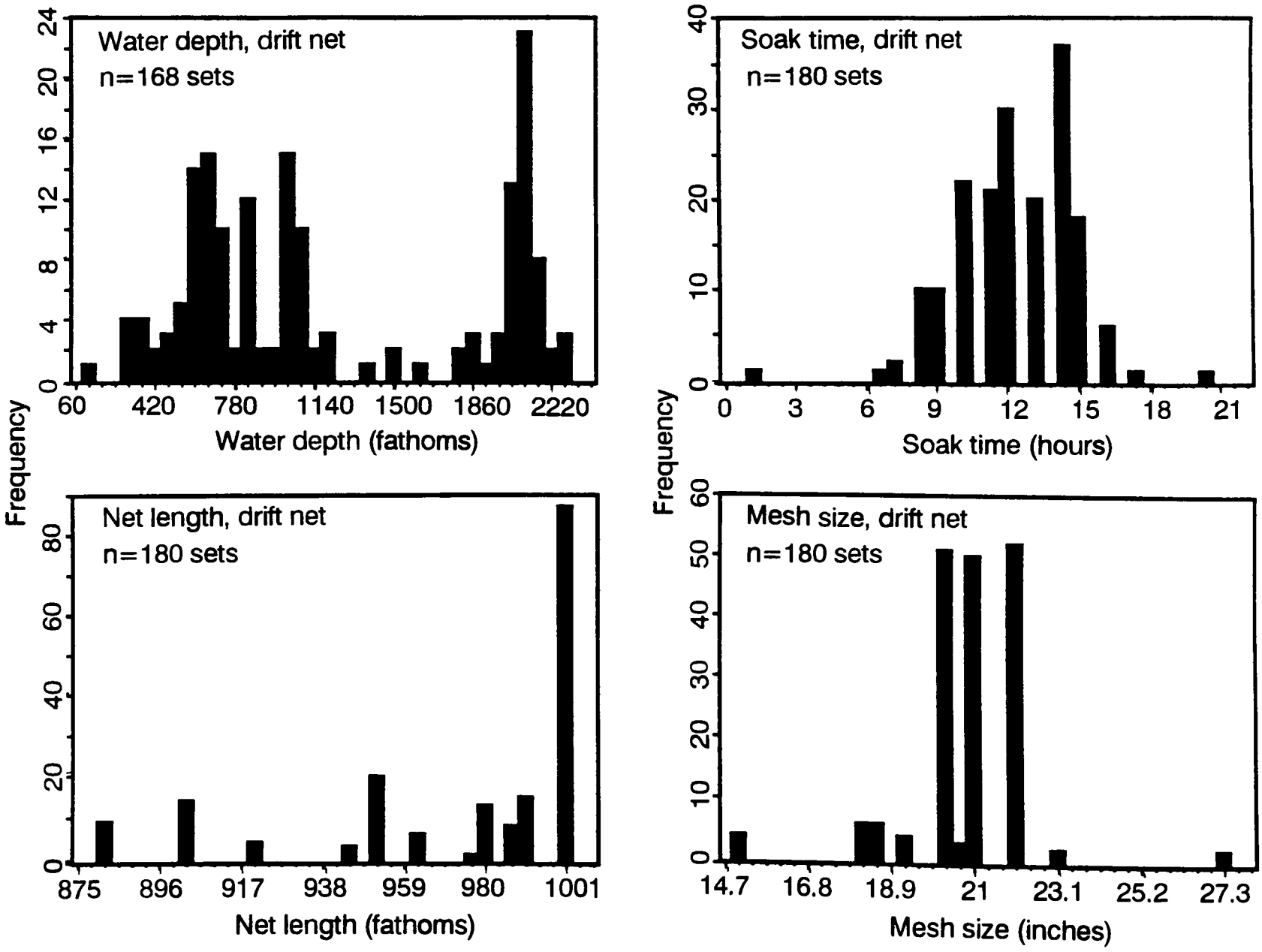

Fig. 6. Frequency distributions of soak time (hrs), net length (fathoms), water depth (fathoms), and mesh size (inches) by set for the driftnet fishery, 1990.

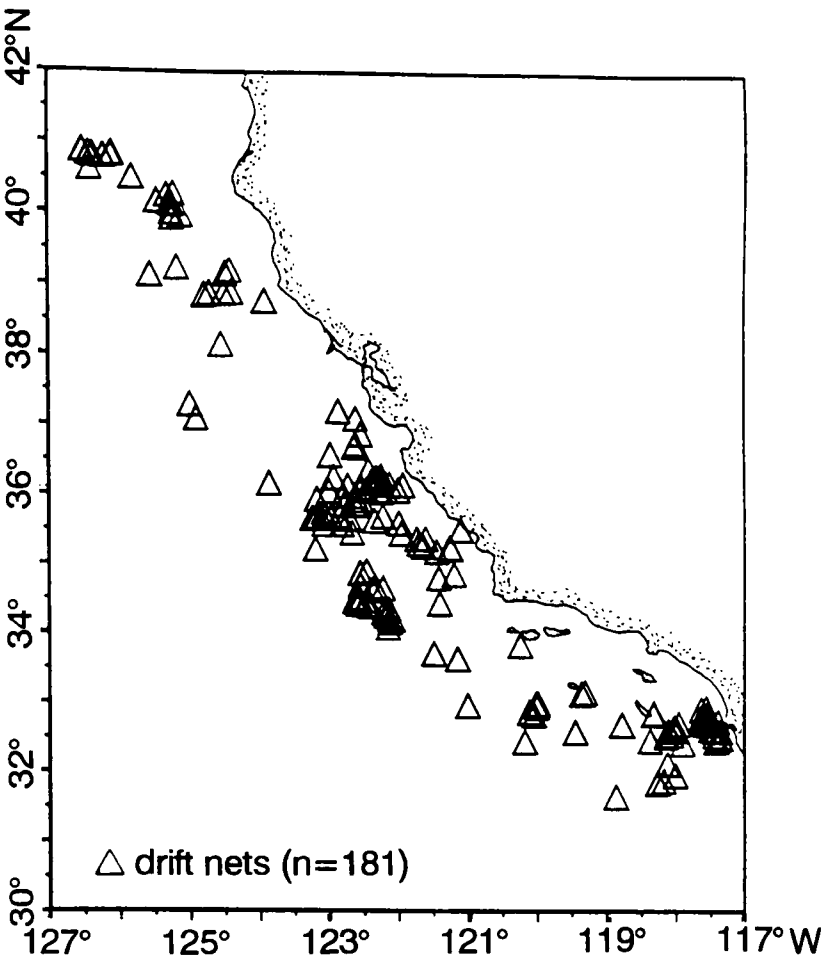

Fig. 7. Locations of observed sets (n=181) for the driftnet fishery, 1990. n=number of sets.

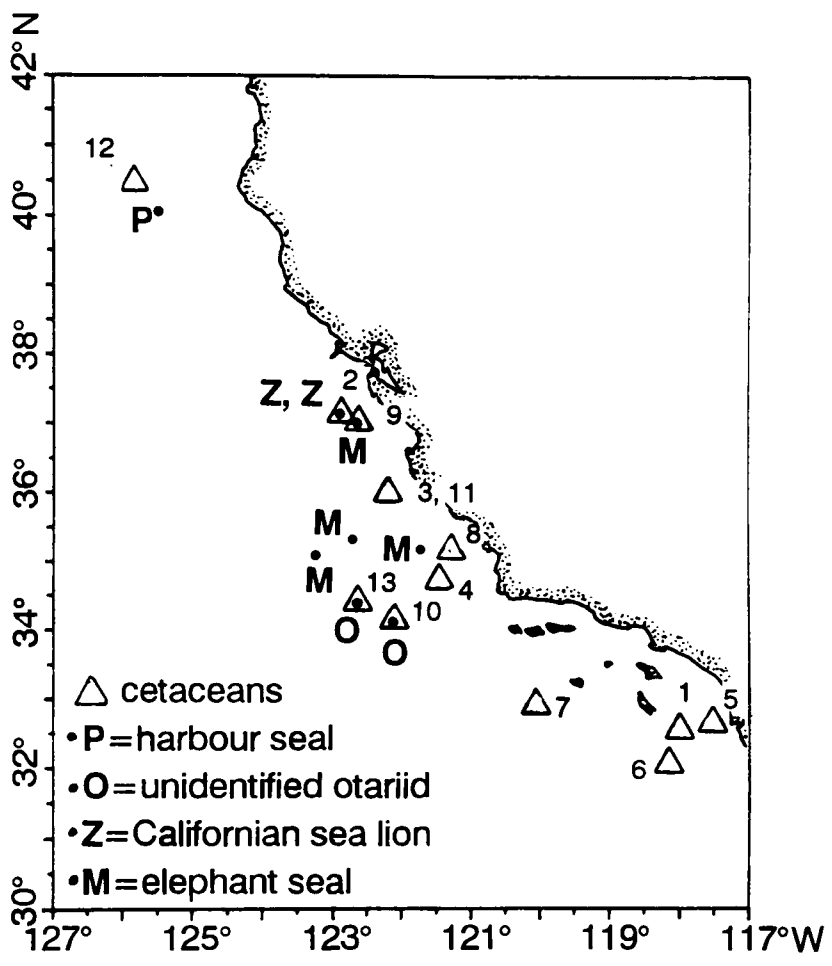

Fig. 8. Locations of observed cetacean and pinniped mortality by set: driftnet fishery: 1990. Numbers next to triangles refer to map codes given in Table 1. P=harbor seal, O=unidentified otariid, Z=California sea lion and M=elephant seal.

Effort and total mortality

As for the set net fishery, observer coverage was well below the targeted level of 20%; an estimated four percent of all driftnet fishing effort was observed. The 'unobservability' of many vessels prevented uniform coverage across the fishery. It is estimated that one or more observations were made on 16% of all active vessels between July and September 30, increasing to 27% between October 1 and December 31. (Active vessels were determined from CDFG effort data). Total fishing effort for the driftnet fishery for July through 31 December 1990 was estimated at 4,078 days. As with the set net estimates of total fishing effort, no variance estimate was available for total effort. Under the assumption that kill rates on unobserved trips were the same as kill rates on observed trips, this estimate of total fishing effort was used to estimate total kill of marine mammals for each species with incidental observed take between July and December 31 1990 (Table 3).

DISCUSSION

Life history

Life history data collected during the 1990 gillnet fishing season were too limited to draw any meaningful conclusions on the age and sex structure of species incidentally killed. As additional data are obtained, studies of reproductive parameters (e.g. Barlow, 1984; Hohn *et al.*, 1985; Myrick *et al.*, 1986) and stock structure will be initiated for species involved in these fisheries.

At least four of the cetacean species incidentally killed in California's gillnet fisheries are thought to be represented by several distinct geographical stocks. These animals include common dolphins (Banks and Brownell, 1969; Evans, 1975; 1982), Pacific white-sided dolphins (Walker *et al.*, 1986), Dall's porpoise (Kasuya, 1978; Winans and Jones, 1988) and harbor porpoise (Calambokidis and Barlow, 1991). Sufficient materials for stock identification were not obtained for most of the animals killed because of logistic problems involved with specimen collection at sea. Data collection protocols have been modified to mitigate these logistic difficulties so that sufficient specimen materials to assess stock structure will hopefully be obtained in the future.

The two female common dolphins collected (169 and 163cm in length) were pregnant. These animals are considerably shorter than the average length of sexually mature *Delphinus* reported from the eastern tropical Pacific (196cm) (Perrin and Reilly, 1984), but are within the range (164–193cm) reported for the short beaked form from coastal California (J.E. Heyning, pers. comm.). One male was sexually mature. Its length was not measured. Testes from three additional specimens were collected, but have not been examined to date.

Length and maturity data were collected from two male Pacific white-sided dolphins killed in gillnets during 1990. These animals were 188 and 180cm long – slightly less than the average length of sexually mature animals (190cm) reported by Walker *et al.* (1986). Determination of the reproductive condition of these two animals is pending.

Two male sea otters (124 and 93cm) were killed. The smaller of these animals was determined to be sexually immature (J. Ames, pers. comm.).

Relatively few life history data were collected from entangled pinnipeds. California sea lions are sexually dimorphic. Mature males average 220cm, and females 180cm (Odell, 1981). All of the sea lions observed killed between July and December were shorter than these figures and therefore were probably immature (Table 2).

The longest harbor seal reported was a 109cm female taken in the set net fishery. Bigg (1981) reports that average lengths of sexually mature *Phoca vitulina* are 161cm for males and 148cm for females (sample from British Columbia). It is probable that all of the harbor seals observed killed and measured this year were immature.

According to Le Boeuf (1979), the average length of sexually mature northern elephant seals is 360cm for females and 450cm for males. Reported lengths of elephant seals entangled this year ranged from 152 to 237cm. It is probable that no mature elephant seals were taken.

In spite of the small sample, it appears that the pinniped bycatch may be biased towards small or immature animals. Age biases in rates of gillnet entanglement have been suggested for harbor porpoise (Hohn and Brownell, 1990), Hector's dolphins, *Cephalorhynchus hectori* (Dawson, 1991) and Risso's dolphins, *Grampus griseus* (Kruse *et al.*, 1990). Additional data on age and reproductive status are necessary to assess bycatch characteristics more accurately.

Mortality rates

Comparability with historical estimates

Although the marine mammal mortality estimated here represents only six months, it is possible to make crude comparisons with annual estimates made for previous years. Our six-month set net mortality estimates for California sea lions, harbor seals, and harbor porpoise were 847, 392 and 44 respectively. These compare with average *annual* estimates of 2,597, 1,267 and 197 for the same species in fishing years 1983/4 through 1987/8 based on the CDFG observation program (data averaged from Diamond and Hanan, 1986; Hanan *et al.*, 1986; 1987; 1988; Hanan and Diamond, 1989; and Konno, 1990). Current estimates appear to be less than half the previous estimates. Given that more fishing typically occurs in the second half of the calendar year, total marine mammal mortality in set nets appears to be less than in previous years. However, average kill-per-day rates in set nets are similar between the data from 1990 (0.279, 0.129, and 0.066 for sea lions, harbor seals and harbor porpoises) and the average kill-per-day rates from 1983/4 through 1987/8 (0.266, 0.130, and 0.066, respectively for the same species). If mortality is truly decreasing, it would seem to be more related to a decrease in fishing effort than a decrease in kill rate. No estimates were made for northern elephant seal mortality in previous years.

Our six-month driftnet mortality estimates for California sea lions and harbor seals were 90 and 23 respectively. The corresponding average *annual* estimates for fishing years 1983/4 through 1987/8 were 328 and 50 (data averaged from Hanan *et al.*, 1988; Hanan and Diamond, 1989; Konno, 1990). Again current estimates are less than half the previous estimates. Average kill-per-day rates in driftnets in 1990 were 0.022 for sea lions and 0.006 for harbor seals, compared with average kill rates of 0.033 for sea lions and 0.005 for harbor seals for years 1983/4 through 1987/8. Effort for the July-December period (which represent the majority of the fishing season) was 4,078 days, compared to an average annual effort of 9,841 days in previous years. As with the set net fisheries, if mortality is truly decreasing, it would seem to be related to a decrease in fishing effort. No estimates were made for cetacean or elephant seal mortality in previous years.

Bias

Marine mammal mortality rates reported here may be unrepresentative of true take rates for several reasons. Unstratified (driftnet) or minimally stratified (set net) estimates of total mortality were computed for most species because it was felt that there were inadequate data to assess many factors considered likely to have affected marine mammal mortality. Additional data and more detailed analyses may indicate that these data should have been stratified and that our estimates are therefore biased estimates of actual take rates. We discuss several particular sources of bias below.

PRIOR-NOTIFICATION

Because of the nature of the set net fishery, it has been suggested that prior-notification of set net fishers of their obligation to carry an observer would result in a biased sample. That we were unable to detect any bias in these data due to prior-notification may indicate that set net fishers do not alter their fishing behavior substantially when an observer is onboard. On the other hand, our inability to detect any bias in the data may be due to the fact that vessel selection was not always based on random sampling. In areas where set net fishers were observed on approximately every fifth trip, the schedule for observation may have been better known than we would have preferred. More importantly, our inability to detect any bias due to prior-notification of fishers may have been a result of the model we used, the unbalanced nature of the data, or low sample size. More data would allow for construction of a more precise model to better describe sources of nuisance variation (e.g., inclusion of 'vessel effects') and increase statistical power. Because mortality data are positive, integer-valued data, and in this case, involved many zeros (60% of the 129 sets used in this analysis involved no pinniped mortality), formulation of this testing problem in terms of a generalised linear model analysis (e.g., natural logarithm link with Poisson-like variation) might well result in a better (and more theoretically sound) treatment of these data.

SOAK TIME

A potential relationship between soak time and marine mammal mortality in the set net fishery was demonstrated using a linear model for the natural logarithm of pinniped mortality per set. These results would conflict with the lack of significance found for the soak time effect on the mortality odds ratio for sea lions and harbor seals (based on a logistic regression analysis). There are several factors likely to be contributing to this disagreement. The two analyses were done on different data sets; the linear model for the logarithm of kill used all pinniped data from central California, the logistic model for the probability of at least one mortality only used sea lion, harbor seal and unidentified otariid data from central and southern California. Although there was a suggested positive relationship (albeit weak) between mortality for some species (in particular elephant seals and California sea lions) and soak time (from estimated correlation coefficients), other species showed no relationship at all (harbor seals were one such species). In addition, data for the logistic regression were grouped by zero kill versus positive kill and soak time (less than 27 hours versus 27 or more hours (following inspection of Fig. 1)). The occurrence of a few high mortality sets with soak times of 72 hours or more may have exerted considerable influence on the results of the linear model for the logarithm of kill. Moreover, interactions between soak time and area (central versus southern California) may exist but were not included in the logistic model because of inadequate data (however, in general, take rates in southern California were much lower than in central California regardless of the time the net soaked). The paucity of observations

involving mortality make identification of factors affecting marine mammal mortality difficult (e.g., in the case of the data set for the logistic regression, less than 15% of the data involved non-zero mortality sets).

AREA

Observer data indicate that take rates of marine mammals for the set net fishery at the Channel Islands may be considerably higher than those for mainland southern California (Table 3). Pinniped rookeries at the Channel Islands tend to cluster animals geographically. Unfortunately our sample size of three trips, while accounting for approximately 7% of the total estimated fishing effort, may not be representative, severely biasing our estimates of take rates for pinnipeds at the Channel Islands. These data only add emphasis to the importance of increasing efforts to monitor fishing activity near the Channel Islands.

Although Monterey and Morro Bay set net data were grouped together as one areal strata, there appeared to be notable (although not statistically significant) differences between the set net fisheries operating in the two areas. The average soak time in Monterey Bay was considerably longer than the average soak time for Morro Bay, although the average number of sets per trip was considerably less (Table 4). Daily rates of cetacean mortality (harbor porpoise) for Monterey and Morro Bay were 0.115 (SD=0.4315) and 0.033 (SD=0.1826), respectively. We were unable to detect a difference in kill rates between the two areas (Student's t test (unequal variances), t=0.9028, d.f.=32, $p > 0.10$).

Table 4

Number of trips and sets and the average number of sets/trip, soak time/set, net length/set and water depth/set reported from the Monterey and Morro Bay-based set-net fisheries: July through December, 1990. Standard deviations are in parentheses. Data are from sets made with nets with stretched-mesh lengths ≥ 8.0 inches (20.3cm). Average soak time, net length and water depth for the Morro Bay area are based on 97 sets due to missing data.

Characteristic	Monterey	Morro Bay
No. sets	32	108
No. trips	26	34
No. sets/trip	1.2 (0.43)	3.2 (1.14)
Soak time (hrs.)	51.8 (16.24)	35.1(13.48)
Net length (fathoms)	352.5(65.17)	235 (26.26)
Water depth (fathoms)	21.7 (1.18)	17.4 (2.25)

OBSERVED VERSUS UNOBSERVED FISHING ACTIVITY

We have assumed that take rates based on observer data are representative of the fisheries as a whole, even though certain segments of both set net and driftnet fisheries were never observed (i.e., small vessels and distant fishing areas). Initial inspection of CDFG gillnet log data has revealed some differences between the log data and NMFS observer data. For example, 43% of the mesh sizes reported in the driftnet log data were between 14 and 19 inches (35.5–48cm); only 8% of NMFS driftnet observer data have comparable mesh sizes (Fig. 6). The distribution of water depths recorded in the gillnet log data for the set net fishery in Morro Bay area is bimodal with 19% of the sets made in water depths less than or equal to 11 fathoms; only 2% of the set net observer data for the Morro Bay area have comparable water depths (Fig. 9). It is clear that further analysis on the CDFG log data in connection with the observer data is necessary. Such analysis may suggest that take rates based on observer data collected under the present methods are not representative of unobserved set net or driftnet activity. In addition, we have estimated total mortality for July 1 through December 31 1990, even though data for estimating take rates were not available from some areas for July and August.

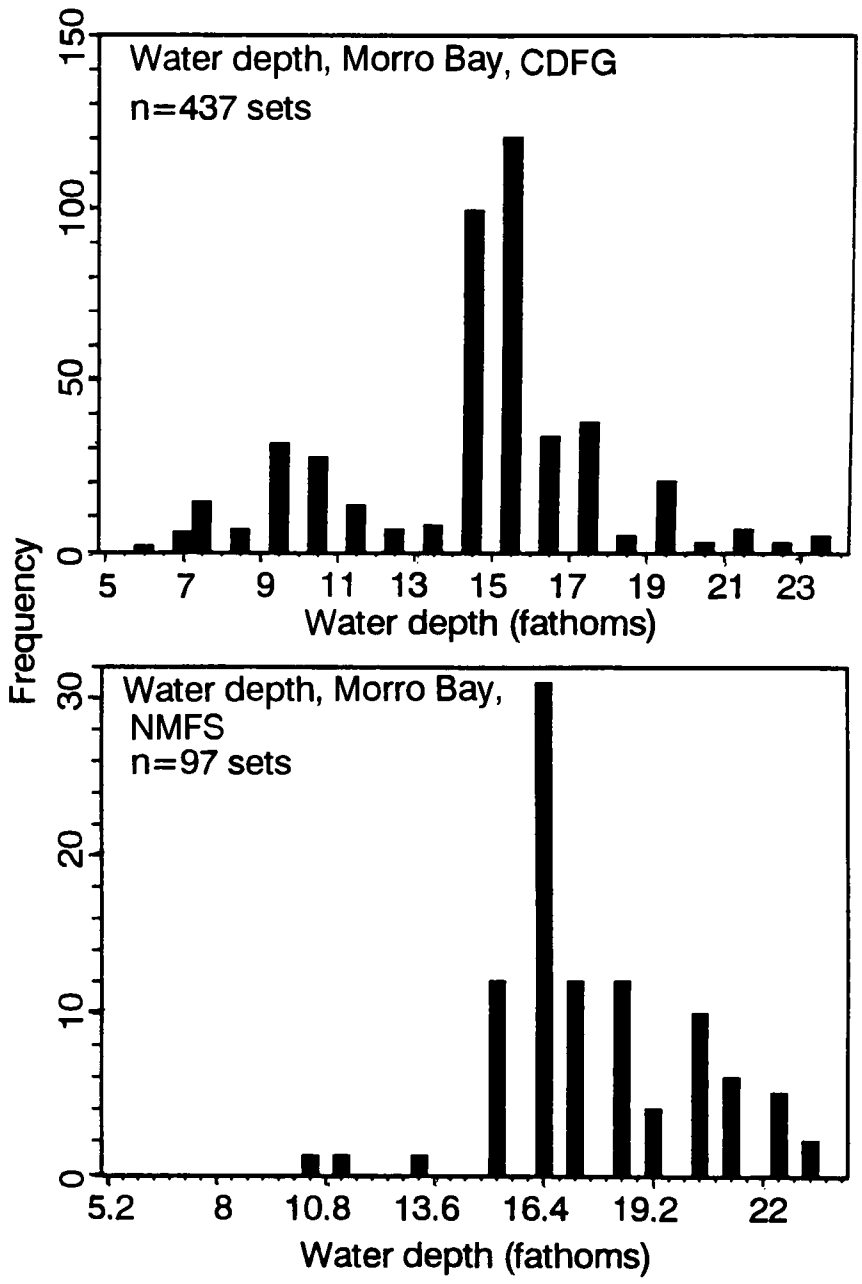

Fig. 9. Comparison of water depths for Morro Bay area set net fisheries, observed vs. non-observed trips: 1990.

Data collection/sampling

Identification of vessels actively participating in these three Category I fisheries has been an ongoing problem. With the exception of the set net fishery in Monterey (a result of previous CDFG programs), fishers are not required by law to notify NMFS personnel regarding their fishing status. In particular, driftnet vessels fishing up and down the coast of California may never visit the same port twice. While cooperation of some vessels has been good, port coordinators may only become aware of active vessels by way of CDFG effort data (which are only available after a three month time lag). The inability of NMFS personnel to identify and track all active fishing vessels affects the percentage of fishing effort observed as well as their ability to obtain a representative sample of data from the fleet. This problem is compounded by the fact that, once identified as active, some vessels are 'unobservable' except from an alternate platform. As opposed to reports of entanglement of baleen whales in driftnets and set nets off the California coast (Heyning and Lewis, 1990), no entanglements for these species have been reported by our program to date. It is possible that more species were taken

by gillnets than were documented by our program. Small sample sizes and/or biases resulting from constraints imposed on the sampling program could result in mortality of certain species never being observed. Clearly, mitigation of logistic sampling problems is crucial to the quality of data that can be obtained through this program.

Estimation methods

Because the only source of total fishing effort for these gillnet fisheries is in terms of days fished, total mortality was estimated using the estimator kill per day. However, for the driftnet data, there was effectively no correlation between marine mammal mortality and number of days fished. It would seem that the number of days fished may be a poor predictor of incidental marine mammal take. In addition, the number of days fished would seem to be a poor measure of effort for the set net fishery because it is not uncommon for more than one net to be pulled in a day. Identifying other measures of fishing effort showing substantial positive correlation with marine mammal take would likely allow for improvement of both the precision and the accuracy of estimated total take of marine mammals.

In this analysis we have treated these data as though they were the result of a simple random sampling scheme. This is not the case for either fishery. In many cases, random selection of vessels in the set net fisheries was considered to be unworkable because of the number of active vessels on any given day, the limited cooperation of some fishermen with NMFS personnel, and the perceived inequity of any particular vessel carrying an observer on more than one consecutive trip. Non-random selection of set net vessels often followed a system similar to that used for sampling driftnet vessels (i.e., every fifth trip). Calculation of variance estimates did not reflect the structure of the data and may be under or over-inflated due to dependencies within the data which were not taken into consideration.

Given the sampling assumptions made, we believe the linearisation method provided a reasonable estimate of the variance for the ratio estimate of kill per day for the driftnet data, even though estimated coefficients of variation exceeded guide lines provided in Cochran (1977). As a heuristic measure of the adequacy of the linearisation technique (as regards truncation of the Taylor series expansion used to estimate the variance function), estimates of the variance of kill per day were computed following a resampling method for finite populations proposed by Sitter (1992b) (Appendix 2). Variance estimates obtained from this procedure were very similar to those obtained using the linearisation procedure (Table 3).

Fishing effort

The estimated total gillnet fishing effort for July through December 31 1990 presented here is only preliminary. Even when the gillnet log data are complete, estimated fishing effort may be biased. It is not clear exactly what percentage of effort goes unlogged. Landing receipts can account for some unlogged effort, but the actual fishing effort associated with each landing receipt may vary considerably from the one day allotted. In addition, the landing receipt database is itself incomplete. Incomplete fishing logs may influence regional effort estimates; gillnet fishers occasionally neglect to record the specific location fished and the effort is subsequently assigned to a general area. Variance estimates for total days fished are currently not available. Inclusion of variability of the estimated total effort would increase the variability associated with estimated total marine mammal mortality.

Our treatment of fishing effort lacking a specific CDFG block assignment undoubtedly affected our estimate of total mortality for the set net fishery because we used a stratified estimator (by three areas). While it seemed unlikely that effort assigned by the CDFG to the general areas of Monterey or Morro Bay would be from fishing occurring in southern California (south of Pt. Conception), unspecified effort for the Los Angeles/Ventura area may have represented some fishing effort that occurred at the Channel Islands. Twenty percent of the fishing effort assigned to southern California was only assigned a regional area (34 days to San Diego and 401 days to Los Angeles/Ventura). Given our uncertainties as to the most appropriate method for prorating this unspecified effort, we chose to use the regional areas to stratify the effort according to our three areal strata (central California, southern California or Channel Islands).

While available data are limited, we can do little other than assume that gillnets fish indiscriminately and that when placed in areas of known marine mammal concentration, are likely to incidentally kill a wide variety of these animals. Preliminary findings underscore the need to continue the gillnet observer program (preferably at an increased level of observer coverage) until adequate analysis of the impact of incidental mortalities on marine mammal populations can be made for all marine mammal species incidentally taken in these fisheries.

Postscript

The NMFS observer programme has now been running for over three years. A summary of the level of sampling coverage achieved, and of marine mammal mortalities for 1991 through 1993 can be found in Barlow *et al.* (1994) and references therein.

ACKNOWLEDGEMENTS

We are indebted to Peter Perkins for his invaluable comments regarding our statistical analyses and the organisation of this report, in addition to providing useful statistical discussions. Susan Chivers, Doug DeMaster, Karin Forney, Tim Gerrodette, Debra Palka, and Steve Reilly of the Southwest Fisheries Science Center (NMFS), Dick Butler and Norm Mendes (NMFS – Southwest Regional Office), and Doyle Hanan (CDFG) kindly reviewed our manuscript and strengthened it with their useful comments and suggestions. Nancy Lo and Bruce Wahlen of the Southwest Fisheries Science Center provided critical reviews of our statistical analyses. We appreciate the cooperation of the California gillnet fishers who allowed observers access to their boats. We especially thank the NOAA observer-technicians and their port coordinators whose hard work and dedication to the California gillnet monitoring program made this report possible.

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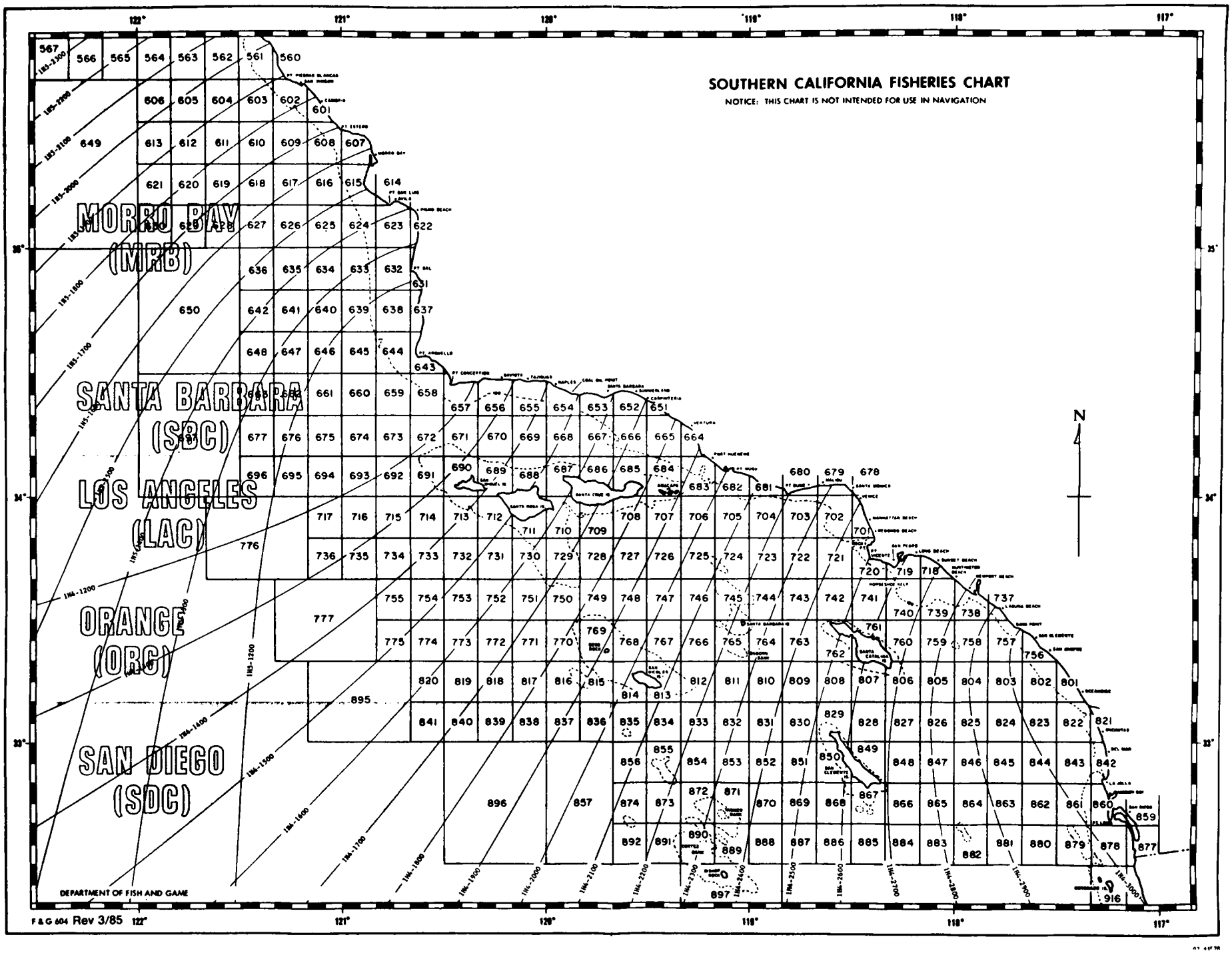
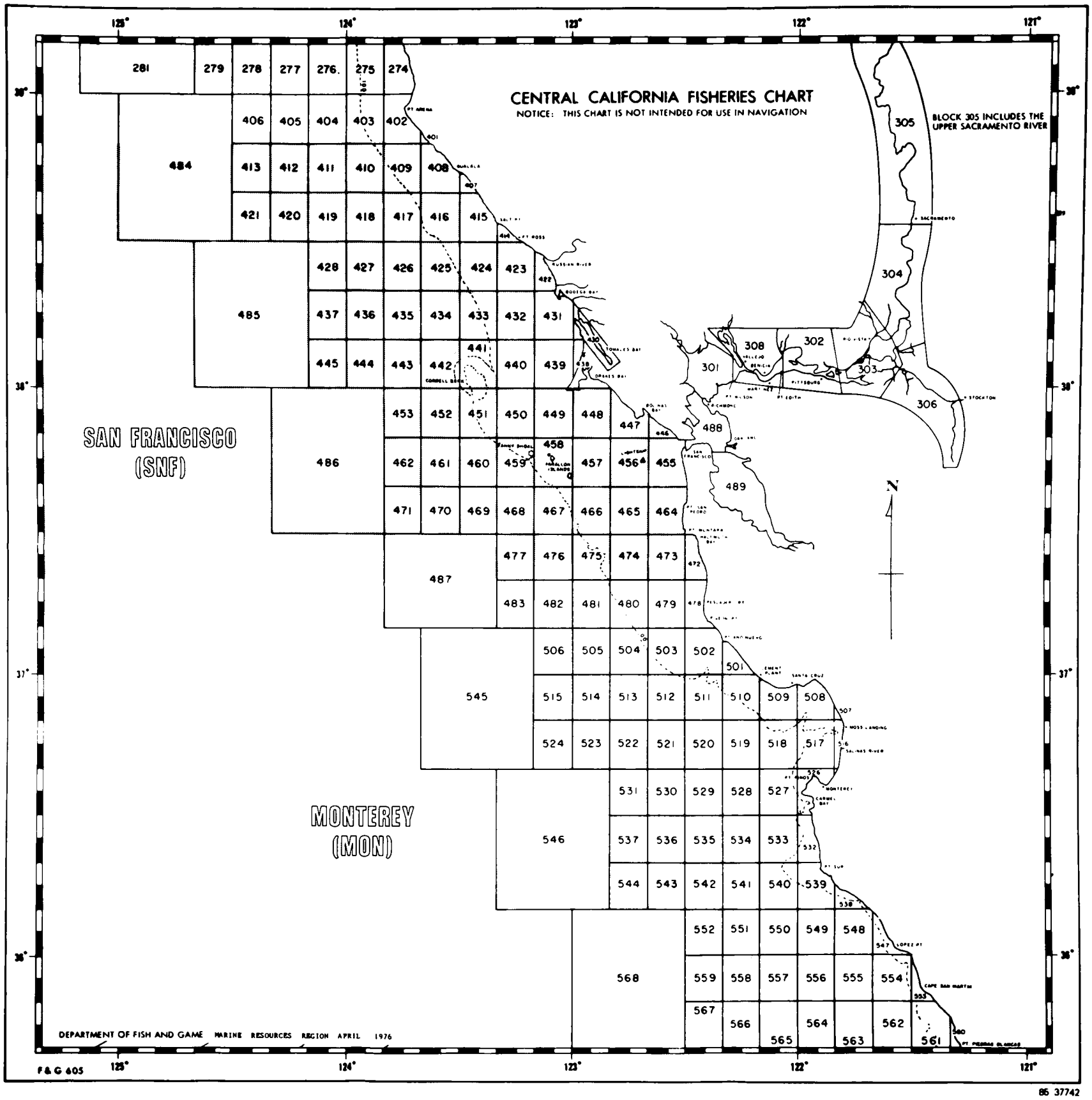
APPENDIX 1

CALIFORNIA DEPARTMENT OF FISH AND GAME FISHERIES MANAGEMENT BLOCKS





APPENDIX 2

Although our sample size from the driftnet fleet was not small (a sample of 54 trips was obtained), the estimated coefficients of variation for mortality per trip and number of days per trip were large. Cochran (1977) gives conditions under which the linearisation technique provides a reasonable estimate of the variance of the ratio. As a comparison against our estimates of variance obtained using the linearisation method, estimates of the variance of kill per day were computed following a resampling method for finite populations proposed by Sitter (1992b). In brief, for each of 1,000 bootstrap samples, trips were resampled without replacement m times where m=f·n, f=sampling fraction for the true population, n=number of observed trips. Then k subsets of size m were drawn with replacement from the n observed trips, k=n·(1-f*)/m·(1-f), where f*= bootstrap sampling fraction. Both k and m were, in this case, non-integer, so randomisation between bracketing integers was used at each bootstrap sample (see Sitter, 1992b, for details). The variance of kill per day was then estimated using the usual Monte Carlo approximation $((1/B)\cdot\Sigma_i(\Theta_i-\Theta)^2$, where Θ_i=ith bootstrap replicate of kill per day, Θ= $(1/B)\ \Sigma_i\ \Theta_i$, i=1,...,B). Variance estimates obtained from this procedure were very similar to those obtained using the linearisation procedure (Table 3). However, estimates were based on the same sampling assumption: that the data were the result of a simple random sample. With additional data, a multi-stage bootstrap procedure which more closely mimicked the actual sampling procedures used in the field could be constructed (e.g., see Sitter, 1992a; 1992b; Rao and Wu, 1988; McCarthy and Snowden, 1985). In as much as the actual driftnet data sampling procedures were more involved than simple random sampling, such a resampling procedure (while computer intensive) would likely be easier to implement than an estimate based on the linearisation method.

Southeastern Pacific

SC/O90/G11

Gillnet Fisheries and Cetaceans in the Southeast Pacific

Julio C. Reyes[1]

Grupo Cetáceos-ECCO. Centro Peruano de Estudios Cetológicos, (CEPEC). Casilla 1536, Lima 18, Peru

and

Jorge A. Oporto

Centro de Investigación y Manejo de Mamíferos Marinos (CIMMA), c/o Instituto de Biología Marina Universidad Austral de Chile. Casilla 567, Valdivia, Chile

ABSTRACT

A general description of gillnet fisheries in the Southeast Pacific area (comprising the waters of Ecuador, Peru and Chile) is presented and their potential threat to cetaceans is discussed. Information was gathered mainly through a literature review and interviews with fishermen and fishery experts but direct observations are included where possible. Gillnets are the main fishing gear used in waters of the region. In Peru they represent around 60% of the fishing gear used. Mortality of small cetaceans in fishing nets is known to be high in Peruvian waters where a market for their meat exists. An unknown number of large and small cetaceans are taken incidentally in the gillnet swordfish fishery in Chilean waters. Some tens to a few hundred dolphins and porpoises die every year in southern Chile in an expanding coastal gillnet fishery for ratfish and sciaenids. The scanty information from Ecuador suggests that a few hundred animals may get entangled in fishing nets every year. No foreign driftnet fisheries operate in or off the waters of the region. Little specific information on gillnet fisheries is available as they are pooled with other fisheries as 'artisanal' by national agencies. It is recommended that national agencies institute studies to evaluate the impact of gillnet fisheries on small cetaceans and other marine organisms, including commercially exploited species. Research on alternative fishing methods should be considered in order to reduce cetacean mortality without damaging the fisheries.

KEYWORDS: INCIDENTAL CAPTURE; SOUTH PACIFIC; FISHERIES; BOTTLENOSE DOLPHIN; SPOTTED DOLPHIN; BURMEISTERS PORPOISE; DUSKY DOLPHIN; COMMON DOLPHIN; RIGHT WHALE DOLPHIN; SHORT-FINNED PILOT WHALE; RISSO'S DOLPHIN; KILLER WHALE; FALSE KILLER WHALE; PYGMY SPERM WHALE; DWARF SPERM WHALE; CUVIER'S BEAKED WHALE; LESSER BEAKED WHALE; HUMPBACK WHALE

INTRODUCTION

The Southeast Pacific is one of the richest marine environments of the world. Exploitation of marine resources is a major activity in countries such as Ecuador, Peru and Chile, and several projects have been implemented in the region to develop or improve fishing methods. Among these, the introduction of gillnets was preferred over others because of the relatively low cost and high yields of such fisheries. However, a disadvantage of such fishing gear is that it may take non-commercial fish species and other marine vertebrates, including marine mammals.

In this paper we review the gillnet fisheries in the Southeast Pacific area (Fig. 1) in an attempt to characterise each of them and document their interactions with cetaceans. The extent of the area and the lack of research on these fisheries is reflected in our report, which is based on a literature review, interviews with fishermen and fishery experts, and direct observations in Peru and Chile. For Ecuador, the only available information to us was that from correspondence with fishery experts. Since our review was completed, new information has been provided in papers included in this volume (pp. 475–83).

LITERATURE REVIEW

Entanglements of cetaceans, in particular small cetaceans, in the Southeast Pacific area have been reported in the literature since the 1960s. Incidental mortality of small cetaceans in Peruvian waters was reported by Clarke (1962), Grimwood (1969) and Clarke *et al.* (1978). More recently the exploitation of small cetaceans in Peruvian

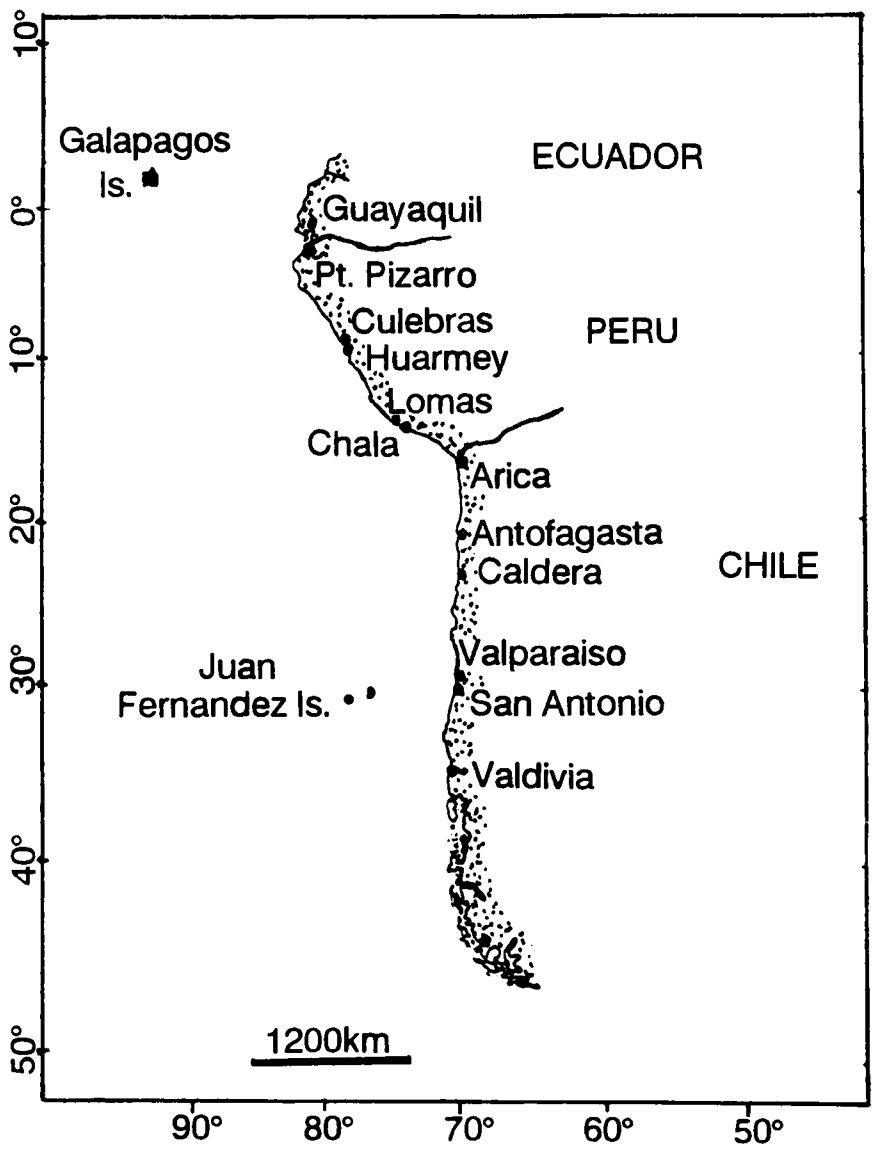


Fig. 1. The Southeast Pacific area with main referencial locations.

[1] Present address: *Casilla 392, Talcahuano, Chile*

waters has been documented in several studies (Read *et al.*, 1988; Van Waerebeek *et al.*, 1988; Van Waerebeek, 1989; Van Waerebeek and Reyes, 1990; 1994; Reyes and van Waerebeek, 1991). For Chile there is information from Norris (1968), Aguayo (1975), Torres *et al.* (1979), Cárdenas *et al.* (1986), Guerra *et al.* (1987) and Oporto (1989). For Ecuador information was lacking until very recently and remains unpublished (B. Haase, *in litt.*, 21 July 1990; K. Van Waerebeek, pers. comm.). Fishery interactions and exploitation of cetaceans in the Southeast Pacific has been reviewed by Mitchell (1975) and Northridge (1984).

Gillnet fisheries have not been the subject of specific studies. Most of what is known has been gleaned from the reports on artisanal fisheries that are released by national agencies throughout the area (Ancieta, 1976; Arana, 1976; Campos, 1976; Instituto Nacional de Pesca, 1976; Herdson *et al.*, 1985; Martínez *et al.*, 1987; Wosnitza-Mendo *et al.*, 1988). The swordfish gillnet fishery in Chile may be the only one under current study (Pesquera Catalina, 1982; Barbieri, 1988b; Bustos, 1990 and pers. comm.).

DESCRIPTION OF FISHERIES AND CETACEAN BYCATCHES

Ecuadorian gillnet fisheries

Location of ports

There are about 60 fishing centres along the Ecuadorian coast within the four coastal provinces, and in most of them gillnets and trammel nets are used (Herdson *et al.*, 1985).

Target species

The main target species are billfishes (*Istiophorus platypterus*, *Tetrapterus audax*, *Makaira* sp. and *Xiphias gladius*), sharks (*Carcharhinus* sp., *Alopias* sp., *Mustelus* sp., *Isurus oxyrhinchus*, *Prionace glauca*, *Sphyrna* sp.), sciaenids (*Cynoscion* sp., *Isopisthus* sp.), tripletails (*Lobotes pacificus*), jacks (*Caranx* sp.), catfish (*Bagre* sp., *Arius* sp.) and shrimps and lobsters.

Area of operation

Although no detailed information is available, it seems that most gillnet fishing occurs in waters close to the coast, within 20–30 n.miles from shore (Herdson *et al.*, 1985; Massay, 1987; Anon., 1989a; b).

Vessels and crew

Fishing boats are made mainly of wood, although some are made of fibre-glass. The most common vessel is the dug-out canoe (6–11m long) powered by an outboard engine. Similar sized boats called '*balandra*' and '*lancha*' are also used in the net operations. Most boats lack basic navigational equipment (Montano, 1987). Nets are hauled by hand; very few boats are equipped with hydraulic winches. The crew usually consists of three Ecuadorian fishermen, but can be as high as five in larger boats. Fish capacity ranges from 1–5 metric tonnes. Fish is handled fresh. Some boats may have facilities to add ice to the fish products (Instituto Nacional de Pesca, 1976; Herdson *et al.*, 1985; Massay, 1987; Montano, 1987).

There are about 230 boats in Manabi Province. In El Oro and Esmeraldas Provinces there are around 1,040 and 287, respectively (Anon., 1989a; b; c). There is no information on how many boats use gillnets.

Gear

Most nets are of nylon, but there are still some cotton nets in use (Instituto Nacional de Pesca, 1976). Trammel nets may be 72m long and 1.8m deep, while gillnets may range from 72 to 216m long and 3.6 to 14m deep (Instituto Nacional de Pesca, 1976; Martínez, 1987). According to Martínez (1987), the total net length may be as high as 3,000m. From information on the length of each panel given by Herdson *et al.* (1985), the number of panels set by vessels may range from 3–40. Mesh sizes in trammel nets are usually 23cm (first net) and 11cm (second net). Gillnets nets have mesh sizes ranging between 5–20cm, depending on the target species (Instituto Nacional de Pesca, 1976). Floats are made of cork, light wood or plastic. The space between floats varies according to the depth at which the net is meant to operate. In the case of large gillnets for sharks, the mean distance may be 1m (Instituto Nacional de Pesca, 1976; Martínez, 1987).

Operations

Trips last from 12 hours to 1–2 days, depending on the type and availability of target species, although in some cases trips may last as long as five days (Herdson *et al.*, 1985; Anon., 1989c). Depth in fishing areas can vary from 80m to 250m (Herdson *et al.*, 1985).

Trammel nets are usually set on the bottom to catch shrimp, lobster and some demersal fish species. Gillnets and trammel nets are left to drift to catch catfish, jacks and tripletails in midwater and billfish and sharks at the surface (Herdson *et al.*, 1985).

Economics and history

Most fishery products are consumed locally (Herdson *et al.*, 1985); billfish are exported to the USA, Japan and Korea (Martínez, 1987). In general, fishery products receive no special processing. Fish are eviscerated and kept fresh by the addition of ice. Part of the billfish catch is smoked (Herdson *et al.*, 1985; Martínez, 1987; Massay, 1987). The only information on fish landings is for 1982 (Herdson *et al.*, 1985) when 3,734.3 tonnes were landed by a variety of fishing methods, including nets (sharks – 279.4; dolphinfish – 1,797.4; billfishes – 4.5; and scombrids – 1,653.0). These numbers refer to fish. There is no information on the levels of fishing effort.

Interactions with cetaceans

The species most likely to be involved with fisheries are bottlenose dolphins (*Tursiops truncatus*) and pantropical spotted dolphins (*Stenella attenuata*), the most common species in coastal areas in Ecuador. There are no direct observations of fishery interactions, but some stranded animals have shown signs of entanglement (B. Haase, *in litt.*, 21 July 1990). Ecuador has legislation protecting cetaceans: tuna vessels are not allowed to set their nets on dolphin schools and the waters surrounding the Galápagos Islands have been declared a whale sanctuary (Hurtado, 1991). Small cetaceans are not utilised and animals captured in nets are released or discarded. The number of animals caught has been roughly estimated, on the frequency of stranded animals with signs of entanglement, at about 100 a year (B. Haase, *in litt.*, 21 July 1990; K. Van Waerebeek, pers. comm.).

Discussion

Although cetacean by-catches have been reported along the Ecuadorian coast, no information is available about the magnitude of the interactions with fisheries. However,

experience elsewhere suggest that gillnets and trammel nets may represent an important source of mortality. There is no information that foreign fleets operate gillnet fisheries off Ecuador.

Peruvian gillnet fishery

Location of ports

This fishery operates in ports and small villages all along the Peruvian coast. Three main zones can be recognised: a northern zone between Puerto Pizarro (03°29'S) and Culebras (09°55'S); a central zone between Huarmey (10°03'S) and Lomas (15°34'S); and a southern zone between Chala (15°50'S) and the Chilean border.

Target species

The target species vary with season and availability. During the summer, the main species are the bonito (*Sarda chiliensis*), the blue shark (*Prionace glauca*), the hammerhead sharks (*Sphyrna* sp.) and the shortfin mako shark (*Isurus oxyrhynchus*); the dolphinfish (*Coryphaena hippurus*) and the thresher shark (*Alopias vulpinus*) may comprise an important part of the catch on the northern coast. In winter, a large fishery for blue sharks and dolphins, particularly dusky dolphins (*Lagenorhynchus obscurus*) takes place off the central Peruvian coast. Other species may be taken throughout the year, e.g. eagle rays (*Myliobatis* sp.), small sharks (*Mustelus* sp.), sciaenids and other teleost fishes.

Area of operation

Artisanal fishermen are requested to operate within 30 n.miles from shore. However, this regulation is difficult to enforce and fishermen may venture as far as 100 n.miles from shore.

Vessels and crew

Boats are mainly made of wood and are of three basic types (Cano *et al.*, 1979; Guerrero, 1989): San José, double pointed and San Andrés.

(a) The San José type is common on the northern coast. They are relatively large, flat-sterned boats, 6–17m long by 3m wide with a fish capacity of 1–30 tonnes. They are powered by a permanent diesel engine located at the centre of the vessel and also have a mast for a sail.
(b) The double-pointed type is one of the most common along the Peruvian coast. The vessels are 5–11m in length by 1.8–2m wide, with a fish capacity of 1.5–8 tonnes. Both the bow and the stern are pointed; these boats may or may not have a deck. The permanent engine is located at the centre of the vessel.
(c) The San Andrés type vessels are smaller (up to 7m long by 2m wide, capacity 1.2 tonnes) with a low bow and flat stern, lacking a deck. They are powered by outboard engines.

Some of the larger boats may carry an echosounder and a few more may use a compass. Most boats, however, have neither basic navigational equipment (Arana, 1976) nor fish handling facilities. Larger boats, especially of the San José type, have a small winch to haul the net. In the other types the net is hauled by hand. A Peruvian crew of 2–3 men is the rule in smaller boats, whereas larger boats may have up to a five man crew. Information on number of boats can be grouped by areas: on the northern coast the number of boats operating in the gillnet fishery is 785; on the central coast it is 1,741 while on the southern coast it is only 43 (S. Ludeña, pers. comm.). These numbers may vary as some fishermen may switch from one gear type to another, or even move to other ports, depending on resource availability.

Gear

Most nets are made of nylon multifilament. Monofilament gillnets are rare and are used mainly to fish for mullet (*Mugil* sp.) or, in some ports of the northern coast, for bonito (Wosnitza-Mendo *et al.*, 1988; S. Ludeña, pers. comm.).

Information on the dimension and number of panels per vessel and mesh size is given in Table 1 for the various target species.

Floats are made of cork. The basic float used is one designed for purse seines: cylindrical and 8cm long by 11cm in diameter. Most artisanal fishermen slice these floats to obtain several smaller floats for their gillnets. The distance between floats may vary from 30cm to almost 1.5m.

Operations

In general, trips last one day, but, depending on the catch, may extend to two days. Fishing mainly occurs between the shore and the 200m isobath, usually at the surface, but in some instances a few metres below the surface. The nets may be used in two forms, depending on the target species. For small sharks (*Mustelus* sp.), rays (especially *Myliobatis* sp.) and sciaenids, nets are set at the bottom, held down by stones.

In the case of the fishery for pelagic sharks, dolphins, jack, mullet and silverside, nets are left to drift either at the surface or in mid-water. Nets are set between late afternoon (for most species) and early morning (for silverside and some sciaenids), left to soak for 4–12 hours and retrieved at dawn.

Economics and history

At present (1990) the price of shark, ray and dolphin meat is the same (values from Pucusana, in central Peru). Fishermen receive US $0.23 per kilogram for these species. This is within the range of prices obtained in 1986 (Read *et al.*, 1988). There is no constant price for other fishery products. Depending on availability and demand, the price paid to fishermen may vary widely. Most fish are consumed

Table 1

Information on the Peruvian gillnet fishery.

Target species	Length(m)	Depth(m)	No. of panels	Mesh size(cm)
Sharks, rays and dolphins	86-270	2.8-19.0	2-30	10.2-44.0
Sciaenids	74-180	2.8-20.0	2-30	6.3-17.5
Bonito and horse mackerel	90-263	6.8-27.0	3-32	11.0-18.0
Jack	108-263	8.8-20.0	3-11	14.6-19.0
Mullet	108-126	2.2- 8.4	6-8	7.0- 9.0
Silverside	72-115	2.9- 5.0	2-8	2.9- 3.3

fresh domestically. Processing is reduced to evisceration at the fishmarket and, in the case of sharks, separation of fins that are sold separately. Rays may be salt-dried and sent to the markets in Lima and other departments.

It is not known exactly when gillnets were introduced in Peru. However, the fishery developed in the early 1970s, after the collapse of the anchoveta fishery. Many fishermen turned to work in the artisanal fishery, that at present provides 60–80% of the marine products consumed fresh by Peruvian people (Espino and Wosnitza-Mendo, 1988). Today the gillnet fishery is carried out by nearly 60% of the artisanal boats operating along the Peruvian coast (S. Ludeña, pers. comm.).

Total landings

Table 2 shows the total landings of species that are taken in gillnets, although the values include all catches of those species, whatever the fishing methods (gillnets, purse seines, shore seines, longlines and harpoon). Total landings for the gillnet fishery alone cannot be estimated.

Effort data

In a study of the artisanal fishery in 11 ports along the Peruvian coast, gillnets showed the highest fishing effort, representing 38% of the total effort. The CPUE for gillnets was 14% (average) of that for other fishing methods (Espino and Wosnitza-Mendo, 1988). The CPUE was estimated as catch per fishing trip, with the catch given in weight units.

Interactions with cetaceans

Cetacean species taken in this fishery include the Burmeister's porpoise (*Phocoena spinipinnis*), dusky dolphin (*Lagenorhynchus obscurus*), bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), pantropical spotted dolphin (*Stenella attenuata*), southern right whale dolphin (*Lissodelphis peronii*), short-finned pilot whale (*Globicephala macrorhynchus*), Risso's dolphin (*Grampus griseus*), killer whale (*Orcinus orca*), false killer whale (*Pseudorca crassidens*), pygmy and dwarf sperm whales (*Kogia breviceps* and *K. simus*), Cuvier's beaked whale (*Ziphius cavirostris*), lesser beaked whale (*Mesoplodon peruvianus*) and humpback whale (*Megaptera novaeangliae*) (Read *et al.*, 1988; Van Waerebeek *et al.*, 1988; Majluf and Reyes, 1989; Van Waerebeek and Reyes, 1990; 1994; Reyes *et al.*, 1991). Although most of these species are taken as a by-catch, a directed catch existed for dusky dolphins until recently. There is no information on how entanglements occur. Small animals, likely less than 4m long, are hauled aboard and removed by rolling the net in an opposite direction to that of the entanglement.

Larger animals may be towed to port where a combination of net-rolling and cutting is used. In general, live animals are not released and are sometimes landed in that state (Read *et al.*, 1988). In a single recorded case a humpback whale entangled in a gillnet off San Juan, southern Peru and was towed to port and then released (Majluf and Reyes, 1989).

Small cetacean landings are compiled in official statistics as total weight of 'marine mammals'; there is no information on species composition. Total landings of small cetaceans (in metric tonnes) for the period 1981–8 are shown in Table 3. It should be stressed that these statistics do not discriminate among capture methods (gillnets, purse seines or hand-thrown harpoons). The meat is used for human consumption, either fresh or salt-dried (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990; 1994). Until recently legislation protecting cetaceans covered only those large whales that were the target species of commercial whaling (Reyes, 1990). Small cetaceans, except for river dolphins, were not covered by legislation until November 1990, when a decree of the Peruvian Ministry of Fisheries prohibited the take, processing and trade of small cetaceans (Anon., 1990).

Brownell and Praderi (1982) reviewed the early data on incidental captures of small cetaceans in Peruvian waters (and see Clarke, 1962; Grimwood, 1969; Mitchell, 1975). They believed that the estimated annual catch of small cetaceans, mainly Burmeister's porpoises, suggested by Norris (in Mitchell, 1975) was a conservative estimate. No other reports on this fishery were published until the development of systematic studies in the mid 1980s, when the take for 1985 was estimated at 10,000 animals (Read *et al.*, 1988). In these later studies, the directed fishery for dusky dolphins contributed to the rise in small cetacean

Table 2

Total landings (metric tonnes) of fish products - Peru. Source: Ministerio de Pesquería, 1970-1988.

Year	Sharks	Rays	Bonito	Mullet	Silver-side	Jack	Sciaenids
1970	14,419	4,540	57,371	992	4,496	6,974	
1971	10,010	1,437	73,043	2,082	2,530	13,666	13,089
1972	10,347	1,223	64,161	4,610	1,799	11,005	10,664
1973	20,348	1,251	34,805	6,871	923	10,370	30,054
1974	15,176	1,813	7,404	7,394	6,053	9,370	26,716
1975	13,023	1,868	4,887	5,843	10,297	7,868	19,089
1976	9,523	1,292	4,057	3,218	3,341	18,257	12,068
1977	12,331	1,596	5,747	6,035	3,313	23,336	20,532
1978	13,656	1,979	4,741	7,824	1,429	19,246	20,856
1979	9,369	2,866	5,302	13,391	4,909	9,416	16,869
1980	10,965	2,655	6,838	18,194	4,387	10,740	16,480
1981	2,646,696	400,099	1,904,572	2,713,090	668,302	4,325,776	3,214,334
1982	15,274	3,595	13,888	15,241	8,078	30,250	27,254
1983	11,182	3,826	14,696	16,264	131	2,296	14,233
1984	29,938	4,614	20,995	21,243	53	5,315	18,936
1985	11,292	5,496	2,349	15,269	1,015	11,161	41,647
1986	15,971	7,276	3,318	17,004	3,930	35,551	25,590
1987	15,219	7,922	18,032	24,475	3,953	43,358	21,856
1988	18,417	8,251	33,986	16,827	5,620	21,514	27,710

Table 3

Small cetacean landings (in metric tonnes) in Peru, by regions. NA=not available. Source: Statistics Department, Peruvian Ministry of Fisheries (MIPE) except 1980 (source: IMPARPE, Statistics Department).

Year	North	Central	South	Total
1969	18	29		47
1970	2	7		9
1971	3	125		128
1972	20	646	15	681
1973	39	569	45	653
1974	168	681	105	954
1975	120	562	34	716
1976	153	513	47	713
1977	154	446	8	608
1978	218	928	26	1,172
1979	270	1,102	36	1,408
1980	NA	NA	NA	685
1981	169	411	44	626
1982	183	714	89	986
1983	146	237	53	436
1984	105	316	94	515
1985	105	607	44	756
1986	171	372	30	573
1987	133	330	7	470
1988	85	339	2	426

landings (Van Waerebeek and Reyes, 1990; 1994). At present the impact of these catches on small cetacean populations remains unknown.

Pinniped bycatches
Incidental catches of sea lions (*Otaria byronia*) and South American fur seals (*Arctocephalus australis*) are known to occur but their magnitude is unknown. In some parts of Peru the meat of these animals is used for human consumption.

Discussion
There have been several studies of artisanal fisheries in Peru (Ancieta, 1976; Arana, 1976; Wosnitza-Mendo *et al.*, 1988), but they were mostly socioeconomic studies of the development of fishing communities, and aspects related to fishing operations were treated in a global context. It is thus difficult to obtain detailed information about gillnet fisheries in Peru. Collection of specific data on mortality of small cetaceans only began five years ago. Paradoxically, obtaining information may become more difficult with the present more strict regulations, since fishermen are now more reluctant to release any information.

There is no information about foreign fleets involved in gillnet or driftnet fishing off the Peruvian coast. Until recently, Soviet trawlers fished for demersal species such as hake (*Merluccius gayi*) and some pelagic species including the horse mackerel (*Trachurus murphyi*). Dolphins, mainly bottlenose dolphins, were reportedly taken by this fishery, although the number of animals taken may have been small (J. Cox, pers. comm.).

Chilean swordfish fishery

Location of port(s)
Ports are located between Caldera (27°04'S) and Valdivia (39°48'S).

Target species
The target species is the swordfish (*Xiphias gladius*).

Area of operation
The artisanal fishery operates from 15 to 120 n.miles offshore, although a few (but an increasing number) boats may operate up to 150 n.miles offshore. Some larger boats dedicated to the industrial fishery are authorised to operate between 120 and 200 n.miles from shore (E. Bustos, unpublished data).

Vessels and crew
Most boats are wooden, although some may be of ferrocement or fibre glass. Boats are usually between 12–20m long, but about seven boats range from 20–28m. The mean displacement is 16 tonnes and fish capacity ranges from 12–20 tonnes. Crews comprise 3–5 Chileans. Boats are either of the 'American type' (with a cabin near the bow) or the 'Norwegian type' (with a cabin near the stern). As basic equipment, boats carry a magnetic compass, sounder and radar, as well as VHF and HF radios. Most boats have a satellite navigation system and a few may have a fax machine to receive information on water temperature (J. Brito and E. Bustos, pers. comm.). Approximately 18% of the boats have a hydraulic power block winch. In the others net-hauling is done by hand. Fish is kept fresh by the addition of ice.

There is no information on the exact number of boats for each port. The location of fishing grounds may change every season, and consequently the boats move along the coast. Approximately 250 boats are registered in San Antonio, but in 1988 around 160 moved north to Caldera (Barbieri, 1988b; J. Brito, pers. comm.). Nearly 800 boats are involved in this fishery along the Chilean coast. Permits for operation of more boats in this fishery are at present under consideration by the government. It is essentially a small-scale fishery with only about 50 larger commercial vessels participating (E. Bustos, unpublished data).

Gear
Nets are nylon multifilament, consisting of 12 to 25 panels. The mean panel length is 54m and depth ranges from 29 to 45m. The average net length is 1,440m, but some nets reach 2,160m. Mesh size varies from 45–56cm. Floats are made of plastic, 48.5cm in diameter on average, with a mean distance of 45m between them (Pesquera Catalina, 1982).

Operations
Trips may last from 3–5 days with an average of four trips each month during the fishing season, giving a total of some 30 trips per season. Usually a single net set occurs, during the night and in waters 4,000 to 5,000m deep. Depending on the sea state, almost all panels are set. In general, fishing is performed at the surface, where nets are left to drift, but in some cases, depending on the vertical distribution of fishes, the nets may be placed at midwater. Fishing takes place from mid-afternoon to the next morning, with a soak time of 12 to 14hrs. The whole net may be retrieved in 3–4hrs or 2hrs if there is no fish. Usual catches are 1–3 fish per panel.

The fishing season has been extended since the introduction of gillnets to the fishery. When only harpoons were used, the fishing season was set between January and March, mainly because good visibility was an important aspect of the harpoon fishery. With the introduction of gillnets, the fishing season has been extended until September (Barbieri, 1988a).

Economics and history
Nearly 80% of the catch is exported to the USA, Spain and France. At the beginning of the season, fishermen may receive up to US $5/kg, but depending on several aspects (fishing conditions, demand, etc.) the price may go down to around US $2/kg (E. Bustos, pers. comm.). The catch does not receive special treatment other than ice, since the product is sold fresh. A part called the 'neck' is cut off; the 'trunk' represents the final product. The neck is used for local consumption. Preparation of the final product for export is made mainly on the central Chilean coast, in areas such as Valparaiso, San Antonio and Santiago (Anon., 1988; J. Brito, pers. comm.). The 1990 value of the exported fish is about US $25,000,000.

The swordfish fishery in Chile dates back to the mid-1950s, although there is one catch record from 1943. Initially a harpoon fishery, gillnets were introduced in 1983. The introduction of gillnets and more boats, as well as the rise in international demand, has contributed to the increase of Chilean catches.

Total landings
Landings ranged from 342MT in 1983 to 5,824MT in 1989 (Table 4). It should be noted that the total landings refer to the weight of 'trunks' (fish with neither head nor tail). Present studies are addressing the estimation of total weight of animals from these trunks (E. Bustos, pers. comm.).

Table 4

Total annual landings (in metric tonnes) of swordfish in Chile:1980-9. Source:Servicio Nacional de Pesca (SERNAP). Anuarios Estadísticos de Pesca 1980-9.

Year	Landings	Year	Landing	Year	Landing
1980	104	1984	103	1988	4,445
1981	294	1985	342	1989	5,824
1982	285	1986	764		
1983	342	1987	2,059		

Effort data
A thorough study of this fishery is at present being developed by researchers at the Instituto de Fomento Pesquero (IFOP), Chile. Data on fishing effort and maximisation of the fishery, as well as other related aspects will be covered. The inclusion of observers on the commercial vessels was recommended to start in 1990 (Bustos, 1990).

Interactions with cetaceans
There are confirmed reports of entanglements of killer whales (*Orcinus orca*), sperm whales (*Physeter macrocephalus*) and southern right whale dolphins (*Lissodelphis peronii*) (J. Brito, pers. comm.). Large animals entangled are cut out and left to drift or sink. Small animals however may be taken to port or are consumed by fishermen (J. Brito, pers. comm.). There is no information about the number of cetaceans taken. No direct efforts to reduce the cetacean by-catch exist. However, in order to manage the swordfish fishery, a reduction in net size and fishing effort has been proposed (E. Bustos, pers. comm.).

Small cetaceans are protected by law in Chile (Torres *et al.*, 1979). The capture, possession and trade of small cetaceans is forbidden. However there are no provisions addressing the problem of incidental mortality.

Discussion
At present, swordfishing is one of the most important fishing activities in Chile, and the increase in the annual landing of cetaceans has been a cause of concern for authorities, researchers, fishermen and traders. In fact, some proposals to regulate the fishery have been made, e.g. reduction of net size and delay in the issuance of new fishing permits. The magnitude of by-catch of cetaceans in this fishery, however, remains unknown, since information on this subject has been gathered only from a few boats. Nearly 800 boats are involved in the fishery; the effort is particularly high off the central Chilean coast, where total landings for the period 1985–7 were higher than landings in the previous 30 years. With such an increase in fishing effort an increase in cetacean bycatch should be expected. The situation should be studied further. There are a few larger ships from other nations fishing for swordfish off Chilean waters, but they use longlines (Reyes, 1989).

Chilean ratfish and sciaenid fishery

Location of ports
This fishery is operated mainly from two small ports, Caleta Queule (39°23'S) and Bahía Mansa (40°34'S).

Target species
Ratfish (*Callorhinchus callorhynchus*) and the sciaenid corvina (*Cilus montti*) are the target species.

Area of operation
Fishermen from Queule operate between Playa Larga (38°40'S) and Punta Manquillahue (39°27'S), while fishermen from Bahía Mansa fish between Punta Dehui (40°15'S) and Bahía San Pedro (40°55'S). Fishing takes place between 2 and 12 n.miles of shore.

Vessels and crew
All boats are made of wood, with length ranging from 7.7 to 11m. The 'Norwegian type' predominates in Queule, but in Bahía Mansa a smaller, outboard powered boat called a '*chalupa*' is used. Most boats have basic navigational equipment (light and compass) and around 20% may carry VHF radios. Fish capacity ranges from 3.5 to 4 tonnes in the Norwegian type and from 2 to 2.5 tonnes in the *chalupa*. The crew of 2–5 is Chilean. There is no net-hauling gear and the fish is handled fresh.

Gear
Nets are nylon multifilament. Each net comprises 2–14 panels, 100m long by 4–6m deep. Mesh size is 15cm.

Operations
Trips may last 12–24 hrs. In Queule, the number of trips may be 108–112/year, while in Bahía Mansa fishermen may complete 180–228 trips/year. Nets are bottom set in waters ranging from 10–217m in depth. Fishermen from Queule set their nets at depths between 15 and 18m in the summer and between 38–45m during winter. Off Bahía Mansa nets are set at 60–80m. Usually setting of nets occurs during the morning or late afternoon, and the soak time is about 10–12 hrs. Retrieval takes 1–4 hrs, depending on the catch. Catch per set ranges from 0.4–3 tonnes.

Economics and history
This fishery sustains a domestic market. Fishermen receive US $ 0.13–0.16/kg for ratfish and US $ 1.00/kg for corvina. The fish are eviscerated and sold fresh. Addition of ice occurs when fish products are shipped to Santiago. Ratfish is sent to fish meal plants located in Puerto Montt and Talcahuano.

The exact date for the beginning of this fishery is unknown, but it was well established by 1962. In the last six years it has been substantially improved with the introduction of better boats and engines and the increasing use of gillnets. Fishermen believe catches may triple in the future.

Total landings
Total catches in Queule are approximately 4,106 tonnes/year, with corvina representing 20%. In Bahía Mansa, corvina represents 15% of 9,216 tonnes/year. There is no information on effort.

Interactions with cetaceans
Cetacean species involved are mainly Burmeister's porpoise and Chilean dolphin (*Cephalorhynchus eutropia*). Sporadically Peale's dolphins (*Lagenorhynchus australis*) are also taken. Entanglements occur during the night or early morning. Animals are hauled into the boats, eviscerated upon arrival at port and used as bait for conger eel fishing. On very rare occasions the meat may be consumed by the fishermen.

The cetacean catch at Queule is given in Table 5 (J. Oporto, unpublished data).

Table 5

Catches of cetaceans at Queule.

Year	*P. spinipinnis*	*C. eutropia*	*L. australis*
1988	62	63	2
1989	57	51	-
1990*	40	32	1

* Until October.

According to one fisherman, the number of animals entangled every year in Bahía Mansa is between 300–400. Apparently the majority are Burmeister's porpoises. The impact of this fishery mortality on the affected populations remains unknown.

No market for dolphin meat exist in Chile because there is legislation protecting all species (Torres *et al.*, 1979).

Discussion
The expansion of this fishery expected to occur within the next few years will pose a potential threat to coastal small cetaceans in southern Chile. It is necessary to monitor operations from both fishing locations in order to determine the impact of the fishery on small cetacean populations in the area.

Other fisheries
Gillnets are one of the most important types of fishing gear used in the coastal waters of the Southeast Pacific region. Other fisheries include those for lobsters and deep sea fish in the Juan Fernandez archipelago (around 33°S) off mainland Chile. The fisheries in the waters surrounding the Galápagos Islands do not use gillnets due to local regulations. Lobsters are taken by diving, and fish such as sea bass are taken with longlines (Barragán, 1987; Rodriguez, 1987). We found no evidence of the use of fishing weirs except those used in the shallow waters of Ecuador to catch shrimp. However the operation of foreign fleets using driftnets in or off the waters of the countries involved (Ecuador, Peru and Chile) should be investigated.

DISCUSSION

Despite the widespread utilisation of gillnets in the region, there are few studies being carried out on the development of these fisheries, except for the so called 'artisanal' swordfish fishery in Chilean waters and the incipient studies in Peru and Ecuador mentioned above.

Swordfishing in Chile sustains an important industry within the frame of economic development through the export of local products adopted by the government. The situation in northern Chile is quite different. There, an industrial fishery for fish meal production is the government's main interest and studies on artisanal fisheries are almost nonexistent (J. Oliva, pers. comm.). Although driftnets were introduced into the fishery in the early 1980s, information on cetacean mortality has only recently become available. The size of the fleet, its area of operation and the total surface of fishing nets, together with actual records of mortality, suggest that the entanglement of cetaceans in this fishery may be substantial. It is necessary to collect more information about the interactions of cetaceans and the swordfish fishery. This information could be gathered through the observer programme that is now in operation.

Entanglement of cetaceans in gillnets off Peru has been documented for a number of years. The recently adopted legislation, however, may significantly reduce the possibility of estimating the number of animals taken incidentally in the fishery. Effort should be made to reduce this incidental mortality. In particular, studies should include observations to determine factors such as distances from the coast and depths to which the gillnet fishery operates, information that could be used if temporal and spatial restrictions are to be considered in the future. Also, modification of fishing gear or replacement by other fishing methods (e.g. longlines) should be considered as potential alternatives. This could help to reduce the proportion of gillnets (today estimated at around 60% related to other fishing methods) used in the Peruvian artisanal fishery.

Relatively little information is available on gillnets and cetacean interactions in Ecuador.

More detailed studies should be implemented by the countries of the region in order to understand the evolution and development of artisanal fisheries and to assess the impacts that gillnet fisheries have on cetaceans and other marine organisms, not in the least the commercially exploited species. Research on alternative fishing methods for a progressive replacement of those gillnets known to be a threat to small cetaceans should be included in fishery research programmes currently undertaken by national fishery agencies throughout the region.

Finally, if the impact of incidental mortality of cetaceans is to be assessed, studies of the stock identity and abundance of the affected species must be undertaken.

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Incidental Catches of Small Cetaceans in the Artisanal Fisheries of Ecuador

Fernando Félix and Jorge Samaniego

Fundación Ecuatoriana para el Estudio de Mamíferos Marinos (FEMM), PO Box 09–01–6637, Guayaquil, Ecuador

ABSTRACT

During 1993, a study was carried out to try to estimate the incidental mortality of small cetaceans in gillnets of artisanal fishermen along the coast of Ecuador. Two ports were selected as convenient study sites: Puerto López and Santa Rosa. In both ports, a sample fleet of six boats was chosen. From December 1992 until December 1993 the two fleets made a total of 2,764 fishing trips and they caught 217 small cetaceans as bycatch. The Santa Rosa sample index (0.1042±0.012 (SE) dolphins/boat/trip) was significantly larger ($P<0.01$) than that for the Puerto López sample fleet (0.038±0.007 (SE)). The estimated total catch for the entire Santa Rosa fleet is 1,150 (CI 95% 874–1,426) dolphins/year and that for the entire Puerto López fleet is estimated to be 156 (CI 95% 99–213). If the results are extrapolated to two similar ports nearby the estimated total bycatch is 3,741 (CI 95% 2,784–4,698) dolphins caught in 1993. If similar capture rates apply to the rest of the country, the total national bycatch would be 2 or 3 times higher. By far the most frequently captured species was the common dolphin (86%) followed by the short-finned pilot whale (9%). Occasionally, spotted dolphins (2%) and dwarf sperm whales (1%) are caught.

KEYWORDS: EASTERN TROPICAL PACIFIC; INCIDENTAL CAPTURE; FISHERIES; COMMON DOLPHIN; PILOT WHALE - SHORT-FINNED; SPOTTED DOLPHIN; DWARF SPERM WHALE

INTRODUCTION

Cetacean species are subjected to a number of human induced mortalities, including direct capture, incidental capture, competition for food resources and habitat pollution (IWC, 1992). Of these, perhaps the most important for affected species is the incidental capture in fishing activities which can result in high mortality rates, particularly for coastal species and river dolphins (e.g. Northridge, 1984; Brownell *et al.*, 1989; IWC, 1994).

Almost no published information on the incidental mortality of cetaceans during fishing activities in Ecuador exists. Only the bycatch of cetaceans in the industrial tuna fishery has garnered attention from the fishing authorities. Current regulations forbid fishing on tuna associated with dolphins in Ecuadorian waters[1]. As in other developing countries, the potential problem of incidental catches in artisanal fisheries has largely been ignored.

In 1993, a study was undertaken along the coast of Ecuador to determine the magnitude of the small cetacean bycatch in artisanal fisheries. The study was financed by the United Nations Environmental Program (UNEP) as part of the Action Plan for the Conservation of the Marine Mammals of the Southeast Pacific (PNUMA, 1992). The study found that at least four dolphin species become entangled in surface gillnets: the common dolphin, *Delphinus delphis*, the short-finned pilot whale, *Globicephala macrorhynchus*, the spotted dolphin, *Stenella attenuata*, and the dwarf sperm whale, *Kogia simus* (Samaniego and Félix, 1994). Bottlenose dolphin (*Tursiops truncatus*) interactions with deep gillnets set for shrimps and other species in the Gulf of Guayaquil (South of Ecuador) were reported by Van Waerebeek *et al.* (1990) and by Félix (In press). It is unknown whether other small cetacean species are involved in interactions with other fisheries in Ecuador.

This paper presents the results from the above study with respect to small cetaceans and artisanal fisheries.

DESCRIPTION OF THE ARTISANAL FISHERY

Artisanal fishing represents a major part of Ecuador's economy. In 1992, the total catch for the eight most important ports of the country was 38,633 tonnes (Villón and Balladares, 1993). In the last decade the fishing fleet has increased dramatically, being ten times higher than in 1982 (Contreras and Revelo, 1992). Overall there are about 50,000 artisanal fishermen found in over 70 fishing communities (Campbell *et al.*, 1991). Since 1989, the National Institute of Fisheries (INP) has made a complete inventory of the artisanal fisheries in eight of the most important ports of the country: Esmeraldas, Manta, San Mateo, Santa Rosa, Anconcito, Engabao, Playas, and Puerto Bolívar (Fig. 1) (Martínez *et al.*, 1991; Contreras and Revelo, 1992; Villón and Balladares, 1993). These ports account for some 75% of the total national fishing effort (Carlos Villón[2], pers. comm.).

Vessel types

The fleet comprises some 7,000 vessels of various types (Campbell *et al.*, 1991), ranging from small rafts for 2–3 fishermen, through long wooden canoes with 25–50HP outboard motors for 3–4 fishermen, to open boats made of wood or fibreglass of up to 10m long equipped with 75–100HP outboard motors (Massay, 1987).

Target species

The target species are mainly large pelagic fish including the 'dorado' (*Coryphaena hippurus*); tuna (*Thunnus albacares*, *T. obesus*, *Katsuwonus pelamis*); swordfish (*Xiphias gladius*); 'picudos' (*Makaira* sp., *Isthiophorus albicans*); sharks (families Alopiidae, Carcharhinidae, Lamnidae, Sphyrnidae and Triakidae) and deep water fish (families Bothidae, Carangidae, Lutjanidae, Serranidae,

* The paper presented to the meeting originally had two parts. The second part is now Haase and Félix (1994).

[1] Ministerial Agreement No. 203, May 10, 1990. Ministerio de Industrias Comenrcio Integración y Pesca (MICIP).

[2] Instituto Nacional de Pesca INP, Fisheries Resources Department.

Sciaenidae). Crustaceans (Penaeus sp.) and various species of molluscs are also taken (Herdson *et al.*, 1985; Martínez, 1987). Artisanal fishing takes place within 40 n.miles of the coast (Martínez, 1987).

Techniques

Longlines (palangre or espinel)

These comprise a large number of down hanging sublines with hooks (100–1,500) connected via a horizontally placed, long thick nylon mother line of between 4.5–11km in length, with signal flags and floats on each end (Cedeño, 1987; Martínez *et al.*, 1991). The use of longlines and handlines is more common along the north coast of Ecuador (Cedeño, 1987; Campbell *et al.*, 1991).

Gillnet (red agallera or trasmallo)

Two types of gillnets are used: (1) surface gillnets of up to 3km in length and 15m in depth, with a large mesh size (7.5–13cm); (2) deep gillnets between 300–400m in length, used to catch deep water species such as slabs, lobsters and shrimps (Cedeño, 1987; Martínez *et al.*, 1991). Gillnets are used mostly by fishermen in the central and southern part of the country.

MATERIAL AND METHODS

By mid-November 1992, all ports in the four coastal provinces had been visited to determine the use of gillnets along the coast. We selected two ports to be representative (Fig. 1): Puerto López, in the province of Manabí (01°34′S, 80°W) and Santa Rosa, in the province of Guayas (02°12′S, 80°54′W). Fishermen in these ports showed interest in the project and in general cooperated willingly.

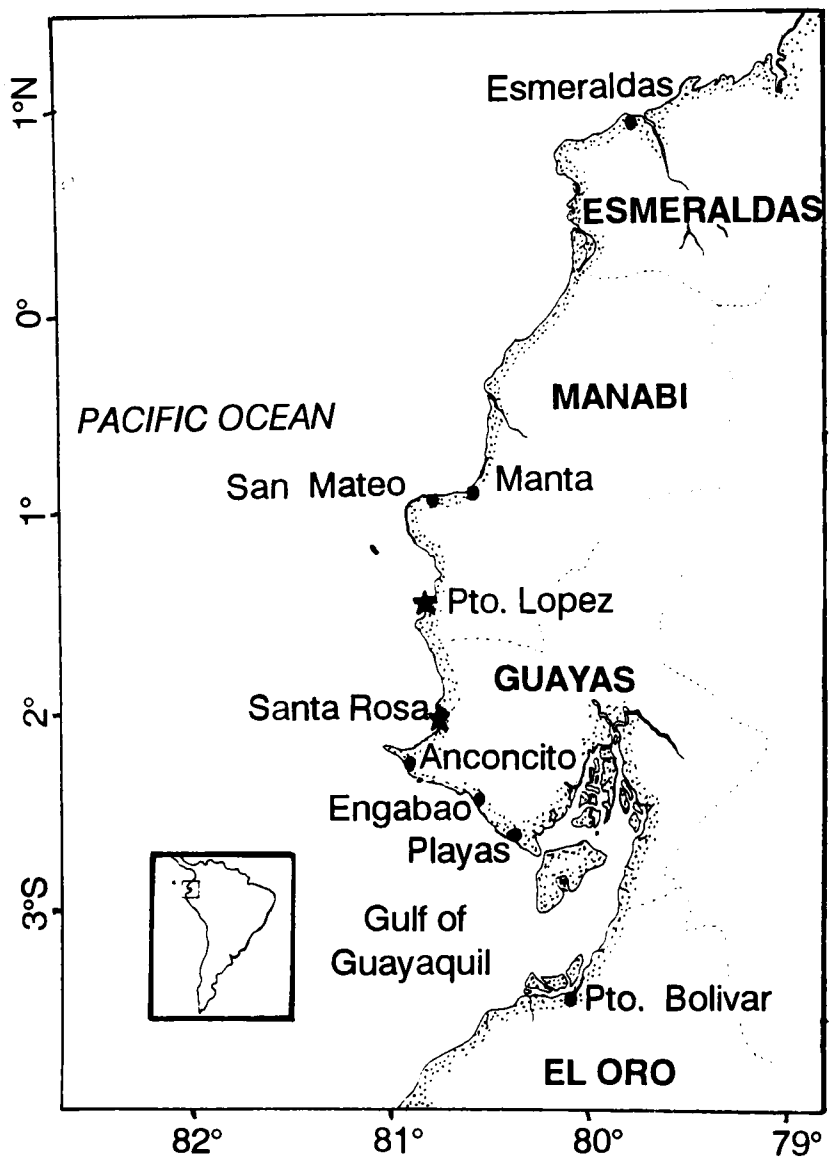

Fig. 1. Main artisanal fishing ports on the Ecuadorian coast.

In order to obtain an idea of the bycatch levels, six boats that used surface gillnets were selected for each port. Between them, the twelve boats made a total 2,764 trips between 15 December 1992 and 15 December 1993. The boats (fibreglass, 7m in length, outboard engine of 75–85HP) and their gear (polyfilament nylon nets, 1,500m long and 15m wide) were similar. Fishing techniques were also similar with the boats leaving port in the afternoon and returning on the following day in the early morning. The nets were set at night for a period of 8–10 hours.

Once back in the port, each crew member was asked to report any interaction with dolphins. Information on the number of captured animals, the species, the distance off the coast where they had been fishing and general information on the journeys was recorded. For 64 trips (2.3%) J.S. and volunteers of the Ecuadorian Foundation for the Study of Marine Mammals (FEMM) were on board as observers. The information obtained from these trips is compared to that for trips without observers later in this paper.

The relevant authorities gave special permission for the fishermen participating in the study to bring the bycatch to land. The animals were photographed and examined, and biological data and other information recorded, including species, sex, weight and external measurements. In addition, the animals were sampled for teeth, reproductive organs, stomach contents and parasites, etc. The samples are being analysed at present.

For practical reasons, not all the dolphins were brought to port. At the beginning of the project the animals were identified on return to port from photographs shown to the fishermen, and quite soon they were able to identify most cases without problems. These animals were not measured and their total length was estimated by the fishermen; this information was excluded from statistical analysis. However, the common dolphins (*Delphinus delphis*) and spotted dolphins (*Stenella attenuata*) were subdivided as: (1) calves, small animals of less than 1.2m; (2) immature of between 1.2m and 1.8m; and (3) adults animals > 1.8m.

Information on the number of artisanal boats, the number of operative boats and the fishing techniques used in Santa Rosa and seven other ports during 1993 were provided by the INP (Table 1). This information was based on comments by nearly 10,000 fishermen interviewed during 1993 and was used to extrapolate the results of our study to the entire fleet in order to obtain estimates of dolphin mortality rate for each port. Non-active boats and those using different techniques were subtracted from the total fleet (Table 1). In addition, as no boats operated

Table 1

Fishing methods of the artisanal fleet in eight ports during 1993.

Ports	Total fleet	Operative fleet (%)	Fishing gear	
			Longline (%)	Gillnet (%)
Esmeraldas	196	21	95	5
Manta	563	36	60	40
San Mateo	210	12	100	-
Santa Rosa	235	41	60	40
Anconcito	370	43	60	40
Engabao	163	6	100	-
Playas	96	48	100	-
Puerto Bolivar	383	87	10	90

Source: Artisinal Fishing Project INP/CISP/MLA. National Institute of Fisheries (Instituto Nacional de Pesca). 1994.

Table 2

Number of monthly trips made by the sample fleet of Santa Rosa, 15 December 1992 - 15 December 1993.

Boat	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
I	14	24	20	23	24	24	22	24	22	20	24	23	11	275
II	15	24	20	24	26	26	26	26	24	22	26	26	11	296
III	14	23	19	23	24	24	22	24	20	20	24	22	11	270
IV	15	24	20	24	26	26	26	26	25	23	26	26	11	298
V	14	23	20	24	26	26	26	26	24	22	26	26	11	294
VI	14	20	20	23	22	24	22	21	22	20	24	23	11	266

Table 3

Number of monthly trips made by the sample fleet of Puerto Lopez, 15 December 1992 - 15 December 1993. G: Gillnet/L: Longline.

Boat	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
												G/L	G/L	
A	10	16	15	16	15	14	16	18	14	15	13	04/10	05/06	171
B	10	17	15	15	17	16	18	19	12	20	12	10/07	00/10	181
C	10	16	16	18	18	17	17	19	13	17	14	09/10	05/06	189
D	10	17	14	17	16	16	17	18	9	17	13	08/09	04/07	176
E	9	16	14	16	17	16	16	19	10	16	14	09/09	05/06	177
F	9	16	15	16	16	16	14	17	14	16	13	04/12	05/06	171

every day of the year, it was assumed that the average number of fishing days in the year for the sample fleet could be applied to the entire fleet.

The number of boats of the Puerto López fleet that used gillnets was determined by the authors. The percentage of operative boats in that port was considered the same as that for Santa Rosa.

RESULTS

Fishing effort

Fishing effort from both ports occurred in all months of the year (Tables 2 and 3) although the mean numbers of trips differed by port. The fishing grounds for the two ports differed considerably. Boats of the Puerto López fleet operated between 11 and 33 n.miles offshore (mean=22.2, SD=5.8), while those from Santa Rosa generally operated further offshore, between 14 and 56 n.miles off the coast (mean=32, SD=7.5).

Santa Rosa

INP data revealed that the Santa Rosa fleet comprised 235 boats, of which 96 (41%) were operative. On average throughout the year, around 38 (40%) used surface gillnets (Table 1). As shown in Table 2, the six sample boats operated for an average of 283 days in the year (SD 14.4). Thus the total number of trips estimated for this fleet is 10,754.

Table 4

Incidental catch for the sampled Santa Rosa fleet.

Boat	No. of trips	Dolphin catch	Capture index dolphins/boat/trip
I	275	21	0.0764
II	296	39	0.1318
III	270	27	0.1000
IV	298	38	0.1275
V	294	32	0.1088
VI	266	20	0.0752
Totals	1,699	177	0.1042

Puerto López

Our census of Puerto López revealed that the entire fleet comprised 89 boats of which 56 (63%) used surface gillnets. Assuming, as for Santa Rosa, that 41% of the fleet operated implies that 23 boats operated using gillnets in 1993. The Puerto López sampled boats carried out an average of 178 trips in 1993 (SD 6.8). Thus the total estimated fishing effort for 1993 is 4,094 trips.

Mortality of small cetaceans

Santa Rosa

The Santa Rosa sample fleet caught 177 dolphins in 1993 (Table 4), with between 21 and 39 dolphins per boat, giving an annual average per boat of 29.5 (SD=8.2). The average capture rate per trip was 0.1042±0.012 (SE). The capture rate from boats carrying observers on board (n=35, 2%) was 0.286±0.131 (SE), 2.7 times higher than the boats without observers (Table 6). The species caught were the common dolphin (*Delphinus delphis*) 90%, the short-finned pilot whale (*Globicephala macrorhynchus*) 7%, the dwarf sperm whale (*Kogia simus*) 1%, the spotted dolphin (*Stenella attenuata*) 0.6% and unidentified dolphins 1% (Fig. 2).

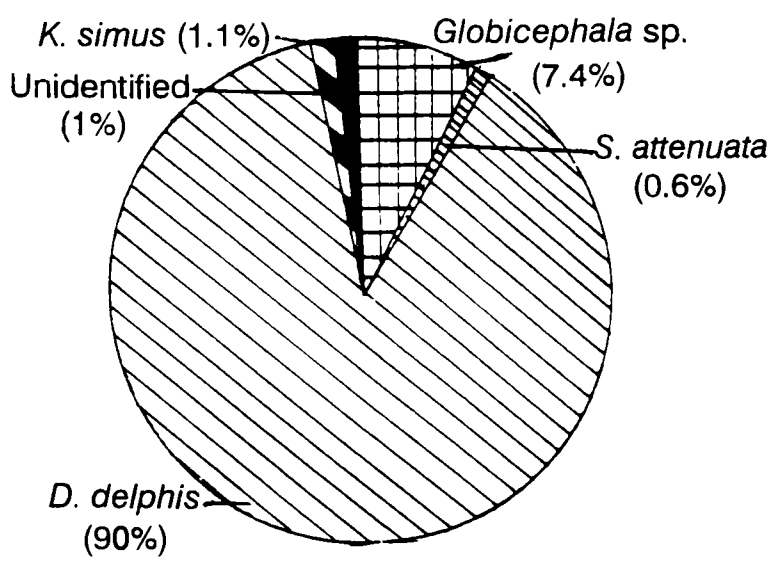

Fig. 2. Composition of the cetacean bycatch in Santa Rosa.

Using the estimated numbers of trips for the entire fleet obtained above gives a total estimated bycatch of 1,150 (CI 95% 874–1,426) dolphins assuming the total average capture rate or 3,157 (CI 95% 320–5,994) dolphins if the capture rate for boats with observers is used.

Puerto López

During 1993, the crew of the Puerto López sample fleet reported a bycatch of 40 dolphins (Table 5). The number of animals caught per vessel varied between 2 and 12, with an annual average of 6.7 (SD=3.4). The mean capture rate per trip was 0.038±0.007 (SE) dolphins (Table 5), was significantly lower than in Santa Rosa (ANOVA, $F_{1,5}=30.35$, $P<0.01$). The capture rate from boats carrying observers on board ($n=29$, 2.7%) was similar to that for boats without observers 0.034±0.033 (SE) (Table 6). The species composition was: common dolphin 67.5%; short-finned pilot whale 17.5%, spotted dolphin 10%; and non-identified 5% (Fig. 3). Using the estimated number of trips for the Puerto López fleet obtained above gives an estimated total bycatch of 156 (CI 95% 99–213) dolphins in 1993.

Other ports

No direct study of the incidental mortality of dolphins for other ports was made. However, we believe that it is instructive to extrapolate the Puerto López and Santa Rosa data for two other important nearby ports: Manta and Anconcito. Manta is situated 70km to the north of Puerto López and Anconcito is 12km south of Santa Rosa. Both ports have similar characteristics to the monitored ports in terms of gillnet use and operative boats. Their locality suggests that they probably exploit the same fishing area. To give an idea of possible mortality we used the Puerto López data for Manta and the Santa Rosa data for Anconcito. The resultant mortality estimates are 548 (CI 95% 350–746) and 1,887 (CI 95% 1,461–2,313), respectively. Despite the large number of assumptions involved, the potential scale of bycatches indicates the need to monitor the problem in Ecuador.

Table 5

Incidental catch for the sampled Puerto Lopez fleet.

Boat	No. of trips	Dolphin catch	Capture index dolphins/boat/trip
A	171	9	0.053
B	181	12	0.066
C	189	7	0.037
D	176	7	0.040
E	177	2	0.011
F	171	3	0.017
Totals	1,065	40	0.038

Table 6

Incidental catch of small cetaceans of boats with observers.

Port	No. of trips	Dolphin catch	Capture index dolphins/boat/trip
Puerto Lopez	29	1	0.034
Santa Rosa	35	10	0.286
Totals	64	11	0.172

Seasonality of the bycatch

Both ports exhibited a similar pattern in incidental captures with two peaks in the year. In Puerto López the bycatch increased between March and August, decreased from September to November and then increased again in December and January (Fig. 4). In Santa Rosa, catches increased between May and September, decreased in October and November and then increased again in December (Fig. 5). Although the study began in December, the first bycatch by the Santa Rosa sample fleet was not reported until February 1993, possibly because the fishermen were initially suspicious. If this is the case, our estimated bycatch for that port may be an underestimate.

Use of the bycatch

All but two (0.9%) dolphins that were released alive, were found dead. They were usually not taken on board, but were freed or cut loose outside the launch and left behind.

However, from July until November in Puerto López, some boats (not of the sampling fleet) brought the bycatch

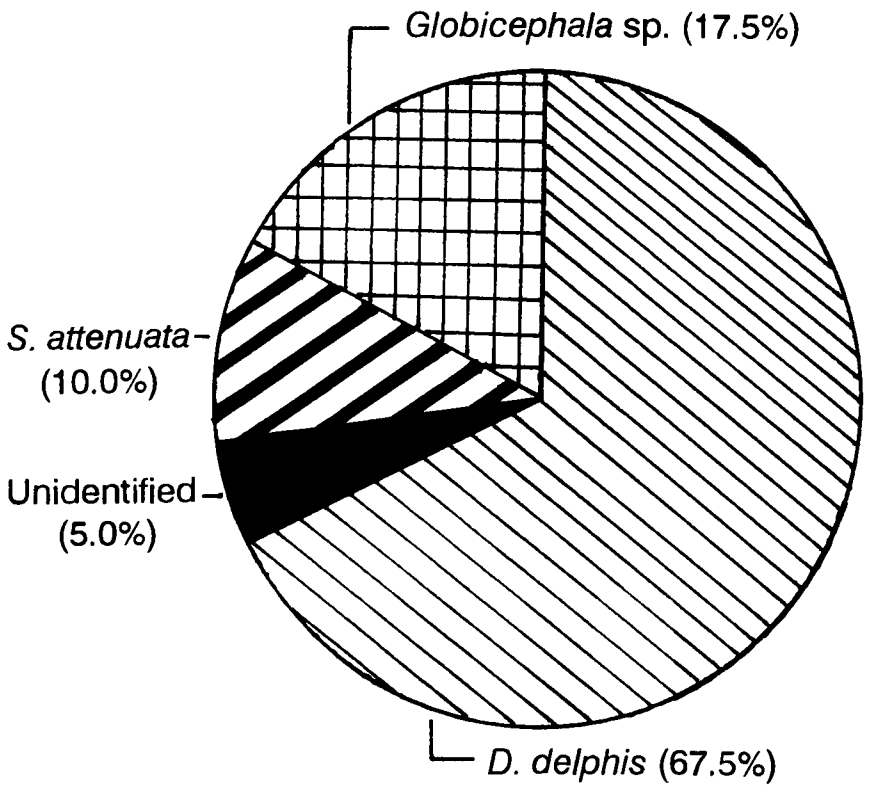

Fig. 3. Composition of the cetacean bycatch in Puerto López.

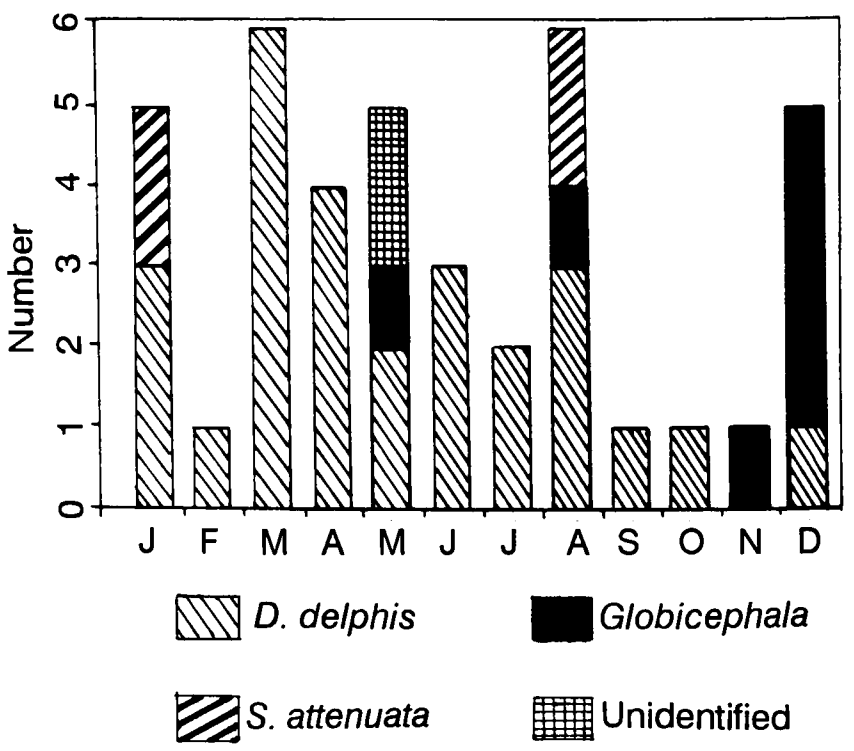

Fig. 4. Monthly cetacean bycatch by the Puerto López sample fleet.

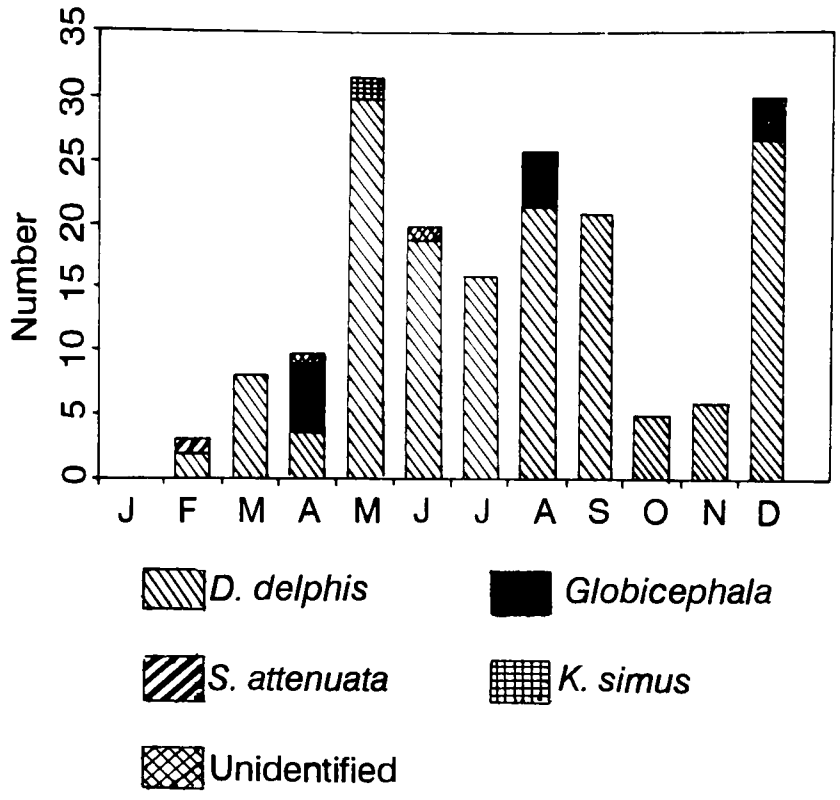

Fig. 5. Monthly cetacean bycatch by the Santa Rosa sample fleet.

Table 7

Composition of the bycatch per age class in Santa Rosa.

Species	Calves n	Calves %	Young n	Young %	Adults n	Adults %
Delphinus delphis	79	49	52	33	28	18
Globicephala sp.	2	15	6	46	5	39
Stenella attenuata			1	100		
Kogia simus					2	100
Unidentified			1	50	1	50

Table 8

Composition of the bycatch per age class in Puerto Lopez.

Species	Calves n	Calves %	Young n	Young %	Adults n	Adults %
Delphinus delphis	13	48	11	41	3	11
Globicephala sp.			2	29	5	71
Stenella attenuata	1	25			3	75
Unidentified			2	100		

to shore and sold it to longline fishermen for bait. This appears to be an increasingly common phenomenon with prices of US $75 for large carcasses being mentioned. Although the harbour authorities were informed and some boats were inspected, there are no clear regulations forbidding this practice. Local fishermen informed us that this trade had begun soon after the arrival at Puerto López of two visiting launches from Puerto Bolívar (in the south of the country), who seemed often to use dolphin and whale meat as bait. This could not be confirmed because we have not surveyed the bycatch situation in Puerto Bolívar.

Fishermen consider both dolphins and whales as fish but not as food. However, the blubber is occasionally used as medicine to cure asthma and other illness.

Examined specimens

Of the 217 caught animals, 33 (15%) were taken ashore to be examined; 27 common dolphins, 5 spotted dolphins and the head of a dwarf sperm whale. Fig. 6 shows the lengths of the common dolphins examined (mean 1.25m, SD=0.32). Most corresponded to animals in their first year of life. The five spotted dolphins were slightly longer, measuring an average of 1.7m (SD=0.5). Tables 7 and 8 show the age class composition of the dolphin bycatch. However, this information is of limited value since only seven dolphins came from boats with observers and large animals were probably not brought back to port because of the effort of getting them on board and the fact that they would occupy space that could be used for fish.

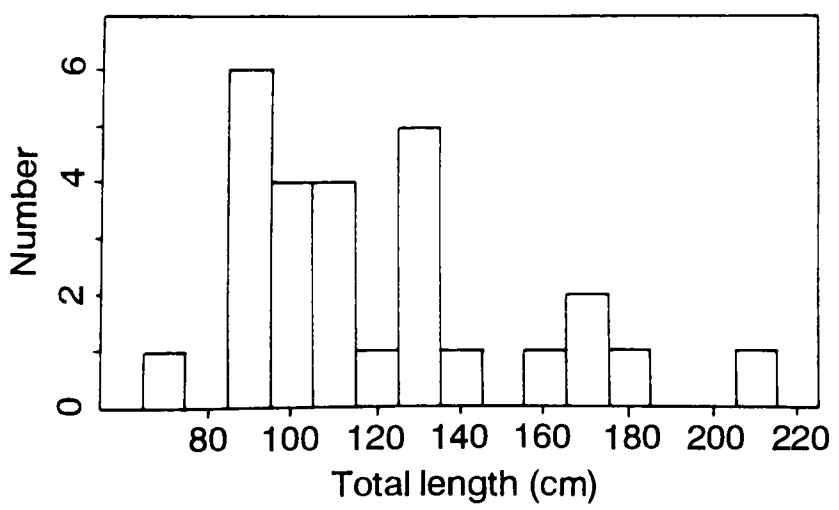

Fig. 6. Frequency distribution of the total length in the common dolphins examined (n=27).

DISCUSSION

This is the first survey of cetacean bycatches in Ecuadorian artisanal fisheries that attempts to quantify the incidental mortality. However, as only two ports in the centre of the country were sampled, it is not possible to provide a national estimate. It would be inappropriate to extrapolate the results from the sampled ports to the entire artisanal fleet, not the least because the capture rate was different in both sample ports and this could be true for other sites. To obtain better estimates more ports should be examined, especially in the south of the country where more gillnets are used. INP data (Table 1) show that Puerto Bolívar has both the highest number of gillnets and the highest percentage of its fleet operating. The potential is there, therefore, for the incidental capture of dolphins from this port to be high and an investigation of that fleet should be given high priority. By contrast, the artisanal fishermen of the north's fishing ports use fewer gillnets and more longlines, and one would expect the incidental capture of cetaceans to be less.

Despite the problems in the extrapolation procedure, the estimated bycatch in 1993 for the fleets in Puerto López and Santa Rosa, and the other two ports (Manta and Anconcito) shows that the incidental mortality of cetaceans is high, perhaps between 2,500–5,000 animals. If mortality levels are similar in other artisanal ports in Ecuador, the total bycatch in 1993 may have been 2–3 times greater than this, i.e. greater than the annual capture in Perú, where a directed dolphin fishery has existed for many years (e.g. Read *et al.*, 1988). In Perú some species of dolphins show signs of being over exploited due to the high bycatch levels (Van Waerebeek *et al.*, 1994).

Our study has only included boats for the pelagic fishery that used wide mesh surface gillnets. However, interactions of small cetaceans (e.g. the bottlenose dolphin, *Tursiops truncatus*) with other types of nets used in Ecuador, such as the nylon monofilament nets used for catching shrimp and other benthic species in coastal

waters, have been reported by Van Waerebeek (1990) and Félix (In press). In this regard it should be noted that the Puerto López sample boats that used both longlines and gillnets in November and December did not report any capture of small cetaceans in longlines.

The two peaks in incidental captures reported (March-September, December-January) coincide with the peaks in catches of small pelagic fish (French *et al.*, 1988; Aguilar and Santos, 1993). This suggests that the dolphins may be more abundant at those periods due to food availability. Unfavourable environmental conditions such as turbid water, swell and current could affect the ability of the small cetaceans to detect and to avoid nets (Jefferson *et al.*, 1991). The highest bycatch of the sample fleet was recorded in August and October when the south trade winds occur and produce strong surf (on one occasion 10 dolphins were caught in one net). The number of dolphins (as reflected by capture rate) also seems to vary geographically but it is not clear if this reflects greater abundance in the south (Santa Rosa) or offshore (Santa Rosa boats operated further from shore).

Variation in bycatch composition was also seen. Although the most affected species was the common dolphin (*Delphinus delphis*) for both fleets, the Puerto López fleet caught proportionally more spotted dolphins (*Stenella attenuata*) and pilot whales (*Globicephala macrorhynchus*) than the Santa Rosa fleet. The Puerto López fleet is more active in coastal waters i.e. where the coastal spotted dolphin is more frequently found (Perrin *et al.*, 1985). Although pilot whales are a deep water species, the higher bycatches at Puerto López can be explained as most occurred when the fleet made longer and (probably) more distant trips in December 1993.

It is noticeable that the trade of (incidentally caught) dolphins was discovered during the time when the whitebait that is used by longline fishermen was scarce. The fishermen know that dolphin meat is excellent bait on their longlines and they are willing to pay a lot of money for bycatch. Haase and Félix (1994) report that sperm whale meat is occasionally used for bait in Ecuador. They note that this might result in deliberate capture of this species unless action is taken by the authorities.

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SC/46/O 6*

A Note on the Incidental Mortality of Sperm Whales (*Physeter macrocephalus*) in Ecuador

Ben Haase and Fernando Félix

Fundación Ecuatoriana para el Estudio de Mamíferos Marinos (FEMM), PO Box 09-01-6637, Guayaquil, Ecuador

ABSTRACT

Between 1987 and October 1994, twenty strandings of the sperm whale (*Physeter macrocephalus*) were recorded along the Ecuadorean continental coast. In eleven cases an interaction with some type of fishing gear (usually gillnets) had occurred. Although the total number of interactions is unknown, fisheries may play an important role in the mortality of these animals. In at least three cases, the animals were taken to the beach by fishermen in order to obtain some profit. The meat and the fat may be used for bait and other parts of the animal such as the teeth and bones have an increasing market value. Although whales are protected by law in Ecuador, this additional income may provide a motive for some fishermen to enter a directed, but illegal fishery.

KEYWORDS: EASTERN TROPICAL PACIFIC; SPERM WHALES; INCIDENTAL CAPTURE; STRANDINGS

INTRODUCTION

The sperm whale (*Physeter macrocephalus*) is widely distributed in Ecuadorian waters. Its presence at these latitudes was known by the 19th century whalers who hunted them throughout the year along the continental coast and around the Galapagos Islands (Clarke, 1962; Whitehead and Hope, 1991). Investigations on the sperm whales found around the Galapagos Islands have been carried out since 1985 and have recently been extended towards continental waters (e.g. Arnbom and Whitehead, 1989; Whitehead, 1989; Whitehead and Kahn, 1992; Kahn *et al.*, 1993).

Compared to other species, the sperm whale does not appear to be as affected by fisheries interactions. In his extensive review, Northridge (1984) noted that it is only from the Mediterranean Sea that there are reports of sperm whale mortality in fishing gear. Since 1987, we have recorded twenty sperm whale strandings on the Ecuadorean coast. In at least eleven cases the stranding appears to be the result of an interaction with fishing gear, mainly artisanal gillnets.

MATERIALS AND METHODS

The information given here is part of the strandings database of the Ecuadorian Foundation for the Study of Marine Mammals (FEMM) developed and collected between 1987 and 1994. It was obtained from villagers at the strandings sites and FEMM members. In eight of the 20 cases at least one of the authors was present. For the remainder of cases photographic evidence, bones or both were assessed. Other possible cases were ignored due to the lack of physical evidence.

The total length of the examined animals was determined in the standard way i.e. in a straight line from the tip of the head to the central notch of the flukes. Age was estimated from the teeth which were cut longitudinally, sandpaper polished and put in formic acid (10%) for 30 hours. The number of growth layer groups formed in the surface of the dentine (Perrin and Myrick, 1980) was counted.

* This was originally an Appendix to SC/46/O 6. The main paper is also published in this volume.

THE STRANDINGS

The available data are summarised in Table 1. The stranding locations are shown in Fig. 1.

Strandings occurred almost throughout the year (10 months), apparently with no seasonal tendency. For those strandings for which it could be obtained, the age/sex distribution was young males (6 cases), adult females (3), adult males (1) and calves (1). For the other nine cases although the sex could not be determined their size meant that they were young animals or adult females. This is in accord with the view that females with calves and the immature males remain in tropical/temperate waters throughout the year, while adult males make seasonal migrations to polar waters (e.g. Clarke, 1962; Whitehead, 1987).

In nine cases, cables and/or other parts of nets were found on the stranded animals, sometimes around the flukes and/or mandible. These animals had thus become entangled in some sort of net, probably artisanal gillnets. Usually these nets have a mesh size of 4" (10cm) and are used to catch large pelagic fishes such as tuna, marlin and sharks. In two cases, the interaction occurred with a tuna purse seiner, which had presumably accidentally caught the sperm whale during fishing activities.

DISCUSSION

For the 11 cases of proven interaction with some type of fishery, the subsequent stranding of the animals appeared to be the direct result of the interactions. Interactions of sperm whales with fisheries have been reported from the Mediterranean by Di Natale and Mangano (1983, in Northridge, 1984; Di Natale and Di Sciara, 1994) and most of the sperm whales died in the Italian driftnet fishery. They suggest that this may play an important role in the mortality of sperm whales in that area. Although the number of sperm whales caught incidentally off Ecuador is unknown, the information presented here suggests that fishery interactions may also play an important role in the mortality of this species in Ecuador.

Most of the stranding records occurred in the most accessible coastal zone of the southwest and central provinces, Guayas and Manabí. It is not known whether

Table 1

Sperm whale strandings recorded on the Ecuadorian coast (1987-1994).

Site	Position	Date	Length (m)	Sex	Remarks	Source
1. Valdivia	01°56'S, 80°55'W	1987	10	?	Skull collected by a resident and brought to Montanita	This report
2. Punta Carnero	02°20'S, 80°55'W	12 Jun. 1988	11	?	Entangled in a gillnet	This report
3. Chanduy	02°25'S, 80°42'W	22 Mar. 1989	13.6	M	Caught by a tuna purse seiner and brought to the shore	Prieto & Bravo, 1991
4. Muisne	00°35'N, 80°03'W	Jun. 1990	?	?	Unknown details	*El Universo* 3 June 1990
5. Engabao	03°34'S, 80°28'W	09 May 1991	11.4	M	Entangled in a gillnet and brought to the shore to remove the net. Estimated age 12 years	This report
6. Salango	01°35'S, 80°52'W	02 Jul. 1991	10.8	M	Entangled in a gillnet	This report
7. Punta Carnero	02°20'S, 80°55'W	15 Aug. 1991	12.6	F	With the maxilaries broken	This report
8. Rio Chico	01°37'S, 80°52'W	12 Oct. 1991	11.8	F	Entangled in a gillnet. Estimated age 25-30 years	This report
9. Bahia de Caráquez	00°36'S, 80°26'W	Nov. 1991	?	?	Stranding reported to FEMM by Mr. Juan Jose Bernal	This report
10. Salinas	02°12'S, 81°00'W	Mar. 1992	3.5		Skull found on the beach	This report
11. Los Frailes	01°28'S, 80°46'W	15 Nov. 1992	11.4	M	Found stranded on the beach	This report
12. Puerto Rico	01°38'S, 80°50'W	09 Feb. 1993	8.4	F	Entangled in a gillnet	This report
13. Anconcito	02°22'S, 80°47'W	16 Jun. 1993	10	F	Entangled in a gillnet and brought to shore to remove the net	This report
14. San Vicente	00°35'S, 80°24'W	28 Oct. 1993	6.5	M	Entangled in a gillnet. Flukes were cut to remove the net. Estimated age 7-8 years	This report
15. Puerto Bolívar	03°16'S, 80°01'W	01 Dec. 1993	10.12	?	Floating 2 days in the channels near to harbour	This report
16. Sucre	00°14'S, 80°20'W	Feb. 1994	?	?	Skull found on the beach	This report
17. Las Manchas	00°45'N, 80°05'W	Apr. 1994	?	?	Skull found on the beach	This report
18. Chanduy	02°25'S, 80°42'W	17 May 1994	13.5?	M	Caught by a tuna purse seiner	Frias *et al.*, 1994
19. Briseño	00°32'S, 80°27'W	15 Aug 1994	11.6	M	Entangled in a gillnet. Estimated age 12 years	This report
20. Engabao	03°34'S, 80°28'W	04 Oct. 1994	10.11	?	Entangled in a gillnet. Estimated age 16 years	This report

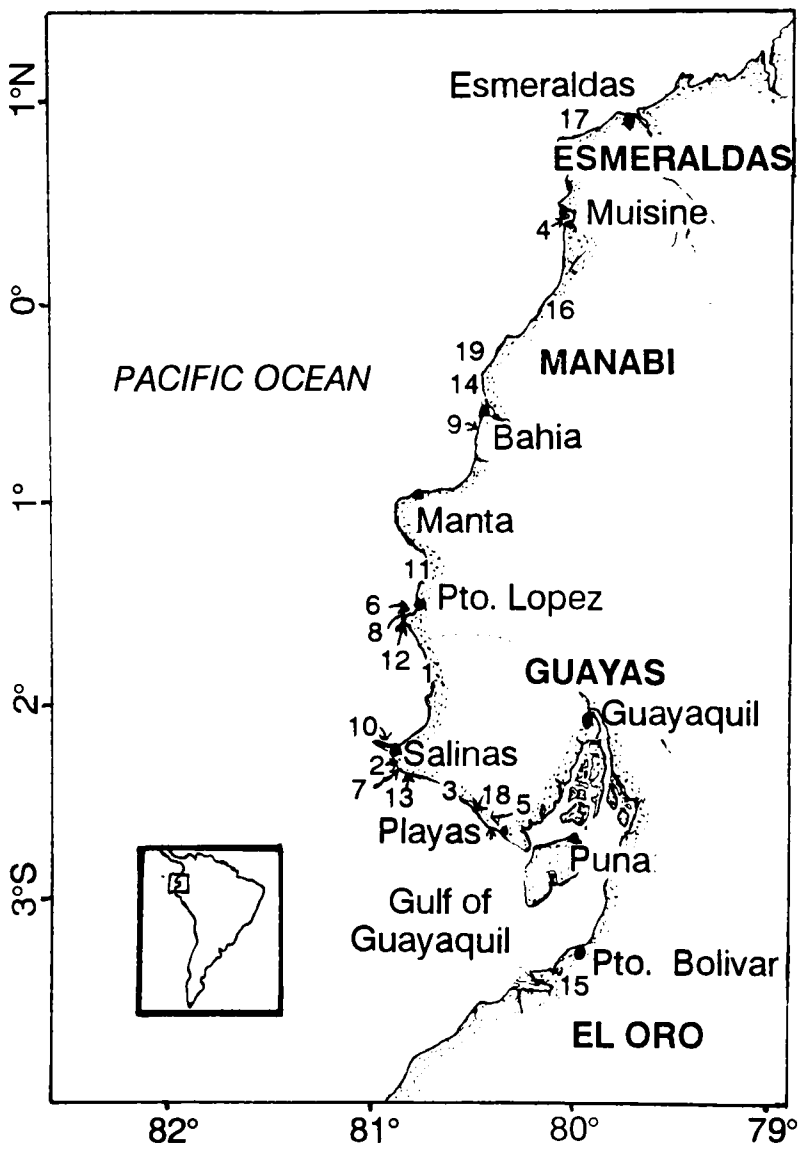

Fig. 1. Sites where sperm whale strandings occured on the Ecuadorian coast during 1987–1994

strandings occur with the same frequency in the northernmost province, Esmeraldas. It should be noted that the use of gillnets in that area is less common (Cedeño, 1987). There are no recorded fishery interactions and/or strandings of sperm whales in the inner estuary of the Gulf of Guayaquil. This part is relatively shallow, mostly less than 100m depth and sperm whales rarely visit such shallow waters (e.g. Leatherwood and Reeves, 1983). However, north of the Gulf, where the continental platform is narrower, artisanal vessels might operate in waters where sperm whales are found. The lack of stranding records for the southern Gulf may also reflect the fact that most of its coast is covered with mangrove trees, with few beaches. The only recorded case of a dead sperm whale in that part of the Gulf (No. 15) was for an animal that did not wash ashore but rather floated for several days in the channels near Puerto Bolívar.

The incidental capture of sperm whales in the nets of artisanal fishermen represents a danger for both the whale and the fisherman. If the drifting net is not free but tied to the boat this may endanger the lives of the fishermen. For example local fishermen believe that animal no. 5 had been responsible for the loss of a launch and its crew a few days before.

Although up until now incidental catches appear to have occurred as an unwanted bycatch during normal fishing operations, it is possible that in the future things might change. In three cases it was proved that fishermen purposefully dragged the incidentally caught animals to shore in order to make some profit out of the event, either to recover the net or to sell parts of the body (e.g. teeth, meat and bones, especially the cranium). The meat and the

fat are occasionally used for bait by artisanal fishermen and by the industrial tuna fishery. The value of a sperm whale tooth has reached a high price (US$50.00 each). It is not inconceivable that this might cause some fishermen to view this species as an alternative source of income and even lead to a 'directed' fishery, despite the fact that sperm whales are protected by law in Ecuador. The situation requires continued monitoring.

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SC/46/SM11

Mortality of Small Cetaceans and the Crab Bait Fishery in the Magallanes Area of Chile Since 1980

Anne-Catherine Lescrauwaet and Jorge Gibbons

Casilla 527, Punta Arenas, Chile

ABSTRACT

Since 1974, species of small cetaceans, fur seals, sea lions, sea birds and to some extent sea otters, have been taken deliberately each year for bait in the Chilean artisanal fishery for centolla, southern king crab (*Lithodes santolla*) and centollón, false king crab (*Paralomis granulosa*). We describe the socio-economic context of this fishery and we review official fishery statistics and unpublished data in order to estimate the magnitude of this direct take between 1980 and 1992. We find that the need for bait in the crab fishery has continually decreased from a peak value of 950 tonnes in 1986 to a minimum of 450 tonnes in 1992. In recent years, three new trends are contributing to alleviate mortality pressure on marine mammals in Magellanes; a change in fisheries legislation, an increased diversification of the artisanal fishery and an increasing public awareness of the values of marine wildlife.

KEYWORDS: INCIDENTAL CAPTURE; DIRECT CAPTURE; FISHERIES; SOUTH PACIFIC; PINNIPEDS; SEA OTTERS; COMMERSON'S DOLPHIN; BLACK DOLPHIN; DUSKY DOLPHIN; RIGHT WHALE DOLPHIN; BURMEISTER'S PORPOISE; MANAGEMENT.

INTRODUCTION

As several authors have reported (e.g. Goodall, 1977; Sielfeld *et al.*, 1977a; b; Torres, 1977; Sielfeld and Venegas, 1978; Cárdenas *et al.*, 1987; Goodall and Cameron, 1980; Goodall *et al.*, 1988b; Leatherwood *et al.*, 1988), small cetaceans have been taken deliberately each year since 1974 in the Magellan region of Chile for use as bait in traps set for centolla or southern king crab (*Lithodes santolla*) and centollón or false king crab (*Paralomis granulosa*). However, no thorough examination of the development of the crab fishery, its geographic expansion or the demand for marine mammal bait has been presented previously. In this paper, we discuss the socio-economic background to the fishery, the historical sequence of relevant political and economic events, and attempt to estimate the numbers of cetaceans that would have been required to support the crab fisheries in recent years.

This work is predicated on the assumption that, to conserve populations in the Patagonian and Fuegian channels, one needs to have: (a) better information on the status of the populations affected by activities related to crab fishing, (b) better information on the numbers of cetaceans killed and (c) a basic management plan for presentation to the Chilean government and the fishing communities.

MATERIALS AND METHODS

We have reviewed the literature on the crab fisheries in southern Chile with respect to the use of bait and the social and economic factors affecting or influencing the fisheries. We especially sought information on cultural elements, ethnic structures and population transitions within the fishing communities of the Magellan region.

Written sources included annual statistics from port authorities, the Servicio Nacional de Pesca (SERNAP), the Instituto de Fomento Pesquero (IFOP), the Servicio Agricola y Ganadero (SAG), the Corporación Nacional de Fomento a la Producción (CORFO), the Instituto Nacional de Estadisticas (INE) and a published socio-economic profile of a part of the artisanal fishing community (Henriquez, 1990). We also checked every issue of the regional newspaper *La Prensa Austral*, from 1987 to early 1993, for articles related to the taking of wildlife for bait, the over exploitation of crab etc. This newspaper search gave us an indication of what information has been made available to the community and the perceived importance of these issues at the regional level.

We conducted extensive interviews with fishermen (approx. 60), 16 of 25 company managers, scientists, representatives of the Chilean Navy and personnel in the fisheries service. Company managers completed questionnaires designed to elicit their views on the condition of the crab fisheries, suggested solutions to problems and likely obstacles to implementation of regulatory measures. The Secretary of Fisheries kindly cooperated with a 'written interview' regarding new policies.

We used the region's 14 fishing areas (IFOP, publications 1979–1990) to identify fishing grounds with the highest catch effort. Annual catch effort values per area are given as fractions of the total annual catch effort. The seasonal and geographical distribution of catch effort was compared with the available information on distribution of small cetaceans.

In this paper, the term 'catch effort' refers only to the effort directed at the trapping of crabs. It does not encompass the effort involving nets or diving gear. We calculated effort using IFOP methods, with the following assumptions:

(a) a 40% loss in active fishing days due to poor weather or technical difficulties;
(b) an average submersion time per trap set (cast) of 72 hours for centolla (one third of the traps are set per cast);
(c) an average submersion time of 48 hours for centollón (one half of the traps are set per cast).

The monthly catch effort per vessel was thus calculated by multiplying the number of traps on board by the number of fishing days per month and then dividing by either 2 (centollón) or 3 (centolla).

Partial monthly and yearly information on crab catch effort was available for 1979–1986 from SERNAP and IFOP. Catch effort for 1987–1989 was calculated from daily

fishing activity as recorded by harbour personnel, who noted the arrival and departure of vessels and the areas from which crabs were harvested (fishing Regions I-XIV, see Fig. 3). Files kept by the port authorities provided each vessel's length. By knowing the average number of traps carried by different length classes of vessels, we were able to estimate the total number of traps deployed from a particular port.

Our estimates of catch effort for centolla and centollón, combined, during 1990–1992 are based on the total estimated number of traps available in the region and the number of effective fishing days. The total catch effort, multiplied by a 'bait unit', gives an indication of the total amount of bait used (both wildlife and legal). Since in reality bait units may vary in size by as much as 1.5kg, the use of a single value is arbitrary. We chose 0.5kg, the minimum amount of bait needed for a single trap, to generate conservative estimates of total bait requirements.

We identified potential legal sources of bait in the region (e.g. slaughterhouse waste, waste from the industrial fishery) and reviewed official information to verify that this bait was being used for crabbing.

Finally, in our discussion we consider available data for 1993 and 1994 in our assessment of conclusions drawn from the main period of our work (i.e. up to 1992).

RESULTS

Government policy and national fisheries

Growth in fisheries has made fishing the second most important category in the Chilean economy, contributing 12% of the total value of national exports in 1990. In 1989, Chile exported a total catch of 6.6 million tonnes of fish, shellfish, crustaceans and algae worth US$930 million. Developments in the Chilean fishery industry occurred under a regime of free access to fisheries and major reductions in all forms of regulation and control. It had an extremely destructive impact on natural resources, with the exhaustion of mollusc banks and the overfishing of important pelagic fish and shellfish populations. Ten of the main fisheries, together contributing 85% of the total export value, showed signs of overexploitation (Couve, 1991).

Unmanageability of the crab fisheries

Chilean commercial fisheries for centolla and centollón are centred in the Magellan Region (49°S-56°S). This region supplies 97% of the national production of centolla and 100% of that of centollón. In 1976, accelerated and sustained growth began in this industry with increases in the sizes of the fleets, the processing companies, the geographical areas, annual landings and exports (Table 1, Figs 1 and 2).

Annual landings before 1976 fluctuated between 200 and 450 tonnes.

By 1986, crabbing had become unmanageable, as shown by the high percentage of illicit captures; Hernandez and Diaz (1986) estimated that 30–40% of the total landings were taken illegally (either undersized crabs, crabs obtained from closed areas or those obtained using illegal methods). Some company owners suggested that this may have reached up to 70% in later years.

Six factors are seen as contributing to the unmanageability of the Chilean crab fisheries.

(1) *Free access*

Little or nothing was required of entrants to the fisheries, resulting in an increase from nine processing plants in 1974 to 27 in 1988.

(2) *State support*

The Chilean government, through CORFO, provided extremely favourable terms for the acquisition of fishing boats and equipment. From 1976 to 1989, 90 beneficiaries in the artisanal sector received, in total, approximately US$600,000 of credit, while four enterprises in the industrial sector received a total of US$2,500,000 of credit from 1982 to 1986 (B. Bonifetti, CORFO, pers. comm.). The artisanal fleet grew from approximately 60 before 1970, to nearly 600 boats by 1988.

(3) *Growth in export demand*

Extremely favourable external market conditions arose in recent years for Chilean crab. In 1990, their export value reached approximately US$2,800 per tonne; 30 times greater than the average value for all other fishing products. This was partially due to the high prices of Alaskan king crab (*Paralithodes camtschatica*) which

Table 1

Characteristics of growth in crab fishery, Magallanes, 1974-1992. Key: (A) Centolla; (B) Centollón.

Year	Total catch	(A)	(B)	No. of companies	No. of fishing vessels (A)	No. of fishing vessels (B)	No. of transport vessels
1974	511			9			
1976		1,028					
1979	3,220	2,268	952	13	150	63	8
1980	1,810	1,381	429	14	105	26	8
1981	1,590	1,280	310	16	133	46	6
1982	1,782	1,473	309	14	138	18	8
1983	3,586	2,755	831	24	177	90	8
1984	3,597	2,746	851		220	123	8
1985	2,902	2,636	266		229	39	21
1986	3,586	2,593	993		282	130	45
1987	3,961	2,188	1,773	27	296		55
1988	4,491	2,161	2,330	27			
1989	4,250	2,297	1,953	27			
1990	3,699	1,834	1,865	25			
1991	5,127	1,738	3,389			550 total	
1992	2,494	1,173	1,321	21		550 total	

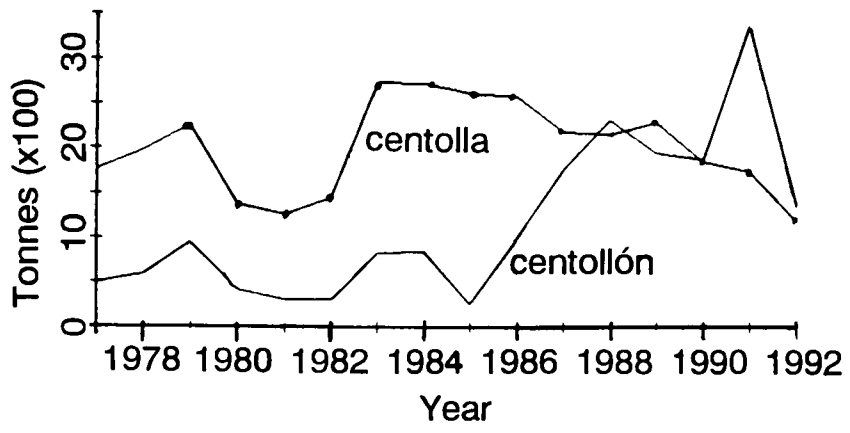

Fig. 1. Annual landings, centolla-centollón.

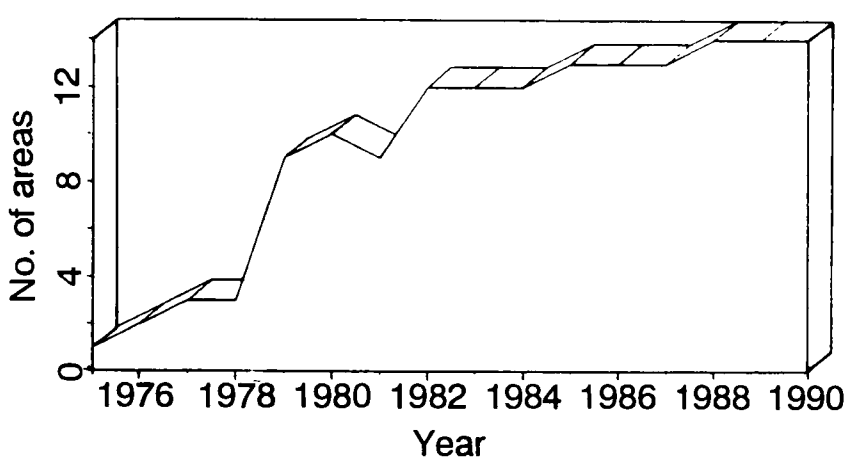

Fig. 2. Geographical expansion of centolla and centollón fishery.

encouraged the USA to import lower-priced crab products from the ex-USSR, Argentina and Chile. The Alaskan fishing grounds were closed from 1982 to 1988. This led to an increase in the number of processing plants in the Magallanes and seriously disrupted the balance between the artisanal fishing sector and the processing capacity of the industry.

(4) *Lack of regulation*

The free market economic policy focused on maximising short-term profits and neglected the government's responsibility for protecting the nation's marine resources. This is evident from the contrast between the major development of the fisheries and the simultaneous decline in SERNAP's work force. In 1973, the SERNAP regional office in Magallanes had 13 inspectors. This declined to between eight (in 1985) and ten (in 1992). The necessary infrastructure (proper vehicles, vessels, radio and office equipment) was not in place to support the staff of inspectors and the legal sanctions were too weak to deter illegal crabbing.

In 1987, only two of the 27 companies were supplied by their own vessels. The remainder of the regional fleet work as individuals, under highly competitive conditions. Crab is bought alive at low prices in the remote fishing areas by company boats that also bring in expensive supplies and gasoline or exchange them for fresh products, often at unfair rates. The increased competition for fresh crab together with poor working conditions has led to criminal activity among fishermen including stealing and sabotage.

(5) *Geography*

Until the mid-1970s, the centolla fishery was limited to nine companies operating only on the west coast of Isla Grande de Tierra del Fuego, around Isla Dawson, in Seno Otway and along the south coast of Peninsula Brunswick (52°S-54°S). Since 1976, the crab fishing grounds have expanded to cover approximately 25,000km of labyrinthian interior channels that are difficult, if not impossible to police. In 1981, the Porvenir area was closed to crab fishing in response to a study that revealed overfishing in this area (Campodonico, 1979). Seno Otway and Seno Año Nuevo were closed for the same reasons, but many fishermen admitted that they had fished in closed areas at one time or another. In 1990, about 20 boats were discovered fishing in Seno Año Nuevo, using camouflage against aerial surveillance (A. Roman, Director SERNAP-Magallanes, *La Prensa Austral*).

(6) *Cultural factors*

Crab fishing is extremely demanding in terms of physical effort, harsh climate (low temperatures, high precipitation, strong winds), exposure to dangerous circumstances and isolation. Most artisanal fishermen have come to the Magallanes from rural areas on Isla Chiloë (42°S-43°S). They generally come from low income backgrounds with limited employment alternatives other than in agriculture or fishing and have little or no formal education (Henriquez, 1990); crab fishing is by far the most lucrative option. For example, the average monthly wage of a shepherd is US$ 100, whereas crab fishermen could earn as much as US$ 1,000 per month in the 1980s.

During 1983–1984, a special effort was made by local authorities in Punta Arenas, with support from the Organisation of American States, to improve fishing techniques in the artisanal sector. Although courses (including training in the use of fishing gear, such as longlines, not represented in the Chiloë fishing culture) were offered free of charge, only 43 persons attended. Longlines are an important tool for obtaining fish as bait in the crabbing areas.

The few attempts to form labour unions or other labour organisations have failed, apparently because crab fishing is so profitable and individualistic (Mr J. Gonzalez – President of the Union of Artisanal Fishermen – Punta Arenas, pers. comm.).

Summary

In summary, the crab fisheries of Chile can be characterised by: (a) a lack of formal responsibility by the industry with respect to the working conditions and methods of the fishermen; (b) strong competition for raw material, which has stimulated illegal capture; (c) over-capitalisation of the fleet; and (d) a failure of governmental authorities to intervene and prevent resource depletion. The fisheries have become unmanageable in spite of a high degree of awareness among politicians, managers, scientists, fishermen and the general public. This awareness is evident from the abundant information in the media, numerous technical reports by IFOP, seminars and workshops organised by regional authorities and, finally, the number of regulations applied to the fisheries.

Between 1983 and 1986, the previously established 5-month closed season (February-June) was abolished. Later, to protect the centolla during its reproductive season, crabbing was suspended from December to February (1987–1991). A special decree in 1991 established a 7-month closed season (December-June) to protect the species from further overexploitation, but the closed season was shortened to five months in 1992 in view of the socio-economic crisis facing the artisanal sector. The December-January closed season for centollón remains unchanged.

Status of small cetaceans in southern Chile

Legal status

Under Decree No. 223, 1979, of the Ministerio de Economia, Fomento y Construccion, traps are the only type of fishing gear that can be used legally to catch crabs. These traps need bait. In 1977, after Torres (1977) had made the authorities aware of the fact that large numbers of small cetaceans were being taken for crab bait in the Magellan region, the Ministerio de Agricultura published Decree No. 381, prohibiting the catch, transport, commercialisation, possession or processing of small cetaceans. Special permits for scientific or cultural purposes have been issued on four occasions – three relating to the export of Commerson's dolphins (*Cephalorhynchus commersonii*) and one allowing the capture of Chilean dolphins (*Cephalorhynchus eutropia*) (SERNAP, Resolution No. 364, 1988).

Actual situation

In spite of the 1977 decree, many publications have referred to continued catches of small cetaceans along the southern Chilean coasts, specifically to support crab bait (Torres, 1977; Sielfeld *et al.*, 1978; Torres *et al.*, 1979; Goodall and Cameron, 1980; Sielfeld, 1983; Goodall and Jordan, 1986; Goodall *et al.*, 1988b; Crespo *et al.*, 1994; and others). Published estimates of the numbers of individuals or meat tonnages of small cetaceans and other marine wildlife are summarised in Table 2; these estimates range from 50 dolphins per week in 1976 (Torres, 1977) to 400 tonnes of marine and other wildlife (including cetaceans) during 1987 (Cárdenas *et al.*, 1987). The species of wildlife known to have been taken for crab bait are listed in Table 3. As to small cetaceans, Peale's dolphins (*Lagenorhynchus australis*), Chilean dolphins and Commerson's dolphins were most affected, while the presence of dusky dolphins (*Lagenorhynchus obscurus*), Southern right whale dolphins (*Lissodelphis peronii*) and Burmeister's porpoises (*Phocoena spinipinnis*) in the area suggest that they also would have been taken occasionally for bait.

Progress of knowledge on small cetaceans

There has been little scientific research on small cetaceans in Chile. During the last century, only three graduate theses on cetological subjects have been produced by Chilean Universities and only one project (for monitoring mortality of small cetaceans in Regions IX and X – in 1989) was entirely financed with national funds. A second project was partially supported by the Chilean Ministry of Agriculture (Clarke *et al.*, 1978).

In consequence, little is known about the general biology, distribution, trophic relations or reproductive habits of small cetaceans in Chile, or on the status of populations and their interactions with humans.

Table 2

Estimates of illegal captures of small cetaceans.

Year(s)	Estimate	Source
1976 (6 months)	50 specimens/week	Torres, 1977
1978	2,400 specimens/year	Torres, 1979
1979	4,120 specimens/year	Torres *et al.*, 1979
1980-1983	240 tonnes/year	Sielfeld, 1983
	[mainly Commerson's and Peale's dolphins, sea lions and sea birds]	
1987	400 tonnes/year	Cárdenas *et al.*, 1987
	[species mentioned by Sielfeld (1983)]	

Table 3

Species of wildlife affected by crab bait fishery.

Most affected species	Species affected to lesser extent
Otaria flavescens	*Phocoena spinipinnis*
Arctocephalus australis	*Lagenorhynchus obscurus*
Lagenorhynchus australis	*Lissodelphis peronii*
Cephalorhynchus commersonii	*Phalacrocorax magellanicus*
Cephalorhynchus eutropia	*Phalacrocorax albiventer*
	Phalacrocorax atriceps
	Eudyptes crestatus
	Larus dominicanus
	Larus skoresbii
	Lama guanicoe
	Lutra felina
	Lutra provocax

Estimation of illegal bait

Amount

Annual catch effort values and estimates of total amount of bait used in the centolla fishery (both legal and illegal) are summarised in Table 4a, while those for the centollón fishery from 1979–1986 are in Table 4b. Data for 1990–1992 in Table 4a refer to combined centolla and centollón catch effort. Centolla catch effort shows a substantial increase starting in 1983, with a peak value in 1986. Centollón catch effort values remain generally low but variable until 1986. Although no data on centollón catch effort after 1986 are included, the substantial increases in total annual landings (Table 1(B) of SERNAP annual statistics) indicate that the

Table 4a

Annual catch effort values for centolla fishery with estimated amounts of bait used (tonnes).

Year	No. of effective traps	Estimates bait used (tonnes)
1979	1,443,782	722
1980	649,487	325
1981	734,155	367
1982	974,864	487
1983	1,537,259	769
1984	1,445,568	723
1985	1,850,787	925
1986	1,900,000	950
1987	1,875,600	938
1988	1,860,000	930
1989	1,700,000	850
1990	1,600,000	800
1991*	1,800,000	900
1992*	900,000	450

* Data include both centolla and centollón catch effort values.

Table 4b

Annual catch effort values for centollón fishery with estimated amount of bait used, 1979-1986.

Year	No. of effective traps	Estimated bait used (tonnes)
1979	100,627	50
1980	44,225	22
1981	50,995	25
1982	48,814	24
1983	200,378	100
1984	272,646	136
1985	66,115	33
1986	282,272	141

Table 5a

Distribution of annual catch effort for centolla (1979-1990*), for the different fishing Regions (I to XII); catch effort per area is expressed as a fraction of the total annual catch effort.

	Region															
Year	I	I-A	II	III	IV	IV-A	V	VI	VII	VIII	IX	X	XI	XII	Undetermined	Total
1979	0.11	-	0.14	0.01	0.22	-	0.17	0.14	0.16	0.03	-	-	-	-	0.03	1.0
1980	0.03	-	0.15	0.00	0.22	0.00	0.02	0.18	-	0.06	-	0.31	-	-	0.00	1.0
1981	0.04	-	0.04	0.00	0.19	0.05	0.20	0.09	0.20	0.07	-	0.11	-	-	0.00	1.0
1982	0.00	-	0.05	0.05	0.08	0.05	0.28	0.02	0.09	0.05	-	0.10	0.22	-	0.00	1.0
1983	0.02	-	0.30	0.01	0.03	0.01	-	-	0.29	0.33	-	-	-	-	0.00	1.0
1984	0.04	-	0.52	0.00	0.02	0.00	0.04	0.01	0.31	0.05	0.00	0.00	-	-	0.00	1.0
1985	0.00	0.07	0.08	0.08	0.09	0.04	0.17	0.10	0.10	0.02	0.00	0.16	0.08	0.00	0.00	1.0
1986	0.01	0.05	0.06	0.08	0.16	0.04	0.16	0.06	0.09	0.05	-	0.17	0.07	-	0.00	1.0
1987	0.01	0.01	0.01	0.23	0.14	0.03	0.06	0.07	0.09	0.06	-	0.18	0.07	0.03	0.00	1.0
1988	0.00	0.01	0.02	0.17	0.18	0.01	0.07	0.00	0.19	0.02	-	0.31	-	-	0.02	1.0
1989	0.01	0.01	0.00	0.14	0.13	0.00	0.22	0.00	0.10	0.03	0.02	0.16	0.10	0.07	0.00	1.0
1990*	0.03	0.02	0.01	0.07	0.15	0.00	0.19	0.00	0.07	0.12	0.04	0.16	0.01	0.13	0.00	1.0
Total (%)	2	1	12	7	13	2	13	6	13	7	0	14	4	2		100%

* Based on data from January to June 1990.

catch effort for this species has increased appreciably since 1986. Our estimates of catch effort are similar to those made independently by Hernandez *et al.* (1986) for the period 1979–1984.

Evaluation of sources

The catch effort values published by IFOP are supplied by the companies, based on declarations by the fishermen. Harbour records generally confirm information on activity as given by the companies, but independent fishermen's reports on the number of traps used are likely to be underestimates.

In Table 4a we used only harbour activity records and independent methods to estimate the number of traps carried from 1987–1992. Thus these estimates should be little affected by biases in the fishermen's reporting. They are, however, biased by the fact that part of the crab catch has been made with illegal gear (e.g. nets) or by illegal means (e.g. diving). This bias is difficult to quantify, but IFOP publications generally correct estimates of bait requirements by subtracting 20% to account for it. There was noticeable increase in the last few years in the number of boats too small to carry a significant number of traps (IFOP, 1988). This trend is interpreted to indicate that netting and diving for crabs has increased. Crab nets are known to cause a significant amount of incidental small cetacean mortality due to entanglement (Goodall and Cameron, 1980).

The amount of bait used by fishermen within crab extraction areas is difficult to determine. The fishermen usually keep their camp sites stocked with about 15% of the total bait needed (Sielfeld, 1983).

Geographical distribution

CENTOLLA

For official management purposes, the centolla and centollón fishing grounds have been divided into 14 different fishing Regions (see map, Fig. 3). The distribution of catch effort for centolla from 1979–1990 is given in Table 5a. Fluctuations between seasons are due to the incorporation of new areas as well as the abandonment of others. Before 1976, the crab fishery was limited to the vicinity of Punta Arenas. From 1979–1989, the main activity was localised in the areas south of the Magellan Strait. Regions V and VII had very low catch effort during 1980–1981, but the crab fishery expanded to Region X during that season. In 1981–1982, Regions V and VII became important crabbing areas again, with no major changes in fishing activity near their northern limits. A further northwards expansion in Region XII occurred in 1987.

After 50 years of intense activity, the Porvenir area (Region I) was closed for four years beginning in 1983. Along with locations in Regions II, IV and VI, this area has been exploited almost continuously for centolla. Accumulative catch effort is highest in Regions II, IV, V, VI and X.

CENTOLLÓN

Region IX, where Commerson's dolphins are commonly observed (Goodall, 1994) has been the primary fishing area for centollón throughout the entire period (1979–1986). Regions II, VII and VIII were used less intensively during this period (Table 5b).

Table 5b

Distribution of catch effort for centollón, 1979-1986.

	Region						
Year	I	II	IV-A	VII	VIII	IX	Total
1979	-	-	-	6,500	-	94,127	100,627
1980	1,056	-	-	-	-	43,169	44,225
1981	-	12,219	-	-	17,151	21,625	50,995
1982	-	1,678	-	27,064	-	20,072	48,814
1983	-	-	-	80,483	31,610	88,285	200,378
1984	-	-	-	87,766	23,313	161,567	272,646
1985	-	-	-	-	27,361	38,754	66,115
1986	-	57,090	-	-	27,037	188,145	272,272
Total	1,056 (1%)	70,987 (6%)	-	201,813 (19%)	126,472 (12%)	655,744 (62%)	1,056,072

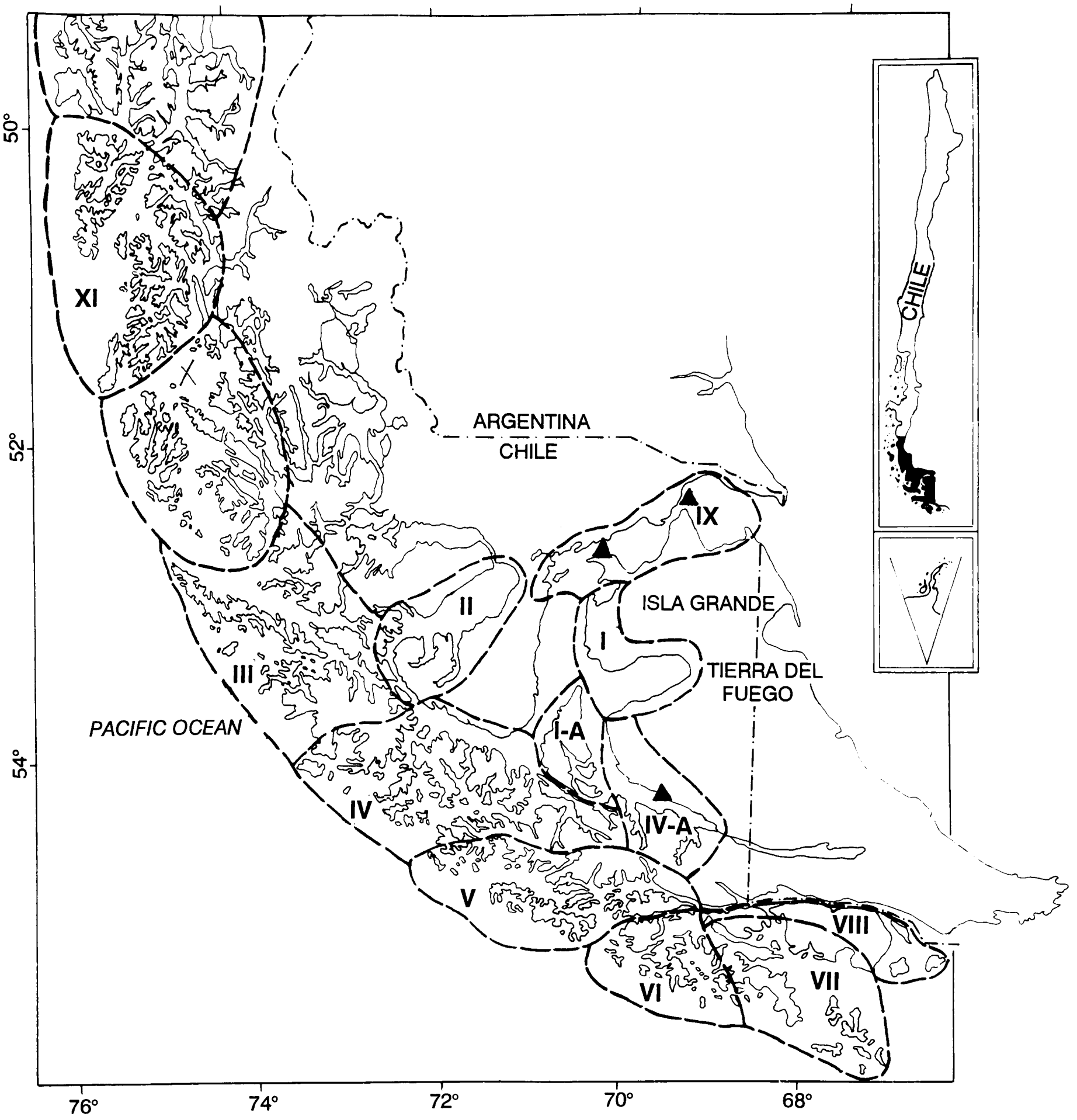

Fig. 3. Geographical location of fishing areas – centolla and centollon (XII Region – from IFOP).

Evaluation of sources

Information on capture sites has become less and less reliable with the growth in illegal crabbing activity, especially since certain areas have been closed. The fishermen are the exclusive sources of data on capture sites. We can therefore assume that there is a negative bias in the amount of catch effort assigned to closed areas and a corresponding positive bias in the amount assigned to areas still open to fishing.

Monthly variations

Table 6 shows monthly catch effort for centolla, 1979–1990. Catch effort for the centolla fishery was low during the first months of the calendar year and gradually increased towards the peak winter months. Data from IFOP show it was highest for the centollón fishery during the first half of the calendar year, with peak values from April to July.

Evaluation of sources

The monthly fishing activity (recorded as departure and arrival of boats in the harbour) information can be regarded as reliable, at least during the open season. During the closed season illegal fishing continues, although probably at relatively low levels.

Table 6

Seasonal variations in catch effort for the centolla fishery 1980-1990. Catch effort per month is expressed as a fraction of total annual catch effort. Key: CS = closed season.

	Month												
Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1980	0.25	CS	CS	CS	CS	CS	0.04	0.06	0.07	0.15	0.18	0.23	0.98
1981	-	CS	CS	CS	CS	CS	-	-	-	-	-	-	-
1982	-	CS	CS	CS	CS	CS	-	0.11	0.13	0.20	0.25	0.30	0.99
1983	0.01	0.01	0.04	0.12	0.17	0.20	0.16	0.12	0.07	0.03	0.02	0.02	0.97
1984	-	0.05	0.12	0.16	0.21	0.18	0.13	0.07	0.04	0.02	0.01	0.01	1.00
1985	0.08	0.08	0.06	0.05	0.05	0.07	0.08	0.09	0.10	0.12	0.11	0.11	1.00
1986	0.06	0.05	0.06	0.05	0.06	0.07	0.08	0.09	0.11	0.12	0.12	0.10	0.97
1987	CS	0.03	0.06	0.06	0.07	0.09	0.11	0.12	0.12	0.16	0.17	CS	0.99
1988	CS	0.04	0.08	0.06	0.09	0.11	0.13	0.12	0.14	0.08	0.09	CS	0.95
1989	CS	0.04	0.08	0.09	0.09	0.09	0.11	0.12	0.11	0.12	0.13	CS	0.97
1990*	CS	0.14	0.22	0.25	0.20	0.18	-	-	-	-	-	CS	0.99

*Based on data January to June.

Presence of cetaceans

The most common small cetaceans in the Magellan regions are Commerson's and Peale's dolphins. Commerson's dolphins are found principally in the eastern Strait of Magellan (Region IX), especially from the Segunda Angostura eastwards (Goodall, 1994). Aerial surveys in this area in January-February 1984 indicated the presence of 3,211 (± 1,680) dolphins (Leatherwood *et al.*, 1988). A more extensive aerial survey carried out in May 1987 gave a population estimate of only 313 (*sic*) individuals (Venegas and Atalah, 1988). The difference may be due to (a) a real decrease in population; (b) seasonal migrations of the dolphins from the area; or (c) differences in survey methods or observer abilities. Commerson's dolphins in the Kerguelen Islands migrate offshore in winter (Robineau, 1985; De Buffrénil *et al.*, 1989) and winter offshore movements have been suggested for those of the Magellan region (Goodall *et al.*, 1988a; Goodall, 1994). It thus seems more likely that there are fewer dolphins in the area during the most intensive fishing periods. Peale's dolphins are found throughout the year and their distribution covers all interior waters including the most intensive crabbing areas, they may be the species most affected by crab fishing. From 1984, the areas south of the Magellan Strait (Regions V, VI and VIII) where dusky dolphins are most frequently observed, have become important crabbing areas. An apparently resident group of Chilean dolphins is observed throughout the year in Seno Skyring, a non-crabbing area.

Interviews and public information

Crab industry interviews

Most of the heads of companies who were interviewed accused the fishermen of ignorance and irresponsible behaviour. They considered the fishermen to be responsible for problems related to the use of wildlife as crab bait. However, they assumed their share of responsibility for the regional overfishing of crab and admitted to participating in illegal practices. For example, one administrator admitted that several thousand pinnipeds had been killed by his company in the last few years for bait and aphrodisiacs; genitals of sea lions (*Otaria flavescens*) and fur seals (*Arctocephalus australis*) were exported illegally to Asian markets while their carcasses served as crab bait.

All of the managers interviewed agreed that their bait supplies did not cover the necessities of the fishermen, but in the case of the companies which did not own their own vessels, the managers assumed no responsibility for the actions of independent fishermen. Fishermen generally accepted their responsibility for killing wildlife but claimed that no economically viable alternatives exist. Many fishermen believe that red meat is by far the best bait.

Many fishermen claimed that the introduction of harpoons by fishermen from the region of Valdivia (Region IX – 40°S) in the 1970s triggered an increase in the use of wildlife, cetaceans in particular. The use of harpoons was well documented in the 1970s (Sielfeld *et al.*, 1977a; b; Goodall and Cameron, 1980). Fishermen argued that the men from Chiloë, the majority of the crab fishermen, did not know how to use longlines or harpoons and that this accounted for the deficit of bait supplies. However, in November 1992, a metal-working shop in Punta Arenas was manufacturing harpoons to catch dolphins.

Alternative sources of bait

Company heads and fishermen agreed that an improvement in the transport to the fishing areas of cheap, legal bait, such as demersal fishery waste could provide part of the solution.

The availability of 'legal bait' in the region is deduced from annual fisheries and meat production statistics. Since most artisanal fish products are sold whole, only waste from industrial fish processing is taken into account; this has increased since 1987 (INE, 1988–1989; SERNAP, Annual Statistics Reports). The availability and applicability of different types of bait were studied by Diaz (1988). The most common species available were frozen hake (*Macruronus magellanicus*), jurel (*Trachurus murphy*), salted sardines (*Clupea bentincki*) and anchoveta (*Engraulis ringens*). His results suggest that although sardines and anchoveta are perhaps the best crab bait, they would cost more than demersal fishery waste.

Cetacean mortality

Both fishermen and industry representatives insisted that the mortality of marine mammals was highest from 1980–1986 and that it had decreased to a minimum since the arrival of the industrial fishing fleet in the region (1988), which produces significant quantities of waste annually.

Nevertheless, according to eye-witness accounts, the take of small cetaceans for bait continued, for example, in Otway Sound (April 1991) and Beagle Channel (February 1991). Photographic evidence of the use of wildlife was published in the local newspaper (19 March 1991). According to Cardenas *et al.* (1986a; b) companies provided up to 30% of the needed bait in 1985/1986. Fishermen claimed that most dolphins were taken during 1983–1986, although the majority of the estimated 2,000 tonnes of bait (mostly illegal) consisted of sea lions. Our estimate of the total amount of bait used in 1986 (950 tonnes) would require a maximum of 6,300 sea lions (average weight 150kg) or 13,750 dolphins (average weight 70kg) in the event that these species had been the exclusive source of illegal bait. We assume that in the actual crab bait fishery (1992), the take of small cetaceans did not exceed 10% of the total demand for bait (45 tonnes), or an equivalent of 600 dolphins per year.

DISCUSSION

Our results indicate that small cetacean mortality in the artisanal sector has declined substantially since 1990, as a consequence of the three factors outlined below.

(1) *A decrease in the demand for bait due to reduced fishing effort*
The estimated 450 tonnes of bait used in 1992 is about half the annual estimate for the period between 1985 and 1989. This decrease in fishing effort may have been a result of the depletion of crab stocks, or for economic or technical (regulatory) reasons. In any event the decrease might facilitate the recovery of regional wildlife populations.

(2) *A decrease in the proportion of illegal bait*
Between 1983 and 1988, much of the bait was provided by wildlife. By 1992, the regional production of waste (in both slaughter houses and the industrial fishery) was sufficient to cover the estimated amount of bait needed. In addition, there are indications that the fishery for legal bait in the fishing grounds has increased substantially.

(3) *A decrease in the proportion of small cetaceans in the illegal bait*
In the last few years, the most affected species of wildlife in terms of bait have been sea lions and penguins, both easy targets when in breeding colonies on land. Dolphins appear to have become less abundant in the fishing areas, which may also be a factor in their decline in relative importance as bait.

The present situation
A number of questions arise concerning the ecological consequences of the historic crab fisheries. In this section we use available data for 1993–4 (i.e. after the main period reviewed in this paper) to describe new trends observed in the artisanal fishery.

(1) *Diversification*
The artisanal fishery in Region XII is slowly recovering after a period of major changes due to certain events that forced restructuring in this sector. As a consequence of the overexploitation of centolla and the establishment of a seven month closed season, artisanal fishermen turned their attention towards other resources.

Although the annual catch of crustaceans continues to be significant (2,487 tonnes in 1992; 2,200 tonnes in 1993), the actual landings have dropped by almost half compared to 1988. This can be better shown by considering the percentage of crustaceans as part of the total artisanal production. Between 1985 and 1989 crustaceans represented 30% of the total artisanal production. Since then the percentage has declined as follows: 1990, 25%; 1992, 20%; 1993, 10%. By contrast, in 1989, sea urchins accounted for only 0.5% of the total artisanal catch (80 tonnes). By 1993, they comprised 50% of the total artisanal catch, most of which was exported to Japan. Early in 1994, a daily average of 3 tonnes of sea urchins was being exported to Japan.

Other traditional resources in the region include clams, mussels, squid and octopus. The exploitation of molluscs initially seemed to offer an interesting alternative, but since 1990, persistent red-tide events lasting up to a year in a large part of the region have meant that they became too toxic for human consumption. In 1992, a red tide lasting for a year or more (Dr Luis Vergara, Director of the Servicio Nacional de Salud, *La Prensa Austral*) affected 100% of the interior waters. Nevertheless, molluscs provided 33% (6,500 tonnes) of the total artisanal catch in 1993 (c.f. 60% in 1989).

Many artisanal fishermen in the region invested in demersal fishery equipment, encouraged by the high catches of the newly arrived industrial fleet. However, for a number of reasons this proved unsuccessful, including a lack of knowledge on the biology and migration patterns of these species, insufficient technical knowledge, an inability to compete economically with the industrial fleet and the fact that artisanal vessels are restricted to interior waters. An estimated 80% of these fishermen returned to the exploitation of traditional resources as illustrated by the percentage contribution of demersal fishing to total artisanal fishery production: 1990, 20%; 1992, 2%; 1993, 5%.

In summary, although with limited diversification the relative importance of crustaceans in artisanal fishery landings has diminished significantly, in terms of absolute production, the catch continues to be important. The Magallanes artisanal fishery continues to be unpredictable and susceptible to sudden changes in the external market.

(2) *Legislation*
Modifications in fishery legislation in 1991 introduced the concept of 'Full Exploitation Regime' with a partial restriction of access through the auction of established fishing quotas. As noted earlier, a special decree was introduced extending the closed season for centolla from 5 to 7 months per year, but this was revoked in 1991 when the red tides prevented the mollusc fishery acting as an alternative source of income during the closed season. The new legislation has enhanced the reorganisation of the crab fishery by restricting the number of operating companies and increasing the requirement for infrastructure as a condition of permits. The fact that artisanal fishermen must subscribe to a regional register and reside in the region of their fishing activity should facilitate control and management in the region. Modifications also refer to the creation of Regional and Zonal Fisheries Councils with consultative and regulatory power, respectively, and the participation of the artisanal sector. Finally, a rigorous application of more severe sanctions should increase the efficiency of control.

(3) *Organisation*
The artisanal sector is beginning to move towards labour organisation through unions and cooperatives, although participation is still limited (approx. 30% of the 1,600–1,700 fishermen). This should facilitate co-operation with regard to control, technical assistance, social and medical care, education etc. The creation of a training centre in 1992 (FUNCAP, Fundación para la Capacitación del Pescador Artesanal) that provides free specialisation courses to artisanal fishermen and the requirement that they subscribe to the local register should result in some improvement in social conditions.

(4) *Education*
The knowledge of and interest in marine mammals in Chile is increasing, as indicated by the number of workshops and conferences and by the growing number of researchers in the field. There is also more concern for conservation by the community channelled through regional and national non-governmental organisations. The strong increase in (eco)tourism in the region may increase awareness of the economic value of marine mammals. Tourism has been the fastest growing sector in Magellanes' local economy for the last three years and in 1993, ecotourism accounted for about 25% of the total regional tourism revenue (total of US$70 million, 160,000 visitors; Servicio Nacional de Turismo, Sernatur, 1994).

Although marine expeditions are now offered, despite the great potential (e.g. see the WDCS report on whale watching in Latin America and the Carribean, 1994) none as yet is based on dolphin or whale watching activities.

(5) *External pressure*
On 13 May 1992, a US based NGO formally petitioned the US government to ban imports of crab and crab products from Chile, under the 1972 Marine Mammal Protection Act. This provides for the Secretary of the Treasury to ban the import of commercial fish and fish products caught with methods that kill marine mammals in excess of US standards. The petition was supported by at least nine major US based environmental and wildlife conservation NGOs and by Fisheries Associations.

In response, the Chilean government through its regional office SERNAP, produced a leaflet on aspects of the biology of some of the species of marine mammals in regional waters and called for a study of the bait problem in Region XII.

A multi-disciplinary commission was established to study the availability of legal bait and mechanisms for its distribution in the fishing areas. The commission determined that a stock of 40 tonnes of bait (mostly originating from industrial fishery waste) should be kept frozen in case no fresh legal bait is available. However, no agreed mechanisms have been established concerning the legal enforcement of the use of this bait or the cost of permanently maintaining such a stock. Ultimately, the decision to buy and be supplied with legal bait depends upon the fishermen themselves.

RECOMMENDATIONS

(1) To reduce to a minimum the use of illegal bait, an independent consultant should be engaged to: (a) assess the current availability of legal bait in the region; (b) make cost-benefit comparisons; (c) plan for the development of an infrastructure to distribute bait to the fishing areas; and (d) provide a legal framework to make the use of legal bait obligatory.

(2) Public awareness regarding cetaceans should be increased by: (a) establishing a follow-up to the 1992 programme of education for children on marine mammals and their environment, supported by the IUCN Cetacean Specialist Group; (b) evaluating the potential of dolphin and whale watching in the region and ensuring that the promotion of projects to develop this activity includes suitable regulations and guidelines; (c) the promotion of marine protected areas in Chile, including the incorporation of sites of special interest for marine mammals.
(3) Studies of the populations of small cetaceans should be supported; these should focus on obtaining data that can be used to assess fishery impacts on populations (e.g. abundance, distribution and stock identity; populations dynamics, trophic relations).

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Interactions Between Small Cetaceans and Peruvian Fisheries in 1988/89 and Analysis of Trends

Koen Van Waerebeek[1,2] and Julio C. Reyes[3]

ABSTRACT

In 1988 and 1989 we monitored the fish terminal of Pucusana, central Peru, for 259 and 233 days respectively, and observed 1,613 and 1,292 small cetaceans landed. The estimated total yearly kills (1988/1989) at this port are 2,289 (SE=130) and 2,320 (SE=117) animals, including 1,725/1,893 dusky dolphins, 383/331 Burmeister's porpoises, 155/57 common dolphins, 18/31 bottlenose dolphins and 8/8 specimens of other species. With few exceptions, the animals were captured incidentally or directly in gillnets in a multi-species artisanal fishery (only about twelve animals were seen with harpoon wounds). The total kill at Pucusana in 1989 had increased roughly by a factor of three compared to 1986 levels and tenfold compared to 1985. A shift was observed in seasonality of peak landings of dusky and common dolphins. Catch estimates for another port, Cerro Azul (13°00'S), are 68 (SE=17) dolphins and porpoises in December 1987 and 131 (SE=47) in July 1988. Analysis of statistics provided by the Ministry of Fisheries (MIPE) suggest a steady decline in small cetacean catches for the entire coast of Peru, from an estimated 9,700 animals (756 metric tonnes) in 1985 to 5,500 (426 metric tonnes) in 1988; the reason for this is unknown since the trend in artisanal fishing effort associated with cetacean mortality cannot be deduced from existing data. There is an urgent need to continue and expand research in the area.

KEYWORDS: INCIDENTAL CAPTURE FISHERIES; SOUTH PACIFIC; DUSKY DOLPHIN; BURMEISTER'S PORPOISE; COMMON DOLPHIN; BOTTLENOSE DOLPHIN; SHORT-FINNED PILOT WHALE; LESSER BEAKED WHALE; DWARF SPERM WHALE; RISSO'S DOLPHIN; SOUTHERN RIGHT WHALE DOLPHIN

INTRODUCTION

Since Clarke (1962) first reported a Burmeister's porpoise (*Phocoena spinipinnis*) for sale in the Chimbote fish market in 1960, several workers have drawn attention to a growing catch of small cetaceans off the Peruvian coast (Grimwood, 1969; Clarke *et al.*, 1978; Mitchell, 1975; Brownell and Praderi, 1982).

Our investigation of the Peruvian dolphin fishery started in 1984 in collaboration with A. Luscombe from the Lima-based Association for Ecology and Conservation (ECCO). For the ensuing two years it was expanded into an IUCN/UNEP funded project directed by D. Gaskin from Guelph University (Gaskin *et al.*, 1987; Read *et al.*, 1988). After 1987 we proceeded to set up a small field laboratory, named the 'Peruvian Centre for Cetacean Research' (CEPEC), in the fishing town of Pucusana and continued the research (Reyes and Van Waerebeek, 1988; Van Waerebeek, 1989; Van Waerebeek and Reyes, 1990a).

Although progress in the analysis of biological data of exploited species has been slow due to a lack of resources, information is available for the Burmeister's porpoise (McKinnon, 1988; Reyes and Van Waerebeek, 1994), bottlenose dolphin, *Tursiops truncatus* (Reyes, 1989; Van Waerebeek *et al.*, 1990) and *Mesoplodon peruvianus*[4] (Reyes *et al.*, 1991). An exhaustive study of the biology of Peruvian dusky dolphins (*Lagenorhynchus obscurus*) has recently been finalised (Van Waerebeek, 1992a; b; 1993; Van Waerebeek *et al.*, 1993; Van Waerebeek and Read, In press).

The purpose of the present paper is threefold: (1) to offer a detailed report of the observed take of dolphins and porpoises at Pucusana in 1988 and 1989; (2) to compare this with equivalent data from earlier years, to identify tendencies and where possible to interpret them; (3) to evaluate official statistics in an attempt to assess the current extent of small cetacean exploitation in Peru.

ARTISANAL FISHERY

Over the period 1984–89, field research was conducted primarily in Pucusana (12°30'S) and to a lesser extent in Cerro Azul (13°00'S), two artisanal fishing villages on the central Peruvian coast. They were selected because of their considerable landings of cetaceans and accessibility (Fig. 1). Other coastal ports and fishing communities were visited on a much less regular basis.

Below we summarise the principal aspects of the small cetacean fishery interaction in Peru, as revealed in earlier work by colleagues and ourselves (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a; Van Waerebeek and Reyes, 1990b; Van Waerebeek *et al.*, 1990). A few minor points have been adapted to match new insights gained.

Fishery mortality of small cetaceans in Peru results from both an incidental and a directed take. Off central Peru, four species account for more than 99% of the catch: the dusky dolphin, Burmeister's porpoise, the bottlenose dolphin and the long beaked common dolphin (*Delphinus delphis* according to current IWC practice c.f. *Delphinus capensis*; see Heyning and Perrin, 1994). Over three quarters of the total kill are dusky dolphins. Occasionally single individuals of other species are landed.

Most animals are caught in medium-sized (600–1,500m x 10m) multifilament nylon drift gillnets with stretched mesh sizes of up to 20cm. The nets are usually set at dusk and recovered in the morning by artisanal fishermen operating from small open boats (<15m). Target species include the blue shark (*Prionace glauca*), the shortfin mako shark (*Isurus oxyrhynchus*), hammerhead sharks (*Sphyrna* spp.), the thresher shark (*Alopia vulpinus*), eagle rays (*Myliobatis* spp.) and other large schooling fish such as bonito (*Sarda chiliensis*) and dorado (*Coryphaena hippurus*) as well as dusky dolphins. In recent years it has become common practice to set driftnets with the intention

[1] *Centro Peruano de Estudios Cetológicos (CEPEC), Casilla 1536, Lima 18, Peru*
[2] *Institut Royal des Sciences Naturelles de Belgique, Bruxelles, Belgium*
[3] Present address: *Casilla 392, Talcahuano, Chile*
[4] We recommend 'lesser beaked whale' be the vernacular name.

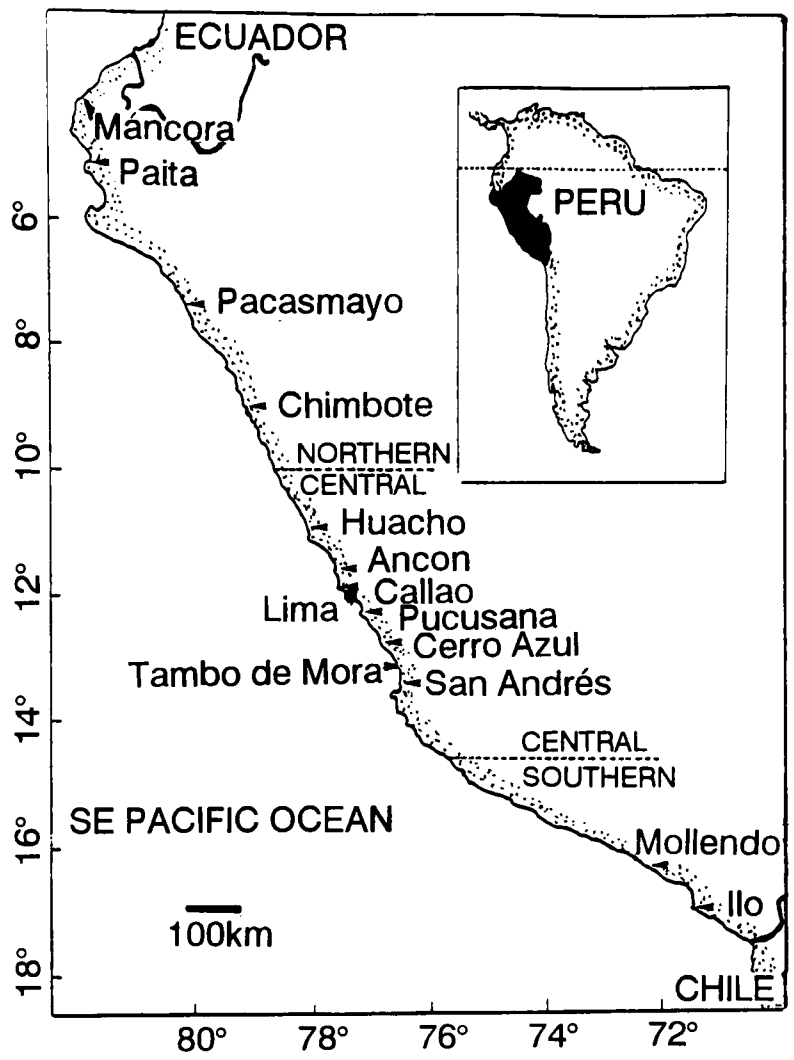

Fig. 1. Map of Peru. Fishing ports with important small cetacean catches are indicated.

of catching dusky dolphins in areas where schools have been located. This occasionally results in several tens of dolphins being unloaded at fish terminals in a single day.

Offshore bottlenose dolphins and other oceanic species are a welcome bycatch to the fishermen, especially in summer months. Burmeister's porpoises become entangled accidentally primarily in demersal gillnets, set for bottom-dwelling rays (*Myliobatis* spp.) and sharks (*Mustelus* spp.), less often for *pejegallo* (*Callorhinchus callorhinchus*) and lorna (*Sciaena deliciosa*).

Dolphins may also be caught by hand-thrown harpoons (especially common dolphins) and in purse seines in the industrial fishery for small pelagic fish. It is doubtful whether purse seines are set specifically on dolphin pods, although in March 1985 some 15 common dolphins, including live animals, were seen landed by a purse seiner at the wharf of Chimbote (09°05′S). From fishermen's reports it seems that such bycatches continue to occur with some regularity.

The meat of the dolphins is primarily used for human food, mostly fresh but also in a dried variety called *muchame*. Estimated total annual kills for Pucusana increased from 170 in 1985 to 760 the next year and 1,101 (SE=32) in 1987. The total catch in Peru for 1985 was roughly estimated at 10,000 dolphins and porpoises.

MATERIALS AND METHODS

CEPEC port monitoring

In 1988 and 1989, we monitored the fish terminal of Pucusana for landed small cetaceans over a total of 259 and 233 days respectively. As in preceding studies (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a, Van Waerebeek and Reyes, 1990b), the mean daily catch rate for each species was calculated, stratified by month, in order to estimate monthly and total annual catches. Standard errors (SEs) were determined following Read *et al.* (1988).

At least one of us was present in Pucusana for an average 21.4 days per month (range: 5–31 days), except for May 1989 when no monitoring took place. The mean daily catch rate for that month was estimated as the sum of the catch rates for April and June 1989 divided by two. The SE was estimated as the square root of the sum of the respective variances divided by two (Wonnacott and Wonnacott, 1969), assuming that covariance between April and June catch rates is negligible.

Unfortunately we were not able to follow closely the dynamics of the fishery dolphin trade as was possible for a short period in 1986 (Lehman, 1988) and nor was it possible to monitor Cerro Azul or other Peruvian ports with sufficient regularity to enable estimates to be made of yearly catches. However, catches were recorded at Cerro Azul for five days in December 1987 and for 13 days in July 1988, and monthly kill estimates for these months were computed. Random visits to a few other coastal towns allowed us to obtain some idea of the exploitation of small cetaceans in those areas.

Shifts in seasonality and catch composition at Pucusana are analysed by comparing combined data over the period 1985–7 with those of 1988–9. Estimated kill figures are evaluated on a yearly basis.

Table 1

Cetacean catch composition (in %) for the period 1985-89, used in the computation of mean weight for a hypothetical 'Small Cetacean Unit' (SCU) to interpret Ministry of Fisheries' (MIPE) statistics expressed in metric tonnes. In square brackets are total counts of small cetaceans examined on which composition is based; for northern Peru this includes some cetacean remains collected in the vicinity of fishermen's landing sites. No data are available for southern Peru. Mean weight of 'other species' category is approximated by the mean weight for bottlenose dolphins.

Species	Mean body weight (kg)	Percent catch composition: Central Peru [N=5,411]	Percent catch composition: Northern Peru [N=114]
L. obscurus	73.00	77.8	0.0
P. spinipinnis	48.93	12.3	71.1
D. delphis	84.67	7.1	15.8
T. truncatus	171.44	2.4	11.4
G. macrorhynchus	951.67	0.30	1.8
Mesoplodon sp.n.	253	0.17	0.0
Other species	171.44	0.18	0.0
Small cetacean unit		76.53kg	84.84kg

Official statistics

The only complete set of quantitative data available for each of the 48 principal maritime ports and fishing villages of Peru are the official statistics compiled by the Ministry of Fisheries (MIPE) in collaboration with the Instituto del Mar del Perú (IMARPE). For management reasons, MIPE divides the Peruvian coast into northern, central and southern zones, with borders set roughly at 10°S and 14°30′S (Fig. 1).

However, MIPE data on cetacean landings do not distinguish among species and catches are expressed in metric tonnes of small cetacean (*tonino*). We estimate approximate numbers of animals caught by dividing the total weight by the weight of a hypothetical 'small cetacean

Table 2

Observed numbers (line 1), estimated numbers (line 2) and standard errors (in brackets) of small cetaceans, stratified per month, landed at the Pucusana fish terminal, central Peru, in 1988. Estimates and SE have been rounded to the nearest integer.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Dusky	2	9	6	8	250	70	269	127	68	12	277	127	1225
dolphin	3	10	9	13	287	88	491	219	93	74	308	131	1725
	(1)	(2)	(3)	(4)	(28)	(8)	(105)	(46)	(11)	(43)	(37)	(26)	(124)
Burmeister's	2	12	3	6	55	44	13	14	41	11	47	11	259
porpoise	3	13	5	10	63	55	24	24	56	68	52	11	383
	(1)	(1)	(1)	(3)	(11)	(6)	(5)	(6)	(8)	(17)	(5)	(1)	(25)
Bottlenose	3	1	2	0	1	0	0	2	0	0	1	3	13
dolphin	4	1	3	0	1	0	0	3	0	0	1	4	18
	(1)	(0)	(1)	(0)	(0)	(0)	(0)	(2)	(0)	(0)	(0)	(0)	(3)
Common	0	0	0	11	15	48	30	1	0	0	1	2	108
dolphin	0	0	0	18	17	60	55	2	0	0	1	2	155
	(0)	(0)	(0)	(5)	(2)	(14)	(13)	(1)	(0)	(0)	(0)	(0)	(19)
Other species	3	1	0	0	0	1	0	0	0	0	1	1	7
	4	1	0	0	0	1	0	0	0	0	1	1	8
	(1)	(0)	(0)	(0)	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(1)	
Total	10	23	11	25	321	163	312	144	109	23	327	145	1613
	13	25	17	42	369	204	569	248	149	143	363	150	2289
	(2)	(2)	(3)	(10)	(29)	(19)	(115)	(45)	(15)	(46)	(37)	(4)	(130)

Table 3

Observed numbers (line 1), estimated numbers (line 2) and standard errors (in brackets) of small cetaceans, stratified per month, landed at the Pucusana fish terminal, central Peru, in 1989. For estimates of the month May see text. Estimates and SE have been rounded to the nearest integer.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Dusky	95	87	53	47	-	201	163	97	53	128	73	63	1060
dolphin	140	87	68	109	205	287	253	334	106	159	81	65	1893
	(34)	(0)	(14)	(14)	(26)	(42)	(37)	(68)	(32)	(29)	(9)	(3)	(151)
Burmeister's	11	36	18	45	-	7	5	2	1	18	16	16	175
porpoise	16	36	23	104	59	10	8	7	2	22	27	17	331
	(6)	(0)	(3)	(14)	(8)	(3)	(3)	(1)	(1)	(4)	(3)	(1)	(19)
Bottlenose	5	0	0	0	-	3	2	0	0	1	12	23	
dolphin	7	0	0	0	2	4	3	0	0	0	1	12	31
	(3)	(0)	(0)	(0)	(2)	(2)	(1)	(0)	(0)	(0)	(0)	(1)	(4)
Common	0	0	0	0	-	4	3	11	3	0	0	0	21
dolphin	0	0	0	0	3	6	5	38	6	0	0	0	57
	(0)	(0)	(0)	(0)	(1)	(2)	(3)	(13)	(2)	(0)	(0)	(0)	(14)
Other species	1	0	0	0	-	2	-	-	-	-	1	1	5
	1	0	0	0	3	3	0	0	0	0	1	1	9
	(1)	(0)	(0)	(0)	(1)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(1)
Total	111	123	71	92	-	217	173	110	57	146	100	92	1292
	165	123	92	212	270	310	268	379	114	181	111	92	2320
	(35)	(0)	(15)	(32)	(28)	(43)	(38)	(68)	(33)	(32)	(9)	(4)	(117)

unit' (SCU). The SCU is based on the mean recorded weight for each species and the average observed species composition from as many ports as possible over the 1984–1989 period (Table 1). While 77.8% of small cetaceans landed in central Peru are dusky dolphins, this species does not normally occur off northern Peru (Brownell and Praderi, 1984; Van Waerebeek, 1992b). Therefore a separate SCU for central and northern Peru are needed. At present we have insufficient data to compute an SCU for southern Peru and thus assume, based on our knowledge of the distribution of small cetaceans (Van Waerebeek *et al.*, 1988) that it is not different from that of the central coast.

RESULTS

Cetacean landings: Pucusana

In 1988 and 1989 we observed, respectively, 1,613 and 1,292 small cetaceans of nine species landed at the Pucusana fish terminal. The total yearly kill at this port is estimated as 2,289 (SE=130) for 1988 and 2,320 (SE=117) for 1989. No correction has been made for small cetaceans killed and lost, since this factor is unknown. The observed and estimated numbers of dolphins and porpoises landed in each month are given in Tables 2 and 3. The months with the highest kill rates are July in 1988 (569 specimens; SE=115); June (310; SE=43) and August (379; SE=68) in 1989.

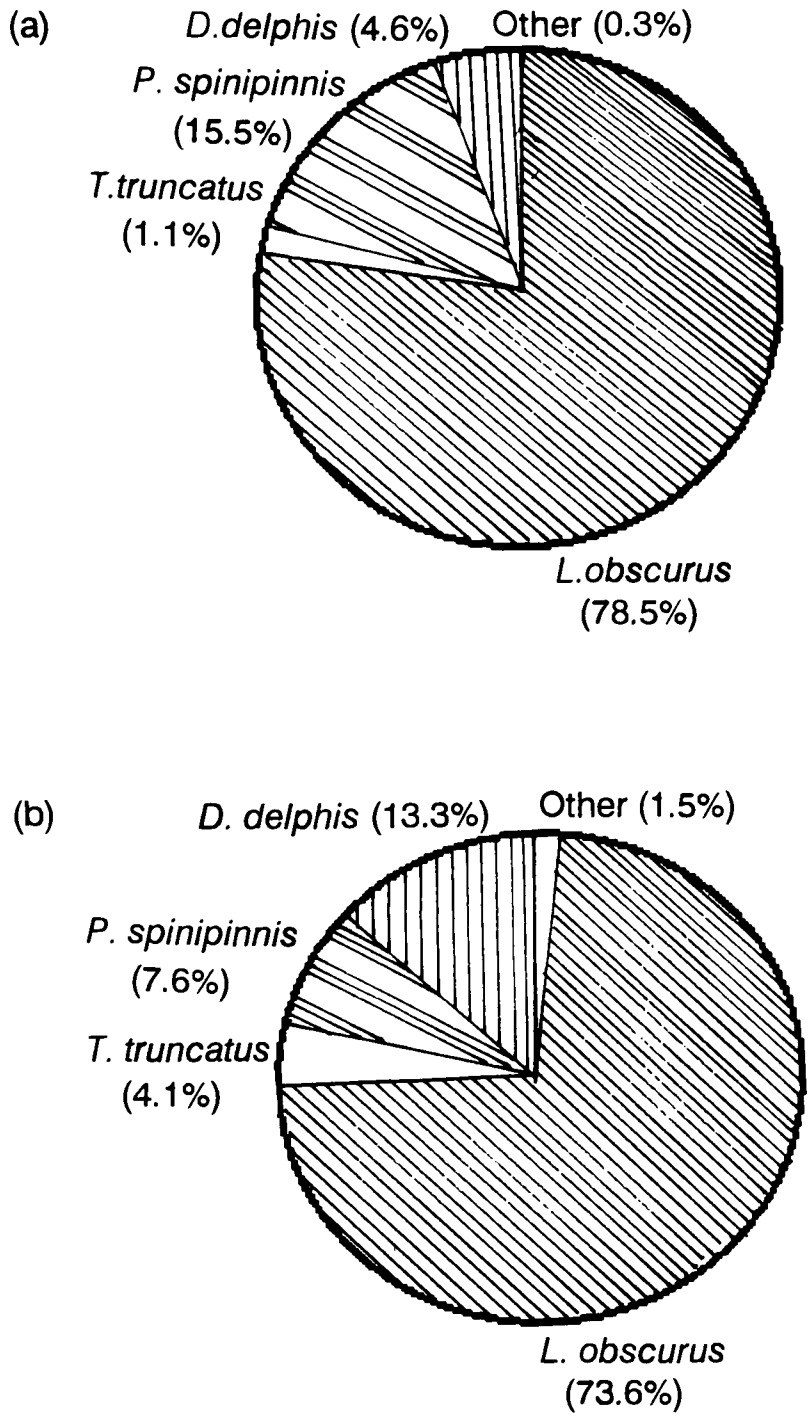

Fig. 2. Comparison of species composition of small cetaceans landed at Pucusana fish terminal, pooled over 1988–89(a) and 1985–87(b).

Dusky dolphins accounted in both years for more than three quarters of the kill, Burmeister's porpoises for an average 15% and common dolpins decreased significantly in prevalence from nearly 7 to 2.5%. Bottlenose dolphins represented on average only 1% (Fig. 2). In the two year period, the following 'other' species were seen at the fish terminal: five short-finned pilot whales (*Globicephala macrorhynchus*), three lesser beaked whales, one dwarf sperm whale (*Kogia simus*), one Risso's dolphin (*Grampus griseus*) and one southern right whale dolphin (*Lissodelphis peronii*). The latter is the second confirmed record of this species in Peruvian waters and the most northerly of its entire known range (Van Waerebeek *et al.*, 1991).

In the 1988–89 period, with few exceptions, dolphins and porpoises were captured in gillnets in a multi-species artisanal fishery as described above. In general, time constraints prevented us from collecting much data on fishery effort or catches by gear type. However, for a controlled subsample of 61 Burmeister's porpoises landed, the following observations were made: 47.5% (29) of the animals were captured in demersal nets set for bottom dwelling elasmobranchids and the holocephalid *pejegallo*, 31% (19) were landed with blue sharks and dusky dolphins taken in surface drift nets, while only some 10% (6) were caught in inshore sciaenid nets.

Harpooning developed into a systematic capture method in 1987 (Van Waerebeek and Reyes, 1990a) but a subsequent local decree prohibited this practice. After a few dolphins had been seized by port authorities, buyers refused further animals with harpoon wounds. As a result, over the two year period only four common dolphins, three bottlenose dolphins and four dusky dolphins examined at the fish terminal showed harpoon wounds. In one instance, however, some fishermen were caught landing a few butchered dusky dolphins directly on the beach at night, which they admitted had been harpooned. Later, with a change of port authority personnel, enforcement relaxed and harpooning resumed to some extent in 1990. At Pucusana we recorded only one animal, a common dolphin, landed by a purse seiner.

The price per kg of dolphin (whole animal) offered to the fishermen almost doubled from US$0.14 per kg in late 1986 (Lehman, 1988) to an average of US$0.25 in April 1989. Several buyers have specialised in the trade in dolphin meat, which has ceased to be regarded as inferior. Prices continue to fluctuate, depending on availability and demand at the Lima central market.

Cetacean landings: Cerro Azul

Part-time monitoring of the small fish terminal of Cerro Azul resulted in a kill estimate of 68 (SE=17) dolphins and porpoises in December 1987 and 131 (SE=47) animals in July 1988. The species composition is given in Table 4.

Table 4

Observed and estimated numbers (±1SE) of small cetaceans landed at Cerro Azul during December 1987 (n=5) and July 1988 (n=13). Estimates and standard errors are rounded to the nearest integer. DD= dusky dolphin; BP = Burmeister's porpoise; BD = bottlenose dolphin and CD = common dolphin.

	Species:	DD	BP	BD	CD	Total
Dec 1987	Observed	6	3	1	1	11
	Estimated	37	19	6	6	68
	SE	±16	±7	±6	±6	±17
July 1988	Observed	51	1	0	3	55
	Estimated	122	2	0	7	131
	SE	±47	±2	±0	±3	47

Official statistics

MIPE data suggest that the total Peruvian kill of small cetaceans has declined since the 1979 peak catch (1,409 tonnes). National landings decreased from 756 tonnes in 1985 to 426 tonnes in 1988 (Fig. 3), equivalent to a decrease from an estimated 9,700 to 5,500 small cetaceans in those years. However, the accuracy of these data is questionable. Only at the best equipped fish terminals, such as Pucusana, are specimens actually weighed. In most smaller ports body weight is still estimated from the size of the animal. We have good estimates of total kills per species for the period 1985–89 in Pucusana and by combining this with data on mean weights we can calculate total weight estimates for the yearly catch. Table 5 shows that the MIPE totals for Pucusana fall well within ±1 SE of our estimates and as such are sufficiently accurate.

Unfortunately we have but a single example to check the accuracy of MIPE statistics for other ports. In 1986, the fish terminal of Cerro Azul was monitored for 142 days and 237 cetaceans were landed. Subsequently the 1986 total catch

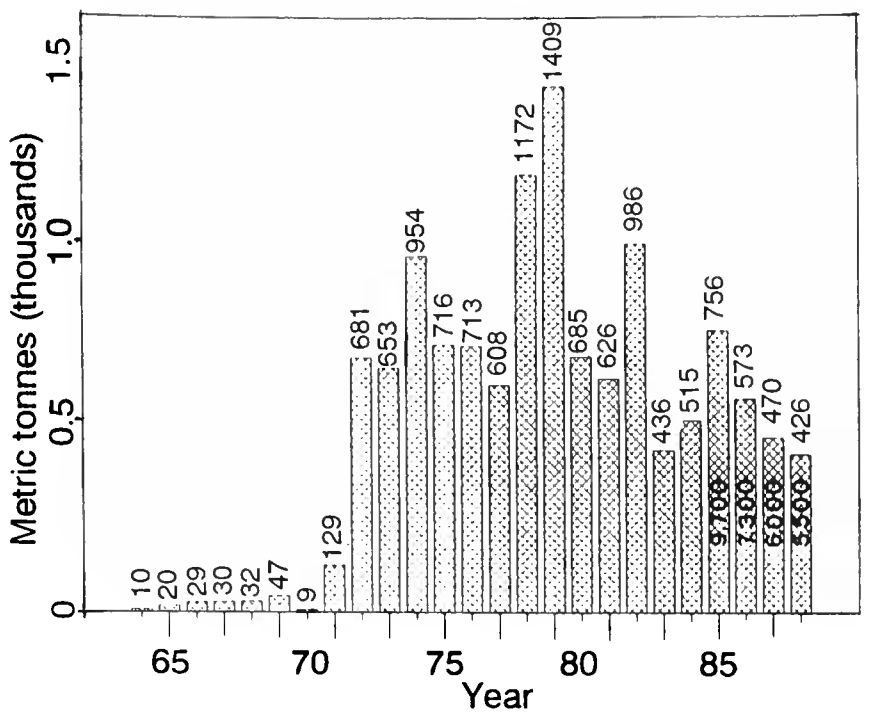

Fig. 3. Total mass (in tonnes) of small cetaceans landed at Peruvian coastal ports between 1964 and 1988. Confidence interval data do not exist. Source: Department of Statistics, Ministry of Fisheries (MIPE), Lima. Figures positioned vertically inside bars are estimated numbers of small cetaceans caught, calculated from total weight, mean specimen weights and recorded species composition (see text).

was estimated at 587 animals with SE 80 (Read *et al.*, 1988). The total weight is estimated at 40.65 tonnes (SE 11.84 tonnes), which is significantly different (99% confidence intervals) from the 99 tonnes cited by MIPE statistics. The difference may have been caused by systematic overestimation of weights or by human error in the manipulation of figures.

Other errors in MIPE data are likely to arise from unreported bycatches. The latter may be particularly true for incidentally caught small cetaceans in the extreme north of Peru, where cetacean meat is of very low esteem. Specimens are often discarded and thus fail to be registered in the port logbooks (S. Zambrano, Asociación de Ecología y Conservación, pers. comm.).

In summary, we suggest that the MIPE data require careful interpretation, since their reliability may vary over time and from one port to another. However, positive and negative deviations might offset each other, resulting in a lower error margin in the total catch figure.

DISCUSSION

Pucusana

The increase in gross cetacean landings at Pucusana in recent years has been dramatic. Catches in 1989 were roughly three times those in 1986 and tenfold compared to 1985 levels (Fig. 4).

The proportion of dusky dolphins in the total kill has remained almost steady at roughly three out of four animals (77%) since 1985 (Fig. 2). The rapid development of the directed gillnet fishery for dusky dolphins (Fig. 5) has been the principal reason for the strong growth in overall numbers of cetacean catches.

The estimated kill of Burmeister's porpoises more than quadrupled from 83 in 1987 to 383 animals in 1988 (Fig. 5) while its relative share in the catch rose abruptly from 7.5% to 16.7%.

Landings of bottlenose dolphins have oscillated around a mean of 26 animals a year, with no apparent changes between years (Fig. 5), with most catches being taken from the offshore stock. Due mainly to the large numbers of

Table 5

Total annual weight (in metric tonnes) of small cetaceans landed at Pucusana and Cerro Azul according to figures of the Peruvian Ministry of Fisheries (MIPE) and estimates by the authors (CEPEC). The latter were calculated based on the observed catch composition and recorded mean weights for each species. The 1985 estimate was taken from Read *et al.*, 1988. MIPE data do not have confidence intervals.

	Source	1985	1986	1987	1988	1989
Pucusana	MIPE	17	77	87	173	?
	CEPEC	18.1	62.8	87.3	163.4	169.1
	SE	±3.6	±16.7	±16.4	±38.9	±42.9
Cerro Azul	MIPE	44	99	47	53	-
	CEPEC	-	40.6	-	-	-
	SE	-	±11.8	-	-	-

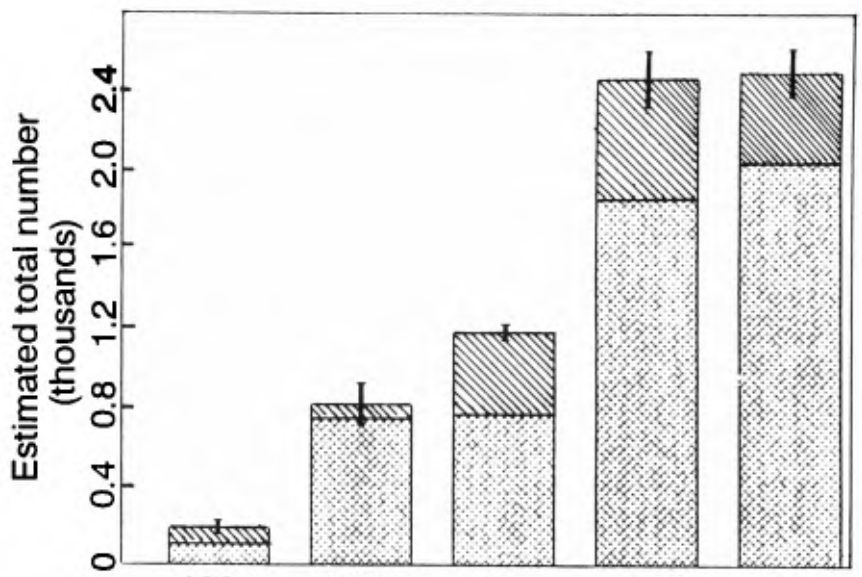

Fig. 4. Estimated yearly numbers, with confidence intervals (±1SE), of small cetaceans landed at Pucusana. Double-hatched area indicates dusky dolphins. Data for 1985–6 are taken from Read *et al.* 1988.

dusky dolphins landed in recent years, bottlenose dolphins represented a steadily decreasing component of total cetacean landings: from a peak of 11% in 1985 to 1% in 1988–89.

In 1985–1986 the common dolphin was so rarely encountered that we included it in the category 'other species'. In 1987, a harpoon fishery suddenly emerged resulting in 264 common dolphins being landed, accounting for 24% of total cetacean landings in that year. Since then catches have been steadily decreasing again (Fig. 5), at least partly due to a successful anti-harpoon campaign.

No pattern seems to exist in the frequency with which *G. macrorhynchus*, *M. peruvianus* or other species are landed.

Months with peak catches of dusky and common dolphins have shifted over the study period (Fig. 6). In the period 1985–87, large numbers of dusky dolphins were landed from August to November, i.e. during late winter and spring, but in 1988–89 catches increased as early as May (late autumn) and were down again by September, the former height of the 'dusky season'. An entirely analogous situation was seen in the long beaked common dolphin (Fig. 6). At this point it is not possible to tell whether this is due to fluctuations in environmental factors, which may affect the timing of movements of the dolphins or a reflection of shifts in fishing effort.

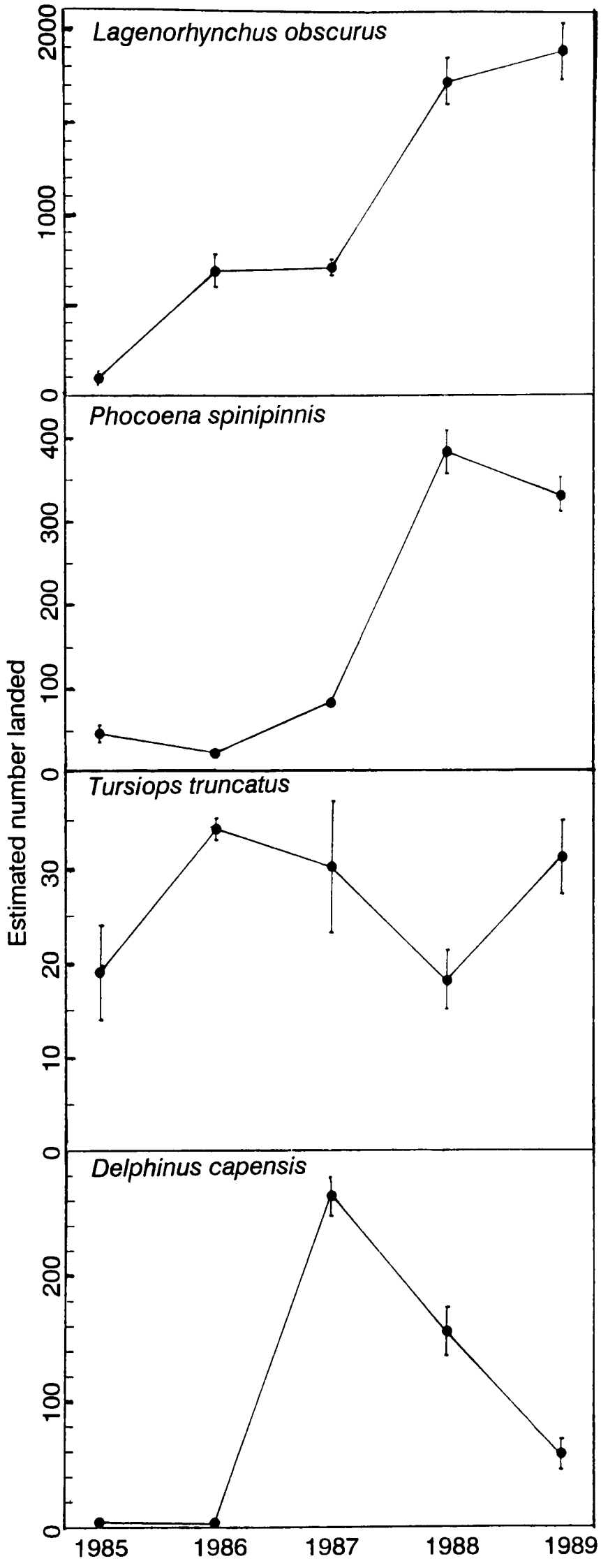

Fig. 5. Estimated annual landings of dusky dolphins, Burmeister's porpoises, bottlenose dolphins and long-beaked common dolphins at Pucusana port, Peru. Confidence intervals are ±1SE, several of which are too small to be visibly indicated.

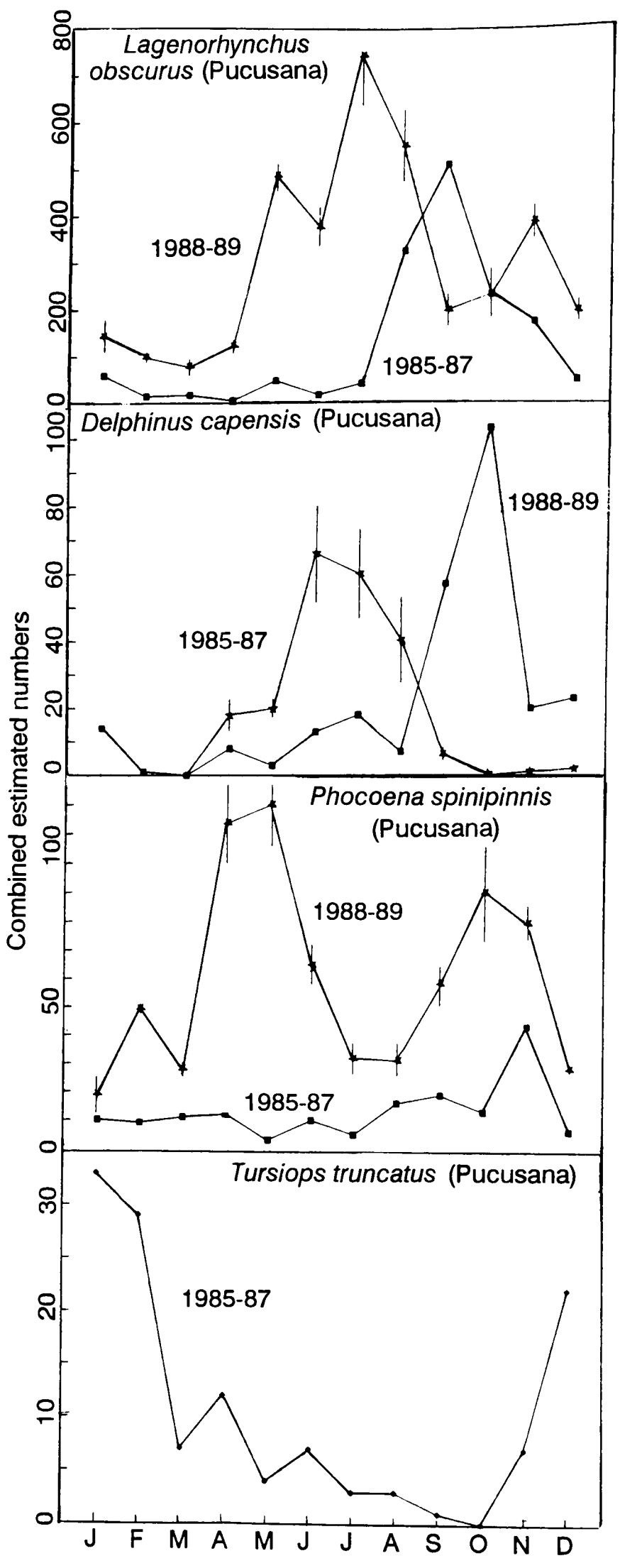

Fig. 6. Monthly distribution in landings of small cetaceans at Pucusana, Peru combined for monitoring periods 1985–87 and 1988–89. Confidence intervals (±1SE) are indicated where available.

A serious problem concerning the winter 'high season' of the dusky dolphin fishery is that it falls in the midst of the reproductive peak, resulting in a high mortality of pregnant or lactating females and neonates. In winter, many of the pelagic (mostly warmwater) fish are too far offshore to be economically and safely fished. This encourages fishermen to set nets closer inshore, on average 40.9±13.7km (Gaskin *et al.*, 1987), resulting in high kill rates of dusky dolphins. In summer the main fishing effort is concentrated

farther from shore at 75.3±61.4km (Gaskin *et al.*, 1987), perhaps beyond the highest density zone of dusky dolphins, which might explain the lower numbers of this species landed during the summer.

In the Burmeister's porpoise, two peaks in fishery mortality can be seen (Fig. 6), one during autumn (April-May) and one in spring (October-November) but the reason for this remains unclear.

Bottlenose dolphins are caught predominantly in summer from November to March (Fig. 6), confirming previous observations (Read *et al.*, 1988; Van Waerebeek *et al.*, 1990). Due to the summer narrowing of the coastal upwelling zone (Schweigger, 1964) and the fact that fishermen in the summer venture farther from the coast, offshore bottlenose dolphins from subtropical waters fall within range of the artisanal fishery.

Trends in the fishery

A cardinal point when discussing the trends in exploitation is whether MIPE cetacean landing data should be regarded as accurate or not. We will assume that they are roughly reliable at least to the point of demonstrating a relative tendency.

Cetacean landings are unevenly distributed along the Peruvian coast (Read *et al.*, 1988). According to MIPE statistics, in the period 1981–84, the central coast accounted for 62% of the kill, the north for 24% and the south for 15%. The dominance of the central area became stronger between 1985 and 1988 (74% central Peru, 22% in the north and 4% in the south; Fig. 7). If true, this could be explained by the observed development of a directed catch of dusky dolphins in a few ports close to Lima and not, or to a lesser degree, in other ports. For example (based on MIPE data), Pucusana and Cerro Azul combined were responsible for 15% of the total Peruvian kill in 1983–85 while this figure had risen to 29% in 1987 and to 53% in 1988.

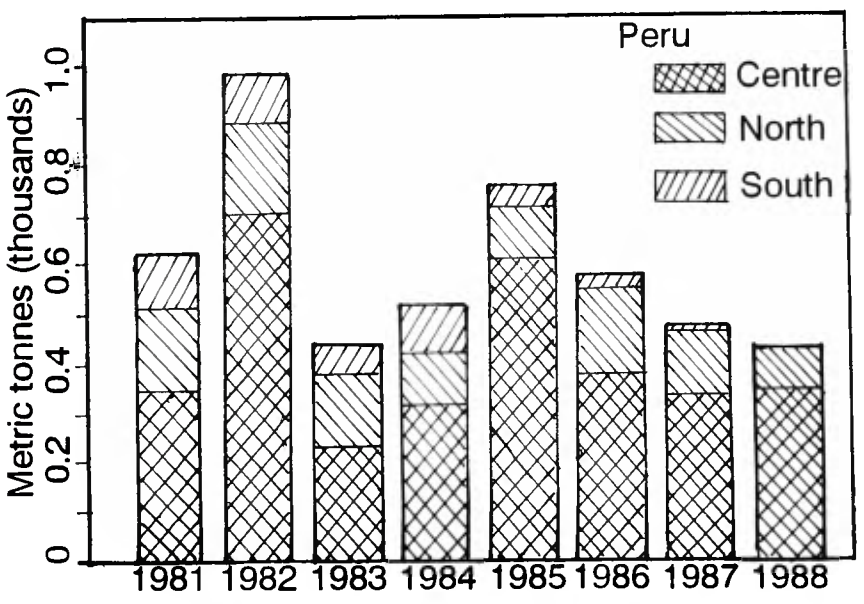

Fig. 7. Regional distribution of small cetacean kill (in tonnes) in Peru between 1981 and 1988. Confidence interval data do not exist. Source: Department of Statistics, Ministry of Fisheries (MIPE), Lima. For definition of regions see text.

Our own data confirm a major increase in catches at Pucusana (Fig. 4) and suggest a fair increase at Cerro Azul, largely as a result of increased landings of dusky dolphins and parallel improvements in land-based facilities for processing and transport and the general efficiency of personnel. Examples range from better availability of butcher's knives to the use of modern thermoregulated transport trucks. As a result, the Pucusana fish terminal has smoothly handled ever larger numbers of dolphins and porpoises. In 1989, one dolphin buyer even systematically transported an important part of the Cerro Azul catch to Pucusana for cleaning and eviscerating prior to final shipment to Lima.

Improved facilities seem to play their own role in enhancing catches. With little doubt partly due to a newly built wharf at Tambo de Mora (13°30'S) this port has nearly tripled its cetacean landings in the past two years (MIPE statistics).

Fig. 8 shows that gross annual landings of fresh fish products (excluding molluscs but including cetaceans) have been rising in the wake of the severe 1982–83 El Niño event (Barber and Chavez, 1983). The higher catches probably should at least partly be ascribed to the rebuilding of fish stocks after the El Niño. Whether this was accompanied by an increase in artisanal fishing effort or not, remains unclear since we were unable to obtain specific effort data.

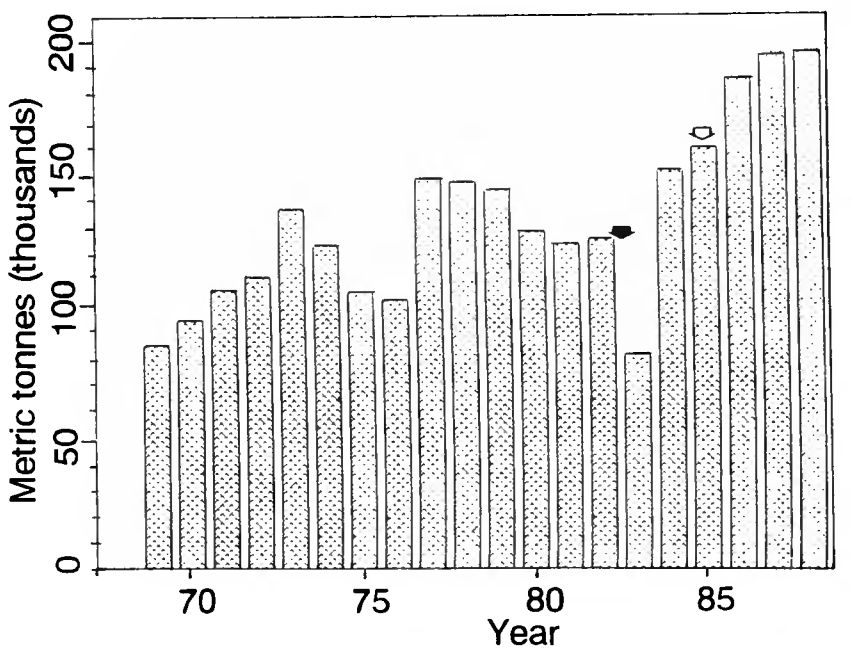

Fig. 8. Total fresh fish landings for human consumption (including cetaceans, excluding molluscs), in tonnes, from coastal Peru in 1969–88. Confidence limits are not available. Source: Department of Statistics, Ministry of Fisheries, Lima. Black arrow: severe 1982–3 El Niño. Open arrow: first port monitoring by authors.

If we would choose to regard MIPE cetacean data as too inaccurate to be useful, we are left with our evidence of very high catches at Pucusana and, probably, Cerro Azul. What happens at other Peruvian ports, especially in the north, is in any case a matter of grave concern and should be investigated as soon as possible.

Research needs

Whereas it is recognised that MIPE is the most appropriate institution to collect data on cetacean catches over the entire Peruvian coast, it is strongly recommended that MIPE modifies monitoring of dolphin and porpoise landings to a number-of-animals-by-species base. Parallel to such a measure, practical instruction of port authority personnel in identification of the most commonly encountered small cetaceans should be arranged.

Dedicated monitoring should continue and be expanded to include at least a few important ports in northern and southern Peru. In particular, more information on catch compositions and actual fishing effort are needed for a more accurate interpretation of available MIPE data. Also

it seems essential that systematic boat surveys be initiated to gather elementary data on relative abundance of species in relation to season, locality and successive years. Finally, biological sampling ought to continue and existing facilities in Peru should be upgraded to allow for specific sample and data analysis.

POSTSCRIPTUM

Ministerial decree #569–90-PE, issued by MIPE (*El Peruano 29 November 1990*), introduced a ban on the taking, processing and trade of small cetaceans in Peruvian waters. However, post-ban monitoring (1991–94) indicated that both incidental and directed takes remained high and may even have increased. It is highly unlikely that current levels of removal are sustainable. Stringent measures should be taken to reduce incidental mortality. The existing law should be implemented to halt directed killing. This is discussed further in Van Waerebeek and Reyes (1994).

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SC/46/SM16

Post-Ban Small Cetacean Takes off Peru: A Review

Koen Van Waerebeek [1,2] and Julio C. Reyes [1,3]

ABSTRACT

Information on small cetacean mortality in Peruvian fisheries is reviewed for the 1990–1993 period, i.e. after the national ban on cetacean exploitation. Most ports along the Peruvian coast were sampled during short visits while Cerro Azul, Pucusana, Chimbote, Ancón and San Andrés were more intensively monitored. The ban was found not to be enforced or at best only partially so. Fishermen often avoided overtly landing entire carcasses, which impeded quantification of kills. Large numbers of small cetaceans were caught directly and indirectly in drift and set gillnets, were harpooned or were netted in purse seines (and often landed alive) by vessels operated by the fishmeal industry. Principal species affected included *Lagenorhynchus obscurus*, *Delphinus capensis*, *Phocoena spinipinnis* and *Tursiops truncatus*, although occasional takes of at least six other small cetacean species occurred. Estimated annual kills (±SE) were: 1,651±53 (1990) at Pucusana; 2,118±389 (1992) and 1,927±237 (1992/93) at Cerro Azul; 2,100 (1991) and 1,383±274 (1992) at Ancón; 1,825±220 at Chimbote (1993) and about 470 at San Andrés (1992). Santa Rosa, San José, Culebras, Huarmey and Chancay also accounted for high landings. Although no scientific estimate of the total annual take of cetaceans in the period 1990–1993 can be calculated, the best available evidence suggests it ranged between 15,000 and 20,000 specimens. Albeit illegal, fresh and processed *muchame* type cetacean meat is widely available and openly sold. A new ministerial decree of August 1994 caused a welcome wave of law enforcement action, but its impact and long-term effects still have to be assessed. Recommendations on how to mitigate kills are discussed.

KEYWORDS: KEYWORDS: SOUTH PACIFIC; DIRECT CAPTURE; INCIDENTAL CAPTURE; FISHERIES; MANAGEMENT; DUSKY DOLPHIN; LONG-BEAKED COMMON DOLPHIN; SHORT-BEAKED COMMON DOLPHIN; BOTTLENOSE DOLPHIN; BURMEISTER'S PORPOISE; SHORT-FINNED PILOT WHALE; LESSER BEAKED WHALE; MINKE WHALE; RIGHT WHALE DOLPHIN.

INTRODUCTION

Peruvian artisanal and commercial fisheries operate from some 181 coastal localities, ranging from international seaports with vast fishing fleets such as Chimbote and Paita, to simple beach-heads. Only about 50 of these have some port infrastructure (Wosnitza-Mendo *et al.*, 1988). Small cetaceans have been taken both incidentally and directly in gillnet and harpoon fisheries at least since the early 1970s but until the mid-1980s almost nothing was known of kill levels and even less on the distribution and biology of affected species.

The 'IUCN/UNEP Burmeister's Porpoise Project' implemented in 1985–86 first tackled these issues in a systematic way. Much of the Peruvian and northern Chilean coast was surveyed to identify the sites with highest cetacean landings. Scientific monitoring and a sampling programme was then started at two selected ports, Pucusana and Cerro Azul, south of Lima (Van Waerebeek and Guerra, 1986; Gaskin *et al.*, 1987; Guerra *et al.*, 1987; Read *et al.*, 1988). Volunteers of the Peruvian Centre for Cetacean Studies (CEPEC) in cooperation with the Association for Ecology and Conservation (ECCO) continued this work and despite limited resources, obtained a wealth of information on fisheries interactions (Van Waerebeek and Reyes, 1990a; b; 1994a; García-Godos, 1993; Van Waerebeek *et al.*, 1993; Van Waerebeek, 1993c; Van Waerebeek *et al.*, 1994) and on the biology of the most frequently captured Peruvian small cetaceans, the dusky dolphin *Lagenorhynchus obscurus* (see Manzanilla, 1989; Van Waerebeek, 1992a; b; 1993a; b; Van Waerebeek *et al.*, 1993; Van Waerebeek and Read, In press), Burmeister's porpoise *Phocoena spinipinnis* (see Reyes and Van Waerebeek, 1995), bottlenose dolphin *Tursiops truncatus* (see Reyes, 1993; Van Waerebeek *et al.*, 1990) and the long-beaked common dolphin *Delphinus capensis* (see Van Waerebeek, 1993c; Van Waerebeek *et al.*, 1994).

The Peruvian Ministry of Fisheries (MIPE) estimated the 1985 cetacean kill in Peru at 756 tonnes (MIPE, unpublished data), equivalent to around 10,000 dolphins and porpoises (Read *et al.*, 1988; Van Waerebeek and Reyes, 1994a). The combined takes of the dusky dolphin, Burmeister's porpoise, long-beaked common dolphin and bottlenose dolphin (inshore and offshore populations) accounted for more than 98% of the catch. The majority of animals were taken by artisanal fishermen in drift and set gillnets, together with several species of sharks (blue, mako, hammerhead and mustelid sharks), rays and other large fishes such as bonito (*Sarda chilensis*), dorado (*Coryphaena hippurus*) and cojinova (*Seriolella violacea*). Large numbers were also killed by hand-held harpoons and in nets set by 300–350 GRT purse seiners fishing for anchovy and sardines for the fishmeal industry. Most of the cetacean meat is consumed fresh by people of modest income groups or salt-dried and commercialised as an expensive delicacy (*muchame*).

After 1985, MIPE statistics suggested a decline in total annual take to 426 tonnes (equivalent to about 5,500 specimens) in 1988 and a subsequent peak kill in 1989 of 1,093 tonnes (Ramírez and Zuzunaga, 1991), i.e. about 14,100 specimens. However, sampling of the Pucusana port by CEPEC volunteers showed that the cetacean kill in 1989 had increased roughly by a factor of three compared to 1986 levels and tenfold compared to 1985 (Van Waerebeek and Reyes, 1994a). In 1989 alone, a total of 2,317±117 SE dolphins and porpoises were landed at the Pucusana wharf. Details of the fishery are given in Read *et al.* (1988), Van Waerebeek and Reyes (1990a; b; 1994a), Reyes and Van Waerebeek (1991), Van Waerebeek (1993c), Van Waerebeek *et al.* (1993; 1994) and García-Godos (1993).

[1] *Centro Peruano de Estudios Cetológicos (CEPEC), casilla 1536, Lima 18, Perú*
[2] *Institut Royal de Sciences Naturelles de Belgigue, 29 Rue Vautier, B-1040, Brussels, Belgium*
[3] Present address: *casilla 392, Talcahuano, Chile*

Legal status of cetaceans in Peru

In 1990, the Peruvian government protected small cetaceans by law following increasing concern expressed in Peru and abroad about the long-term survival of these animals. Ministerial resolution No. 569–90-PE of 23 November 1990 (Anon., 1990) outlawed the capture and trade in small cetaceans or products thereof (meat). Responsibility of enforcement lay with the regional governments, regional offices of the Ministry of Fisheries and the National Office of Port Authorities and Coast Guards of the Ministry of Defence. Resolution No. 321–94-PE of 8 August 1994 (Anon., 1994) replaced the 1990 law. The contents are the same but now district and provincial municipalities are also made responsbile for implementing the prohibition. In addition, river dolphins, including the boto (*Inia geoffrensis*) and the tucuxi (*Sotalia fluviatilis*) have been legally protected in Peru since 1973 by decree No. 943–73-AG, which prohibits hunting, capture and trade in all species of the Peruvian Amazon basin.

Subsequently, legislative decree No. 635 (Codigo Penal) of 3 April 1991 in article 308 (paragraph XIII) considers crimes against the Natural Resources and the Environment and stipulates imprisonment for the hunting or commercial exploitation of species of fauna and flora that are legally protected (Cresci, 1993). International trade in cetaceans and cetacean products is subject to regulations set by the Convention on the International Trade of Endangered Species of Fauna and Flora (CITES), signed by Peru. The three most frequently captured delphinids and the Burmeister's porpoise all feature on Appendix II of CITES. Peru joined the IWC in 1979 and adopted its provisions through Ministerial Resolution No. 345–79-PE. In December 1991, the Peruvian Government approved the UNEP proposed 'Action Plan for the Conservation of Marine Mammals in the Southeast Pacific'. The principal objective is to support participating governments (Colombia, Chile, Ecuador, Panama and Peru) to improve the conservation policy of marine mammals in the region (UNEP, 1992). The UN Convention on the Law of the Sea (UNCLOS) will officially come into force in November 1994 after Guyana became the 60th nation to submit its formal ratification to the UN. Article 65 of UNCLOS provides for the international conservation of marine mammals and cetaceans in particular (Cetacean Society International, 1994).

Despite legal protection, limited post-ban sampling by CEPEC suggested that directed takes of small cetaceans, after an initial decline in some ports, had returned to former levels. In 1992, UNEP and the Whale and Dolphin Conservation Society (WDCS) agreed to support a 1993 survey to assess cetacean mortality levels with authorisation from the Peruvian Ministry of Fisheries.

MATERIAL AND METHODS

As noted above, before the 1990 ban on cetacean exploitation, the Ministry of Fisheries recorded cetacean landings in metric tonnes per port (e.g. Ramírez and Zuzunaga, 1991). Albeit crude, for many ports it represented the only available measure of fishery-related kill levels. After the ban, MIPE stopped gathering information on cetacean mortality, presumably because removals should have ceased. This paper reviews information on cetacean mortality collected during the post-ban period (November 1990 – December 1993) by the authors and volunteers of CEPEC (see acknowledgements) as well as unpublished results of the 1990 monitoring at Pucusana. It thus complements the papers by Van Waerebeek (1994) and Van Waerebeek and Reyes (1994a). Complete daily sampling data and a preliminary analysis are given in Van Waerebeek *et al.* (1994).

Data collection was essentially the same as in previous years (see Gaskin *et al.*, 1987; Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a; 1994a). In summary, the authors and collaborators visited ports along the 2,500km Peruvian coast in 1993. A day spent at a particular port was counted as a sampling day only when the entire landing process of takes was observed. Three ports known to have high landings of cetaceans (Chimbote, Cerro Azul and Ancón) were selected for more intensive sampling. San Andrés was monitored by V. Tenicela (Museo Nacional de Historia Natural, Lima) in 1992. The long-term sampling programme at Pucusana had to be discontinued since the activities of the port authorities prevented fishermen landing whole carcasses at the fish terminal (although meat was routinely brought ashore). Fishermen also avoided landing cetaceans overtly in many other ports which greatly complicated our efforts to quantify takes; recorded numbers of animals may thus be lower than those actually captured. At some locations, e.g. Cerro Azul, Chancay and (initially) Ancón, dolphins and porpoises were brought ashore as if no prohibition existed.

Cetacean remains such as heads, flippers, strips of blubber, vertebra etc. found near coastal communities (±5km strip of beach either side) were presumed to originate from fishery interactions unless there was a good reason to believe otherwise. That the density of such material was usually high immediately north of ports and significantly lower or absent south of it, can be explained by the dominant northbound inshore currents. Specimens encountered on the many beach surveys were quantified by means of cranial evidence only, except where only scant remains were found. Informal interviews with hundreds of fishermen and other locals provided useful information on the best places to look for specimens. Several coastal sites could be visited only once or a few times due to their remoteness and our limited resources. The composition of the cetacean take was determined per port and per coastal region for the post-ban years and compared with pre-ban data (where available). The three coastal regions as defined by MIPE are northern Peru (Puerto Pizarro to Culebras), central Peru (Huarmey to Laguna Grande) and southern Peru (San Juan de Marcona to Vila Vila) (see Fig. 1).

Two types of estimates are employed, a 'scientific estimate' based on a random or near-random sample of acceptable size and linked to some measure of error, and a 'tentative estimate' which is an approximation based on the best available evidence but which was not necessarily derived mathematically. Standard errors (SE, further indicated by '±') of mean daily catch rates were estimated as $SE = (SD/\sqrt{n}).\sqrt{(1-\phi)}$ with SD the standard deviation, n the number of days monitored and $\phi = n/N$ the sampling fraction (Snedecor and Cochran, 1980). Standard errors and 95% confidence intervals (CI) of proportions were calculated according the normal approximation rule (Wonnacott and Wonnacott, 1990). To permit a tentative annual (post-ban) catch for Peru to be estimated, we classified ports for which no scientific estimate was available into the most plausible of four categories (Categories B-E) based on survey data and interviews and assigned an average take for each (shown in brackets); to

avoid problems of possible overestimation, Category A status was not assigned to any port unless it was scientifically monitored. The five categories are described below.

Category A
Very high annual catches, exceeding 1,500 cetaceans; largely the result of directed takes.

Category B
High annual catches, 500–1,500 (1,000) animals; many caught directly. Large numbers of fresh animals and abundant remains were recorded during limited surveying. Local sources confirm high takes as the norm.

Category C
Moderate annual take, 50–500 (275) animals; predominantly incidental. Some fresh specimens and abundant skeletal material found in the neighbourhood of the port. Local sources admit cetacean takes.

Category D
Low annual take, 0–50 (25) animals. No fresh animals were seen but some skeletal material was retrieved on nearby beaches.

Category E
Virtually no take (0). No fishery that can cause cetacean mortality operates in the area. No specimen evidence (fresh or other) encountered.

'Directed take' means all live-landed and harpooned cetaceans, dolphins caught alive in purse seine nets but not released (probably most) and animals captured in large-mesh driftnets (*animalero* nets). Unusually high numbers of Burmeister's porpoise caught in nearshore small-mesh gillnets in localities where the meat is fully utilised commercially (e.g. San José) are also included. Other takes are considered 'incidental'.

Since 1990, CEPEC members have observed more than 2,000 dolphins and porpoises landed. Due to the haste with which animals are butchered, for most only the locality,

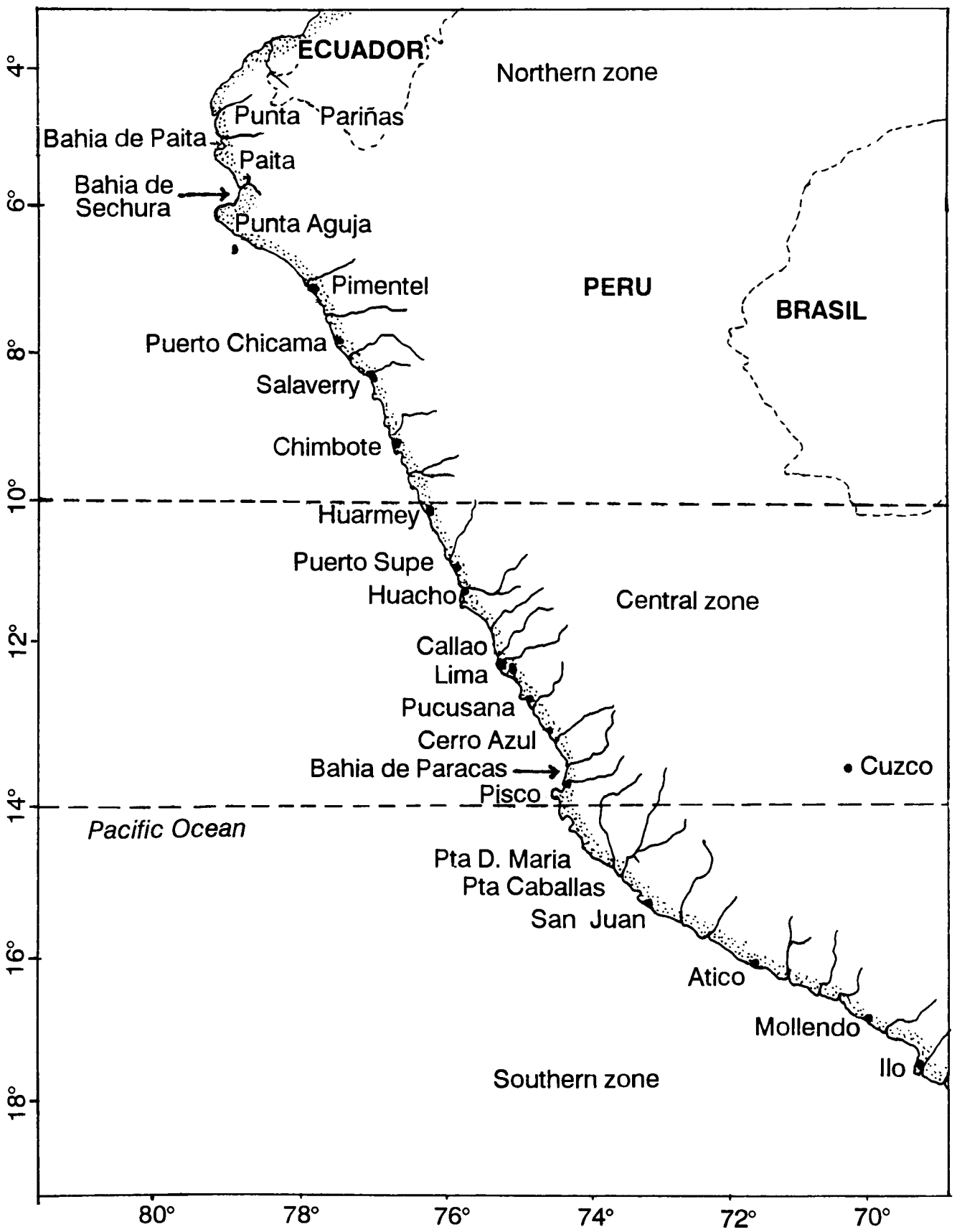

Fig. 1. Map of the region showing place names mentioned in the text.

date, species, sex and total length could be recorded. For a few hundred we documented more or less complete life history data. This and previously collected information will be analysed on a species by species basis and presented at a later date.

RESULTS

Chimbote

Chimbote (420km north of Lima) is one of Peru's few natural harbours and its largest fishing port, hosting several fishmeal factories. A 1985 attempt to set up a sampling programme in Chimbote identified high kills but was discontinued due to adverse conditions (Gaskin *et al.*, 1987).

In 1993, we sampled the artisanal terminal for 53 days, 37 days in summer (January-April) and 16 days in winter (June-August). A total of 265 dolphins and porpoises were observed: 132 *D. capensis* (49.8%, CI 43.8–55.8%); 119 *P. spinipinnis* (44.9%, CI 38.9–50.9%); 13 *T. truncatus* (4.9%, CI 2.3–7.5%); and one unidentified dolphin. Several independent sources reported occasional takes of 'much larger' cetaceans, most likely short-finned pilot whales (*Globicephala macrorhynchus*) or lesser beaked whales (*Mesoplodon peruvianus*). Results are summarised in Table 1. Although the mean daily kill was somewhat higher in summer than in winter, the difference was not significant (Z=-1.48, Mann-Whitney, P=0.14) due to large daily variations. The annual kill estimate for 1993 based on the pooled sample (mean daily take = 5.00±0.60) is 1,825±220 (CI: 1,394–2,256). These numbers refer to recorded animals only, which almost certainly underestimates true kill rates. Indeed, market workers are known to pay bribes and/or hide animals to avoid confiscation. In addition, not all captured cetaceans necessarily pass through the artisanal terminal, some are landed elsewhere and taken straight to markets.

Table 1

Catches at Chimbote in 1993

	Days			
Period	Observed	Total	Estimated catch	Mean daily kill
Summer	37	120	672 (513-831)	5.60 ± 0.67
Winter	16	92	334 (179-489)	3.63 ± 0.85

Burmeister's porpoises were typically taken by gillnet boats and small-scale purse seiners (<100 GRT). Most common dolphins were taken by industrial purse seiners (>100 GRT), fishing principally for anchovy and sardine, or small purse seiners which set on a variety of pelagic schooling fishes. A great variety of fish species was marketed at Chimbote. In January 1993, for instance, bonito, mackerel, jack mackerel, cachema, sierra, lorna, cabinza, coco, pintadilla were most often seen; more occasionally flounder, guitar fish, machete, cherlo and castañeta. Due to the often dense crowds at the port, the restricted access to the pier and the huge volumes of catches, it was rarely possible to determine from which boats individual cetaceans were unloaded. No evidence of harpooning was found in Chimbote but many common dolphins had plastic bags or wet paper stuffed into the blowhole and nasal passage, a method often used to suffocate dolphins. We witnessed two battered but live animals being killed this way, while one had its throat slit and was left to bleed to death. Unlike net-killed dolphins, the skin of most dolphins at Chimbote showed extensive bruising suggesting a violent death while out of the water, presumably onboard purse seiners.

Overall there was a solid demand for cetacean meat; carcasses were usually sold within 10–15 minutes after being eviscerated. Cetacean meat in bulk (with bone) was sold for US$0.6–0.7/kg at the terminal although when large numbers were landed, apparently temporarily saturating the market, whole dolphins were reportedly sold by wholesalers for US$6. Much of the meat was bought by fishmongers who resold it on the central market at Chimbote for US$0.9–1.2/kg. Almost as a rule, after 0800hrs little evidence of the illegal trade was visible. Fishmongers commented that by doing so they effectively avoided interference by MIPE personnel 'who rarely show up in the early morning'. We witnessed a few cases of apparent bribery involving marines on patrol (Van Waerebeek *et al.*, 1994).

The large catches of cetaceans have been a persistent problem at Chimbote. In 1986, KVW photographed 11 long-beaked common dolphins, several alive, inhumanely unloaded from a purse seiner. In three days we counted 26 common dolphins, 4 bottlenose dolphins and 1 Burmeister's porpoise at the former artisanal terminal (Read *et al.*, 1988). However, there are also apparently exaggerated claims of high catch levels. Stuart Wilson (Environmental Investigation Agency, unpublished data) claimed that during July/August 1990 catches at Chimbote averaged 200 dolphins per day. Although locals have hinted at occasional huge single-day landings, it is highly unlikely this number reflects daily mean catches over extended periods. Inappropriate extrapolations have led to overestimates of total kills (see Currey *et al.*, 1990).

Pucusana

The general characteristics of the Pucusana small-scale fishery have been described in detail by Gaskin *et al.* (1987), Read *et al.* (1988) and Van Waerebeek and Reyes (1990a; 1994a). During a total of 230 days sampled at the Pucusana artisanal terminal in 1990 we registered 958 small cetaceans: 750 *L. obscurus* (78.3%, CI 75.7–80.9%), 139 *P. spinipinnis* (14.5%, CI 12.3–16.7%), 44 *D. capensis* (4.6%, CI 3.3–5.9%), 21 *T. truncatus* (2.2%, CI 1.3–3.1%), 2 *Globicephala macrorhynchus*, 1 *Lissodelphis peronii* and 1 *Mesoplodon peruvianus*. Landings stratified by month are given in Table 2 and based on this information the 1990 annual take at Pucusana is estimated at 1,651±53 (CI: 1,547–1,755). The majority of dolphins were killed in large-mesh animalero driftnets together with large fishes, but as in earlier years, some were taken in smaller-meshed drift and set gillnets (especially porpoises). In addition, two common dolphins and one dusky dolphin were harpooned on 12 March 1990 by a single boat and there were a few animals for which cause of death could not be ascertained. A shift in the species composition of catches from dusky to common dolphins (Fig. 2) is discussed by Van Waerebeek (1994).

In response to the 1990 legislation, the Pucusana port authorities prohibited the landing of cetaceans at the terminal (and enforced it) which made it impossible to monitor kills. However, fishermen continued taking dolphins but covertly landed and sold their catches. Dolphins are unloaded into anchored boats before docking

at the terminal, or are butchered on the way back from the fishing grounds. Meat hidden in boxes topped with fish is brought to shore and swiftly transferred to cool-storage trucks for transport to Lima markets; although usually this is done at night, we have also observed it during the day. Offal including intestines, blubber, backbones and heads is tossed overboard, often in the bay of Pucusana. Questioned fishermen made little attempt to deny that this occurs. Additional evidence comes from the discovery of tens of skulls and backbones scattered over the bay's seafloor (snorkeling by KVW and others). In 1992, fishermen attempted twice to revert to landing carcasses at the terminal, only to abandon it when they noticed that we resumed taking notes and photographs. In ten days 59 animals were landed (Table 4). There is little reason to believe that actual kills have diminished compared to earlier levels and port officials do not interfere with these illegal operations.

Van Waerebeek and Reyes (1994b) report on two juvenile southern minke whales, the first confirmed records for Peru, that were butchered at Pucusana after being accidentally caught in gillnets in September and October 1993; the meat was partly consumed locally and partly taken to Lima.

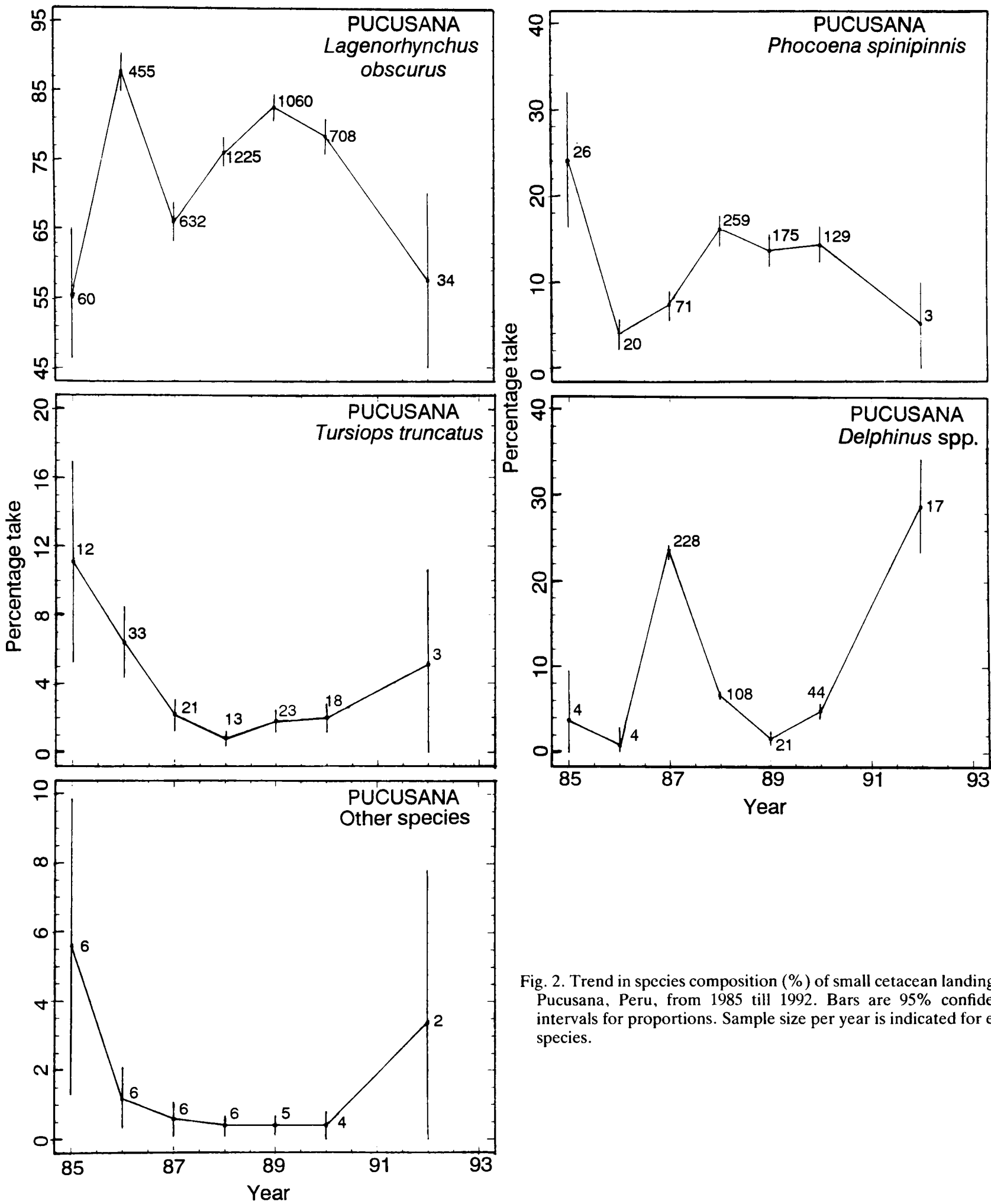

Fig. 2. Trend in species composition (%) of small cetacean landings at Pucusana, Peru, from 1985 till 1992. Bars are 95% confidence intervals for proportions. Sample size per year is indicated for each species.

Table 2

Observed numbers, estimated numbers and standard errors (stratified per month) of small cetaceans landed at the port of Pucusana, central Peru, in 1990. 'Other species' include *Lissodelphis peronii* (Sept.) and *Globicephala macrorhynchus* (Dec.). All numbers are rounded to their nearest integer; some totals may appear erroneous due to this rounding.

Month		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
No. days monitored		25	21	28	30	17	16	9	25	23	9	4	26	230
L. obscurus	OBS	28	34	76	133	49	61	44	47	165	79	8	26	750
	EST	35	45	84	133	89	114	152	58	215	272	60	31	1,289
	SE	3	1	6	0	9	11	27	6	25	17	14	4	44
P. spinipinnis	OBS	13	10	18	17	12	8	5	9	10	7	4	26	139
	EST	16	13	20	17	22	15	17	12	13	24	30	31	230
	SE	3	3	2	0	5	6	11	2	3	10	10	3	21
T. truncatus	OBS	2	2	4	3	4	0	0	0	0	0	1	5	21
	EST	2	3	4	3	7	0	0	0	0	0	8	6	33
	SE	1	1	1	0	3	0	0	0	0	0	6	2	7
Delphinus spp.	OBS	0	2	2	1	11	16	9	1	1	1	0	0	44
	EST	0	3	2	1	20	30	31	0	0	3	0	0	93
	SE	0	1	1	0	4	9	9	1	1	3	0	0	14
Other species	OBS	0	0	0	0	0	1	0	0	1	0	0	2	4
	EST	0	0	0	0	0	2	0	0	1	0	0	2	6
	SE	0	0	0	0	0	1	0	0	1	0	0	1	2
Total	OBS	43	48	100	154	76	86	58	57	177	87	13	59	958
	EST	53	64	110	154	139	161	200	71	231	300	98	70	1,651
	SE	4	3	6	0	11	15	31	6	25	20	18	5	53

Cerro Azul

During January-March 1992 (summer), we sampled the Cerro Azul fish terminal for 41 days and examined 199 small cetaceans; during winter (June-September) 25 animals were recorded in four days. The composition of the take is presented in Table 3. The mean daily catch rate for 1992 is estimated at 5.07 ±1.22 (N=45). While only about half (51.3%) of the catch consisted of *L. obscurus*, a significant decrease from the more than 80% in 1985–90, about 40% were *D. capensis*, an all-year peak (Fig. 3). Of 25 cetaceans seen landed in winter 1992, 21 were *D. capensis*.

In 1993, the fishmarket of Cerro Azul was monitored for 125 days in March-December, during which we observed a total of 684 (1,652 ±128) dolphins and porpoises (Table 3). The mean daily catch rate in 1993 was 5.16 ±0.59 (N=128), practically identical to the rate recorded in 1992 (Mann-Whitney pairs test, Z=0.24, P=0.81). Considering that different seasons were sampled, we feel confident in concluding that catch rates remained stable throughout the entire period. Using a weighted mean daily catch rate (5.28 ±0.65, N=174), the annual take for the 1992–93 period is thus estimated at 1,927 (CI 1,457–2,397) specimens.

Most cetaceans were landed together with rays, blue sharks, mako sharks, hammerheads and, to a lesser degree, with bonito. The gillnets with stretched mesh size of 20–30cm (*animalero* nets) cause by far the highest mortality. About 20 gillnet boats operate from Cerro Azul although the actual number may fluctuate; not infrequently boats from Pucusana are temporarily based at Cerro Azul and vice versa. Fishermen easily switch between nets of different mesh size which impedes estimation of effort data. Each year specimens (at least 3 in 1992) of a presumably resident group of coastal bottlenose dolphins which feed on inshore fishes (especially mullet) close to the pier, are harpooned. In 1993, we documented several harpooned animals (H) or animals killed by an unidentified piercing object (P): 6 *D. capensis* (3H, 3P), 2 *L. obscurus* (1H, 1P), 2 P. spinipinnis (P) and 1 offshore T. truncatus (H). Because we sampled Cerro Azul only part-time, the true numbers of harpooned animals must be higher.

Ancón

A. Garcia-Godos of CEPEC monitored cetacean mortality at the port of Ancón in the course of 1991–92 and carried out a preliminary analysis (García-Godos, 1993).

In 1991, Ancón was sampled for 57 days spread over all months (except April, May and July) during which 608 small cetaceans were recorded. The daily kill rate was significantly higher (Mann-Whitney pairs test, Z=-4.23, P<0.0001) in August-September (winter, mean=15.53, SD=12.55, n=32) than during other months (mean=4.44, SD=3.67, n=25). In summer, mortality is lower as most fishermen set gillnets with small mesh (5–9cm) for juvenile bonito and mackerel, which rarely entangle dolphins. The observed species composition was: 358 (58.9%, CI 55.0–62.8%) L. obscurus, 168 (27.6%, CI 24.1–31.2%) D. capensis and 82 (13.5%, CI 10.8–16.2%) P. spinipinnis. Sampling was insufficient and kills too seasonally variable to allow a scientific estimate of the total 1991 take. A tentative estimate ranges from a minimum of 1,600 animals, prorated from low-season mean daily take, and a high of 2,600, accounting for the two-tier kill rate and assuming a three-month high winter rate. The mean (2,100) is taken as best estimate. From August until September, 172 boat trips were recorded with an average kill per boat of 2.8 (SD=2.11, range=1–16), if trips with no catches are excluded. One bottlenose dolphin was harpooned, but most dolphins were caught in a directed fishery with large-mesh (22–30cm stretched) drift gillnets. Apart from the dolphins, these nets target blue, mako and hammerhead sharks, *Carcharhynus* sp., and rays. Smaller meshed (10–16cm stretched) nets were set for bonito, cojinova and elasmobranchs. Twenty-five boats were involved in the dolphin fishery on a continuous basis and another eight boats captured dolphins occasionally. Over

Table 3

Observed numbers, estimated numbers and standard errors (stratified per month) of small cetaceans landed at the Cerro Azul fish terminal, central Peru, during months sampled in 1992-1993. 'Other species' include *Globicephala macrorhynchus* (Nov.) and *Mesoplodon peruvianus* (Dec.). All numbers are rounded to their nearest integer; some totals may appear erroneous due to this rounding. Line totals are stratified estimates of corresponding period totals (three months for 1992 and ten months for 1993).

		1992				1993										
Month		Jan.	Feb.	Mar.	Total	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
No. days monitored		5	16	20	41	10	9	12	14	13	12	13	11	15	16	125
L. obscurus	OBS	52	54	5	113	29	26	53	20	35	29	6	43	135	19	395
	EST	322	101	8	431	90	87	137	43	83	75	14	121	270	37	957
	SE	185	23	4	186	26	24	27	9	28	21	8	37	75	17	103
P. spinipinnis	OBS	2	4	7	15	0	6	3	7	5	9	0	7	34	79	
	EST	12	7	11	30	0	20	8	15	12	23	0	20	68	16	182
	SE	7	3	4	9	0	7	4	8	16	7	0	11	21	5	32
T. truncatus	OBS	0	3	4	7	0	0	9	8	0	0	0	3	3	8	31
	EST	0	6	6	12	0	0	23	17	0	0	0	8	6	16	70
	SE	0	4	2	4	0	0	12	9	0	0	0	3	4	8	18
D. capensis	OBS	29	35	4	68	8	16	59	29	10	18	0	3	34	0	177
	EST	180	65	6	251	25	53	152	62	24	47	0	8	68	0	439
	SE	64	12	2	65	11	18	35	16	11	16	0	3	21	0	52
Other species	OBS	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
	EST	0	0	0	0	0	0	0	0	0	0	0	0	2	2	4
	SE	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total	OBS	83	96	20	228	37	48	129	64	50	56	6	56	207	36	684
	EST	514	179	31	724	115	160	320	137	119	145	14	157	414	70	1,652
	SE	196	29	6	197	10	41	46	20	35	31	8	51	81	26	128

the first three days of August 1991, some additional animals may not have been accounted for as we suspect that the fishermen hid some specimens in order to avoid control by MIPE personnel (García-Godos, 1993). During 61 observation days between February and December 1992, 231 cetaceans were caught: 113 *D. capensis* (48.9%, CI 42.5–55.4%), 102 *L. obscurus* (44.2%, CI 37.8–50.6%), 11 *P. spinipinnis* (4.8%, 2.0–7.5%) and five *T. truncatus* (2.2%, CI 0.3–4.0%). The mean daily kill was 3.79±0.75, with no obvious variation over the year. An approximate total kill estimate for Ancón in 1992 is thus 1,383 animals ±274 (CI 846–1,920). The location of the bottlenose dolphin captures suggests that they belonged to the offshore population. The dolphins were either killed by harpoon or captured in large-mesh gillnets.

In November 1992, as many as 90% of dolphins (n=199) were killed with hand-held harpoons by boat crews which originated principally from Callao and Chorrillos. In an attempt to avoid monitoring, fishermen shifted the landing and eviscerating of cetaceans towards the night. During a short visit on 3–4 August 1993, pejerrey and juvenile bonito were sold at the market, but no cetaceans; allegedly boats from Chancay had been unloading harpooned dolphins in the early morning. Support for continued kills comes from the fact that processed *muchame* type dolphin meat was available at US$7.50 per kg (wholesale price).

San Andrés

Artisanal fishermen operate mostly from San Andrés, a few kilometres south of Pisco while the industrial fishery is based further south at Paracas. Tenicela (1993) visited the port of San Andrés seven days per month for six months in 1992 (January, May, June, August, October-November). In 42 days 23 *Delphinus* sp., probably mostly *D. capensis*, (42.6%, CI29.4–55.8%), 17 *P. spinipinnis* (31.5%, CI 19.1–43.9%), 7 *L. obscurus* (13%, CI 4.0–21.9%) and one Risso's dolphin *Grampus griseus* (1.9%, CI 0–5.4%) were seen at the fishmarket.

The mean daily kill rate at San Andrés in 1992 was 1.29 specimens, suggesting a minimum annual take of 470 specimens. No SE can be estimated since Tenicela (1993) did not provide a *per diem* landing record. As in other places, the numbers cited are probably underestimates considering that the hiding of animals may be widespread. In addition, fishermen have been known to land cetaceans on surrounding beaches or at the El Chaco jetty. In January 1992, for instance, locals claimed daily takes were as high as 3–4 specimens (Van Waerebeek *et al.*, 1994) while sampling showed a daily catch estimate of only 2.5.

Most cetaceans were gillnet victims but some harpooning almost certainly occurs. Carcasses are either landed clandestinely or butchered offshore. Offal is tossed into the sea and often strands on nearby beaches. There was a significant and progressive decrease in total landings from January until November 1992 (chi-square=16.9, df 5, P=0.005) although the reason for this is unknown. No dusky dolphins were landed during winter while the single Risso's dolphin (female, 320cm) was caught in summer. Locals reportedly consume both fresh cetacean meat and prepare *muchame*. Some of the meat is transported to Lima.

Industrial purse seiners fishing for anchovy, sardines and bonito (the latter for canning) dock at private wharves and could not be inspected. However, it seems likely that non-negligible numbers of common and dusky dolphins are caught, as is generally true for Peruvian purse seine operations. Tenicela (1993) found remains of *Delphinus* sp. and *L. obscurus* near the Paracas fishmeal factories. Within the Paracas reserve, the fishing communities of Lagunillas and Laguna Grande (see below) also account for an unknown take. In 1993, cranial and fresh specimens were encountered during short visits (Table 4) but were not sufficient to enable estimation of total mortality.

Table 4

Summary results of scientific monitoring of cetacean fishery mortality at Peruvian ports in post-ban period. Type information: landings of fresh animals (L) and non-fresh remains (R). *L. obs.* = dusky dolphin; *D. cap.* = long-snouted common dolphin; *P. spi.* = Burmeister's porpoise; *T. tru.* = bottlenose dolphin.

Port	Date	Type	*L. obs.*	*D. cap.*	*P. spi.*	*T.tru.*	Other	Comments
Northern coast								
Puerto Pizarro	1 April 93	L,R	0	0	0	0	0	Small cetaceans said to be caught infrequently
La Cruz	1-2 April 93	L,R	0	0	0	0	0	Few interactions occur; shrimp fishery with trawlers and scoop nets (larvae)
Zorritos	21 February 93	L,R	0	0	0	0	0	Dolphins caught in gillnets; reportedly spotted dolphins present
Cancas	21 February 93	L,R	0	0	0	0	0	Fishermen use harpoons to take swordfish, sailfish and possibly dolphins
Mancora	19-22 Feb. 93	L,R	0	0	0	0	0	Common dolphins and porpoises are taken; also see Orozco (1988)
Los Organos	20 Feb 93	L,R	0	0	0	0	0	Fisherman described how he harpooned dolphins from bowsprit
Talara	16-17 Jan 93	L,R	0	0	0	0	0	Porpoises are said to be caught but landed furtively for fear of confiscation
Negritos	17 Jan 93	L,R	0	0	0	0	0	Landed takes transported to Talara
Paita	21-22 Feb, 28 Sept 93	L,R	0	0	0	0	1	Strip of blubber of unident. small cetacean found at terminal
Parachique	18-20 Feb 93	R	0	2	4	1	0	Tail and flipper of bottlenose dolphin; 0 fresh landings
	27,29,31 Sept 93	L	0	0	0	0	0	Pilar Tello (pers. comm. to KVW, 25 Oct 1993)
San José	14-16 Jan 93	R	0	3	6	0	1 *Ziphiid*	Also 2 backbones of *D. cap.* and 1 of *P. spi.* dump & south beach
	17 Jan 93	R	0	4	35	1	0	Tursiops vertebra only, on *ca.* 6kmof northern beach
	15,16,18 Feb 93	L	0	0	2	0	0	Fresh heads, blubber and intestines
	15,16,18 Feb 93	R	0	4	13	1	1 *G. macro.*	Also non-fresh blubber and a mummified porpoise
Santa Rosa	13-18 Jan 93	L	0	1	0	0	0	Dolphin landed on 15 January
	17 Jan 93	R	0	16	5	0	0	Beach between Santa Rosa and Pimentel
Pimentel	12 Jan 93	L,R	0	1	0	0	0	Freshly cut blubber on beach
	15-16 Jan 93	L,R	0	0	0	0	0	Large amounts of bonito landed; no full monitoring days
Eten	18 Jan 93	L,R	0	2	4	0	1 *Grampus*	One fairly fresh blubber piece of a porpoise; on beach north of the port
Pacasmayo	15 Jan 93	L	0	0	2	0	0	Juveniles (KVW-2379, -2380) caught in gillnet with rays, dogfish and robalo
	15-16 Jan 93	R	0	5	0	1	0	Northern and southern beach
Salaverry	10-11 Jan 93	R	0	2	5	0	1 *Ziphius*	Skulls
	20 Jan 93	L	0	0	1	0	0	Fresh head and testicles
	19 Dec 93	L	0	0	3	0	0	Fresh head and viscera found (D. Montes, pers. comm. to KVW, 16 Jan 93)
Chimbote	Jan-Aug 93	L	0	132	119	13	0	53 sampling days (see Van Waerebeek *et al.* 1994)
Coishco	20-21 Jan 93	R	0	1	0	1	0	Only about 100m of beach was accessible
Besique	22 Jan, 18 Mar 93	R	1	5	2	1	0	Found stranded on beach
Samanco	9 Jan 93	R	0	2	0	0	0	Decomposed carcasses, dorsal musculature removed
Los Chimus	10 Jan 93	R	0	1	9	0	1 *Grampus*	Skulls found on beach near fish terminal
Casma	25-26 Oct 92	R	0	1	1	1	0	Vertebrae of *Tursiops*
Culebras	21-25 Oct 92	R	0	0	0	0	Unident.	No cetaceans seen landed; abundant vertebrae
	11 Feb 93	R	0	1	0	0	0	Head and backbone, landed: dorado, dogfish, rays and squid
	12 Feb 93	L	0	0	0	0	0	Abundant dogfish and hammerhead; 23 gillnet boats, 10 small purse seiners
	26 Feb 93	L	0	2	0	0	0	Harpooned dolphins;
	27 Feb 93	L	0	2	4	0	0	Harpooned; fishery of bonito and mackerel declining
Regional total:			1	187	215	20	5	

/cont.

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Table 4 (cont.)

Port	Date	Type	*L. obs.*	*D. cap.*	*P. spi.*	*T.tru.*	Other	Comments
Central coast								
Huarmey	21,22,24 Oct 92	R	1	12	0	0	0	
Supe	19-21 Oct 92	L,R	0	0	0	1	0	Mandibula; no fresh cetaceans seen landed
Huacho	18 Oct 92	L	2	0	0	0	0	AGG-G11, -612; taken in bonito nets by different boats
	19 Oct 92	L	0	0	0	0	0	No cetaceans landed; unident. remains of *Delphinus* or *L. obs.*
	10 Feb 93	L,R	1	0	0	0	0	Skull on beach; no animals seen landed
	11 Feb 93	L	?	?	?	?	?	Meat of 2-3 unident. animals disembarked clandestinely
Chancay	16 Oct 92	L	0	0	0	0	0	No cetaceans landed
	17 Oct 92	L,R	3	1	1	0	0	Skulls found on beach; no fresh animals seen
	9 Feb 93	L	0	0	4	0	0	Taken with dogfish and cojinova
	10 Feb 93	L	0	0	0	0	0	Small fishes were landed; one live *Dermochelys coriacea*
	9-10 Feb 93	R	3	1	0	3	0	In addition 12 backbones of either *Delphinus* or *L. obs*
	25 Oct 93	L	6	0	0	0	0	Landed with rays, blue and hammer shark (gillnet; 1 boat)
	26 Oct 93	L,R	8	24	2	0	4	Skulls state 2-4; around fish terminal; no fresh animals
	6 Nov 93	L	26	5	0	0	0	6 *L. obs* butchered in terminal; others kept in cool storage room
	7 Nov 93	L	0	0	0	0	0	No boats returned to port
Ancón	1991	L	358	168	82	0	0	57 sampling days (see García-Godos, 1993; Van Waerebeek *et al.* 1994)
	1992	L	102	113	11	5	0	61 sampling days (see García-Godos, 1993; Van Waerebeek *et al.* 1994)
Pucusana	28 Apr 92	L	6	0	1	0	0	Gillnetted
	29 Apr 92	L	6	6	0	0	0	Gillnetted
	1 May 92	L	7	5	0	0	0	Gillnetted
	3 May 92	L	0	4	0	1	0	
	4 May 92	L	0	1	0	0	0	
	5 May 92	L	0	1	0	1	1	*Globicephala macrorhynchus*
	6 May 92	L	8	0	0	1	1	*Grampus griseus*
	10 Oct 92	L	0	0	2	0	0	KVW-2352, -2353
	14 Oct 92	L	2	0	0	0	0	KVW-2354, -2355
	15 Oct 92	L	5	0	0	0	0	Dusky dolphins seized by port authority
Cerro Azul	20 Mar 91	L	1	0	5	0	0	JCR-1928 till -1933
	1992	L	117	89	15	7	0	45 sampling days (see Van Waerebeek *et al.* 1994)
	1993	L	395	177	79	31	2	128 sampling days (see Van Waerebeek *et al.* 1994)
San Andrés	Jan-Nov 92	L	7	23	17	6	1	42 sampling days (see Tenicela 1993)
	8 Jan 92	R	0	0	1	2	0	Fresh heads; coastal *Tursiops*, one collected
	16 Jul 92	R	0	5	1	0	0	Skulls on the beach near the port
	5 Nov 92	R	0	0	3	0	0	Skulls on the beach near the port
	10 Apr 92	R	3	1	0	0	0	Freshly butchered dusky dolphins; state 3 *Delphinus* head
Tambo de Mora	8 Oct 93	L	0	0	2	0	0	Landed together with rays
	9 Oct 93	L,R	0	0	0	1	0	Skull on beach close to wharf; no fresh animals
Laguna Grande	5 Nov 92	R	2	6	18	3	0	Skulls near jetty (Antigua rancheria)
Regional total:			1,069	642	246	62	2	
Southern coast								
S.J. de Marcona	17-18 Aug 93	R	4	0	1	0	0	Osteological material
Lomas	18-20 Aug 93	R	8	0	1	2	0	Skulls
Matarani	12,13,21 Aug 93	L,R	0	0	1	0	0	Blubber floating in harbour
Llo	405 Aug 93	L,R	0	0	1	0	0	Skull on beach, possible stranded; no fresh animals
Meca-lte	6 Aug 93	L,R	0	0	1	0	0	Weathered skull on beach; no fresh animals seen
Regional total:			12	0	5	2	0	

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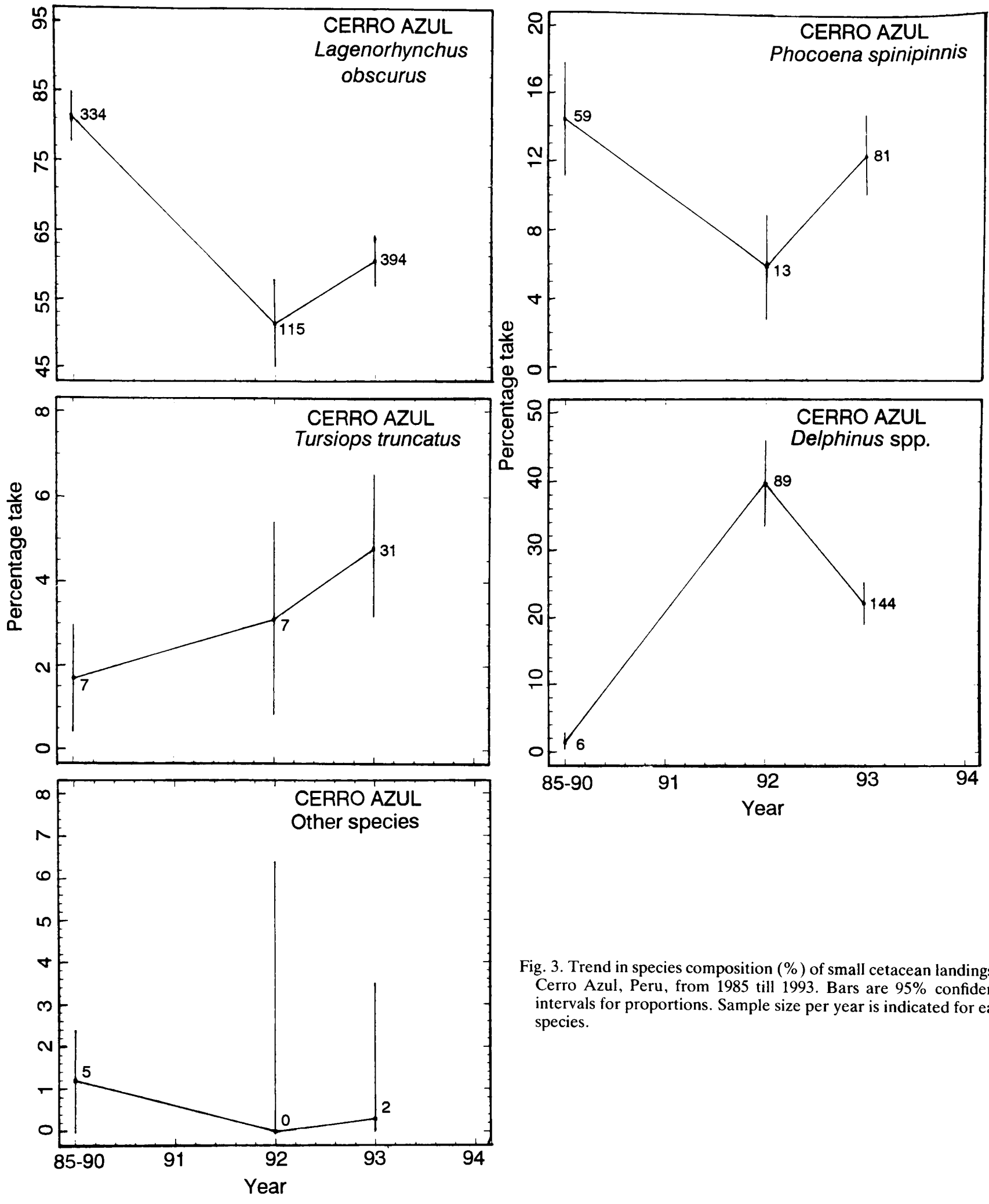

Fig. 3. Trend in species composition (%) of small cetacean landings at Cerro Azul, Peru, from 1985 till 1993. Bars are 95% confidence intervals for proportions. Sample size per year is indicated for each species.

OTHER PORTS

Below we discuss evidence of post-ban cetacean catches at less intensively surveyed Peruvian ports. Additional information can be found in Van Waerebeek *et al.* (1994). Information and sampling dates are summarised in Table 4.

Puerto Pizarro (03°29′S, 80°28′W)

This port is home to some 120 mostly gillnetting boats, apart from a few small purse seiners. Several fishermen use monofilament gillnets. Reportedly small cetaceans are caught incidentally and brought to port infrequently. If landed, they are often given away for free because they have little value compared to the still abundant commercial fish species. No cetacean remains were found in the environs of the disembarking site.

La Cruz (03°37′S, 80°37′W)

Industrial vessels trawl for shrimp (*Penaeus panameniae*) and local fishermen gather shrimp larvae with individual scoop nets. Some line-fishing also occurs. Beaches north and south of the pier were examined over a distance of about 3km but no cetacean material was found. This suggests that few, if any, interactions occur.

Zorritos (03°41′S, 80°35′W)
Some 50 boats operate out of Zorritos using both gillnets and longlines. Dolphins are caught 'at times' (two independent sources). One fisherman was familiar with 'dolphins with white dots', identifiable as the pantropical spotted dolphin, *Stenella attenuata*, frequently seen close inshore in southern Ecuador (Ben Haase, Centro Informativo Natural Peninsular, unpub. data). No direct evidence of cetacean captures was found.

Cancas (03°53′S, 80°55′W)
Moreno (1988) discussed the artisanal fishery at Cancas. The prevalent fishing methods are long-lines (47% of unit effort) and gillnets (20% UE), the latter set primarily for flounder and dogfish. Many boats carry a bowsprit which permits harpooning of swordfish and sailfish and at least occasional kills of dolphins must be expected (see Los Organos). About 50 boats, including small purse seiners, operate from Cancas.

Máncora (04°05′S, 81°04′W)
Some 50 fishing boats are based at Máncora, and deploy both gillnets (typically 10cm mesh) and longlines depending on target species. Hand-held harpoons are carried by most boats and are said to be used for harpooning swordfish and large tuna. Orozco (1988) named dogfish (*Mustelus whitneyi*), conger, sierra, dorado, bonito and thresher shark as the main commercial species and reported takes of unspecified small cetaceans in late 1986. Interviews with fishermen by one of us (KVW) using photographs of Peruvian cetaceans suggested that common dolphins, Burmeister's porpoises and, rarely, pilot whales are taken. Fishermen also recognised the bottlenose dolphin but not the dusky dolphin, as expected from their known distributions. Various sources claimed that 'dolphins' (probably bottlenose) occasionally swim in large groups close to shore. No cetacean remains were found on nearby beaches.

Los Organos (04°11′S, 81°07′W)
Catches of a large variety of fish species by more than 80 boats are unloaded daily at a tiny wharf. Both gillnets and longlines are used. One fisherman described how he regularly harpooned 'long-beaked dolphins', presumably common dolphins, from the bowsprit of his boat. Cetacean meat is consumed locally by fishermen and their families. Inshore swimming (bottlenose?) dolphins were mentioned.

Talara (04°35′S, 81°25′W)
We counted 40 small purse seines and some 45 wooden boats equipped with mast and sail used in a nearshore hook-and-line fishery at this major fishing centre of northern Peru, but from interviews it was clear that many more boats were out at sea. Porpoises are caught and consumed at Talara but are not openly sold to avoid confiscation. Our general impression was that control was fairly strict, more so than in any other port visited. This probably helps to explain why no evidence of cetaceans was encountered during our stay.

Negritos (04°36′S, 81°15′W)
This is an anchorage site just south of Talara for small sailing boats that fish mostly nearshore. Fish is transported to and sold at the Talara market. There was no evidence of any dolphin take.

Paita (05°05′S, 81°10′W)
Moreno and Mendieta (1988) studied the artisanal fishery at Paita during 1986–88. Of the total fishing effort, 13% was accounted for by gillnetting (for dogfish and suco), 52% by small purse seines (sardines, suco, cachema) and 35% by longlining (dorado, blue and mako sharks). Landings of cetaceans were confirmed but not quantified (Moreno and Mendieta, 1988). During our two visits, only a strip of blubber from an unidentified small cetacean was found, although the importance of this fishing port suggests that considerable bycatches probably occur. Paita should be monitored more closely in the future.

Yasila (05°07′S, 81°10′W)
A small group of fishermen reside at Yasila, a tiny resort south of Paita. They mostly gather shellfish although a few gillnet boats and purse seiners were seen. We found no cetacean remains on nearby beaches.

Caleta Constante
A small beach-head without infrastructure. No cetaceans were landed in the period 25–30 September 1993 (Pilar Tello, pers. comm., 25 October 1993). On the first day, three bottlenose dolphins were sighted swimming close inshore in a southerly direction.

Parachique (05°44′S, 80°52′W)
Meléndez (1988) reported in some detail on fishing effort in Parachique: 80% consists of small-scale purse seining (for sardine, mullet, suco, cachema), 7% gillnetting (for dogfish, bonito, suco), 8% longlining, 2% bottom trawling (for *Penaeus* spp.) and 3% diving. Gillnets are either polyfilament (No. 12, 18, 24) or monofilament (No. 50) with mesh-size 7.6–12.7cm. Fishermen admitted an incidental take of Burmeister's porpoises but no fresh specimens were seen landed during two visits in 1993. However, in two hours of beach-combing north of Parachique, skeletal remains of *P. spinipinnis*, *Delphinus* sp. and (probably) *T. truncatus* were found. A group of 6–7 bottlenose dolphins were sighted very close to shore on 19 February 1993. The community of Matacaballo has a small jetty a few kilometres north of Parachique where divers land mostly shellfish.

San José (06°46′S, 79°58′W)
The San José fishing community specialises in an inshore set-gillnet fishery for several species of rays, guitarfish, dogfish and flounder (rays and guitarfish are salted and dried for the production of a popular local dish (*chinguirito*)). This fishery results in relatively high levels of mortality of *P. spinipinnis* and other small cetaceans (Table 4).

Pimentel (06°45′S, 79°55′W)
The fishermen's community at Pimentel is fairly small compared to that at neighbouring Santa Rosa: some 263 fishermen (7% of the Lambayeque total) are registered. Annual harvest of fishery products in 1992 was 4.56% of the regional total, equivalent to 1,740 tonnes (Anon., 1993). Gillnetting is the prevalent fishing art at Pimentel. There is evidence of at least occasional catches of *Delphinus* sp. (Table 4) but no estimate of total kills is available.

Santa Rosa (06°56′S, 79°57′W)
With 2,200 registered fishermen this is by far the largest artisanal fishermen's community of the Lambayeque region (55% of total). In 1992, IMARPE officials recorded

a total volume of 33,949 tonnes of marine products (Anon., 1993). During our visit, about 80 large boats were operative. Fishing trips may last up to three days. Large numbers of bonito have been taken for two years using typical gillnets extending 36.6–54.9 deep and stretching 512m in length. The net maze used is 3.8–4.4cm wide. Several fishermen admitted capturing dolphins with some regularity. However, since the ban, dolphins have been butchered in the boats and the meat taken to shore hidden in baskets. A beach survey from Santa Rosa north to Pimentel yielded abundant cranial material of *D. capensis* and *P. spinipinnis* (Table 4). No cetacean material was found south of Santa Rosa which suggests that remains are dumped at the port and are swept to the north by inshore currents.

Puerto de Eten (06°57′S, 79°52′W)
This tiny community of 50 fishermen contributes only 1% of the total regional catch (Anon., 1993). Beach seines are set from the pier to trap inshore fish, mostly mullet. Line-and-hook fishermen claimed no dolphins are seen. Although locals did not report cetacean bycatches, on a beach search north of Eten we encountered skeletal material of six specimens (Table 4). A check of the southern 'Media Luna' beach yielded only one Burmeister's porpoise vertebra and one vertebra of an unidentified small delphinid, besides a weathered vertebral fragment of an unidentified large whale.

Pacasmayo (07°20′S, 79°35′W)
Two juvenile Burmeister's porpoises were photographed when hauled onto the wharf together with rays, dogfish and robalo. The porpoises, sold together for about $15, were eviscerated at the end of the pier. Remains were pitched into the sea except for the head, kept with the meat to prove the species identity to port authority personnel. For some unknown reason, porpoises are permitted to be used commercially but not *Delphinus* spp. This situation existed long before the 1990 ban came into effect (Van Waerebeek and Reyes, unpub. data). Abundant skeletal material, especially of *Delphinus*, was found on nearby beaches (Table 4).

Pto. Chicama, Malabrigo (07°40′S, 79°15′W)
This is a small port with factories for fishmeal and canned fish. During our visit, 13 small-scale purse seiners, 8 gillnet boats and one industrial purse seiner were anchored. Sharks, guitarfish, mullet and suco were landed. A MIPE employee admitted that porpoises are caught. Fishermen prefer to keep cetacean meat for their own consumption rather than risk having it seized by port authorities who, apparently, enforce the dolphin protection law. No skeletal material was found along the shores.

Salaverry (08°14′S, 78°59′W)
According to a watchman at the industrial seaport of Trujillo, industrial seiners often land cetaceans. Fishermen claimed to catch more porpoises than dolphins and 'almost daily'. The takes were confirmed by the finding of skulls of eight cetaceans, including an adult Cuvier's beaked whale (*Ziphius cavirostris*). Monitoring showed *P. spinipinnis* is regularly captured.

Puerto de Santa (08°58′S, 78°38′W)
This is an impoverished fishing community at the mouth of the Santa river, some 20km north of Chimbote. Thirteen small boats, two with gillnets, were anchored in the bay during our visit. Beach seines were observed. No cetacean remains were found along the beach, but neither was any fish offal. Sources confirmed that landings from Santa are usually taken to Chimbote by road. On one occasion a Burmeister's porpoise was seen being unloaded in Chimbote from a small truck which came from Santa.

Coishco (09°04′S, 78°37′W)
Fishmongers at Chimbote reported that large numbers of dolphins were landed at Coishco, a small town close to an industrial fishery complex with private wharf and several fishmeal processing units. About 50 purse seiners (100–350 tonnes) were reportedly fishing for anchovy. Mr. Felipe Velásquez of COPES claimed no dolphins were captured by his company's purse seiners and granted us access to the wharf. One worker stated that, although company regulations did not allow dolphins to be unloaded on the dock, they were simply landed on the beach nearby and sold in Chimbote. This was supported by the fact that a fresh piece of blubber with a dorsal fin, a partial backbone and several loose vertebra, most likely from *Delphinus* sp., were retrieved on a 100m strip of the beach.

Besique (09°11′S, 78°30′W)
This resort in the Bay of Samanco is frequented in summer by tourists from Chimbote. Beach seining for a variety of inshore fishes is widely practised. Beaches were searched during several visits in 1993 and abundant small cetacean material was retrieved (Table 4), probably originating from dolphins caught by purse seiners and gillnet boats docking at Samanco. Groups of six and three coastal bottlenose dolphins were sighted from the beach on 18 and 24 March 1993 respectively.

Samanco (09°16′S, 78°30′W)
This is an industrial complex with a modern, private pier, serving three companies principally dedicated to fishmeal production. CEPEC members visited the complex several times in 1993, each visit lasting a few hours. About 20 purse seiners were landing anchovy round the clock. According to workers, a single purse seiner occasionally may land 10–15 'long-beaked dolphins', presumably common dolphins. The latter are butchered at the wharf and the meat is either distributed locally or sold in Chimbote. The few artisanal gillnet boats present mostly set nets for small inshore fishes. On 8 January we observed four purse seiners disembarking anchovy and (as we were told the next day) two dolphins. Later, two somewhat decomposed *Delphinus* sp. carcasses, with dorsal musculature removed, were seen stranded close to the pier. For monitoring to be effective, a 24hr/day presence is required.

Los Chimus (09°20′S, 78°28′W)
This small resort and fishing town south of Samanco has a newly-built fish terminal that was not in use when we sampled the port. Thirty-four small fishing boats (29 with gillnets, five with diver air compressors for mollusc gathering) were anchored beyond the surfzone. On *ca.* 1km of beach we found 11 small cetacean skulls (Table 4), more than 25 carapaces of green turtles (*Chelonia mydas*) and unusually large numbers of *Otaria byronia* skulls. All specimen remains are thought to originate from fishing interactions.

Tortugas (09°22′S, 78°25′W)
This is a small fishermen's settlement at the southern end of the Los Chimus Bay. Fishery activity is limited to shellfish and octopus extraction. Locals stated that no dolphins were killed; no cetacean bones were found in the vicinity.

Casma (09°28'S, 78°19'W)
This is home to both an artisanal and industrial fishery fleet. Local fishermen stated that they 'occasionally' capture cetaceans in gillnets and this was confirmed by small cetacean bones found along nearby shores (Table 4). Long-term monitoring is needed because Casma has the potential to account for high cetacean mortality.

Culebras (09°56'S, 78°13'W)
Although no fresh dolphin remains were found, we discovered large numbers of vertebrae from small delphinids near this port in 1992. Local sources referred to high dolphin kills both by gillnets and harpoon (up to 5–10 animals per boat) especially in winter. Four harpooned *D. capensis* were registered in four days of monitoring in February 1993 (Table 4) and it seems possible that high *D. capensis* mortality occurs; this port should be monitored more thoroughly.

Huarmey, Puerto Grande (10°04'S, 78°10'W)
Artisanal fishermen land catches directly onto the beach close to the industrial wharf. No fresh cetacean remains were found but large amounts of skeletal material, especially from *D. capensis*, was collected on the beach in 1992–93 (Table 4). This substantiates reports by fishermen that dolphins are regularly taken, including by harpoon. Purse seiners reportedly have landed 30–40 animals at once on occasion. Much of the meat is sold locally and sells for $1.7/kg – comparable to the cheaper cuts of beef.

Puerto Chico (10°44'S, 77°47'W)
This beach, close to Barranca, has no infrastructure but is used as a disembarking site. On our visit only lorna was brought ashore by gillnet fishermen but cetaceans are reported to be landed occasionally; no remains were found.

Puerto Supe (10°48'S, 77°46'W)
During our visit we counted 21 wooden boats, 10 small purse seiners and 10 industrial purse seiners. We found one bottlenose dolphin mandibula during a short beach search. Fishermen admitted to landing and selling dolphins in the knowledge that it was illegal but, curiously, notified port authorities before doing so. Dolphins killed in purse seines were said to be tossed on the beach where they were quickly used by locals.

Caleta Vidal (10°50'S, 77°44'W)
This is a tiny fishing community 5km south of Supe from where approximately ten boats operate. Catches are landed directly on the beach and taken to Puerto Supe or Barranca for sale, which may explain why no cetacean remains were found.

Huacho (11°07'S, 77°37'W)
Both an artisanal and industrial purse seine fleet are based at Huacho. Large catches of *L. obscurus* were recorded in winter 1985 (Gaskin *et al.*, 1987). We found both freshly landed animals and skeletal remains during short visits in 1992 and 1993 suggesting that gillnet mortality persists (Table 4), but no kill estimates can be made. Meat was sold at $1.3/kg. Industrial purse seiners 'occasionally' land *L. obscurus* and *Delphinus* sp. (Engineer Ayala, Instituto del Mar del Perú, pers. comm. to A. García-Godos, CEPEC).

Chancay (11°37'S, 77°16'W)
Chancay is home to an important purse seiner fleet and some 60–70, mainly gillnet-equipped, wooden boats. Gaskin *et al.* (1987) reported large catches of *L. obscurus* in winter 1985. During several visits in 1993 large numbers of fresh cetaceans and skulls were encountered (Table 4). The species composition (n=82) was: 52.4% (CI 41.6–63.2%) *L. obscurus*, 36.6% (CI 26.2–47.0%) *D. capensis*, 7.3% (CI 1.7–13.0%) *P. spinipinnis* and 3.7% (CI 0–7.7%) *T. truncatus*. Interviews suggested that 'moderate to large' catches, interspersed with periods of low or zero kills, occur year-round. Several port workers blamed the industrial fishery for high takes of common dolphins. Most dusky dolphins seen were caught in gillnets. Although port authorities are known to seize dolphins they do not do so systematically.

Tambo de Mora (13°30'S, 76°11'W)
During our short visits only a few *P. spinipinnis* were seen landed here and only a bottlenose dolphin skull was found (Table 4), however, the relative inaccessibility of the wharves impeded adequate sampling. Reportedly cetaceans are 'often' landed but so far there is no indication that a true dolphin fishery has developed as had been feared (Van Waerebeek and Reyes, 1994a). Much of the meat is said to be processed into *muchame* and is probably sold in nearby Chincha where it has been readily available for a long time (Dr. Robert Clarke, Pisco-Peru, pers. comm., 2 April 1994). CEPEC observers sighted bottlenose dolphins swimming close to the piers on two consecutive days.

Laguna Grande (14°10'S, 76°13'W)
This is a squatters' fishing community situated in the Paracas Marine Reserve which has its roots in the scallop exploitation boom of the early 80s. A single visit in 1992 yielded large numbers of cetacean bones on the beach in the proximity of a jetty (Table 4).

San Juan de Marcona (15°20'S, 75°09'W)
About 60, mainly outboard-powered, gillnet boats operate from this port. Before the ban 'very few dolphins and porpoises have been landed' (P. Majluf, cited in Gaskin *et al.*, 1987). Carlos Castañeda (pers. comm. to A. García-Godes, CEPEC, 17 August 1993) resident at San Juan during the summer of 1992–93 reported an averaged daily take of three small cetaceans during that period and had witnessed landings of live animals. The presence of skeletal material on the shore around the port supports claims of persisting catches (Table 4).

Lomas (15°32'S, 74°50'W)
Gillnet boats and small purse seiners were said to net dolphins 'at times'. Fairly abundant skeletal remains of *L. obscurus, P. spinipinnis* and *T. truncatus* was found in the immediate vicinity of the port (Table 4). From partly burned cranial and vertebral remains of a balaenopterid whale only the atlas was collected.

Chala (15°32'S, 74°50'W)
Chala harbours about a dozen boats which mainly extract molluscs and crustaceans. Inshore fishes are captured with handlines. No longlines are deployed. Two partial backbones of small dolphins (either *Delphinus* sp. or *L. obscurus*) and a few loose vertebra were found around the wharf and the beach to the north of it. Fishermen admitted they sometimes take dolphins accidentally.

Ocoña/La Planchada (16°26′S, 73°08′W)
Ocoña features a fishmeal factory and a large wharf where the purse seiners dock. Artisanal fishermen extract mostly shellfish, especially abalone (*Concholepas concholepas*). However, some gillnetting activity occurs and locals commented that at times dolphins are caught and eaten. Due to rough weather little fishing occurs during winter months.

Matarani (16°58′S, 72°07′W)
This medium-sized port has three fishmeal and canning factories which rely on the purse seine fishery for anchovy and sardines. Some 35 longline and gillnet boats and 25 diving-equipped shellfish boats operate from Matarani. Fishermen, fully aware that the capture of small cetaceans is prohibited, maintain that port authorities exert control. However, the blubber of a freshly skinned Burmeister's porpoise was seen floating in the harbour. A few locals admitted they occasionally ate dolphin meat. Several stated also that bottlenose dolphins and large whales, probably southern right whales (see Van Waerebeek *et al.*, 1992), are sighted from the pier with some regularity. The port of Mollendo (17°02′S, 72°01′W) has been closed for years.

Ilo (17°38′S, 71°20′W)
Ilo hosts three fishmeal factories. Small scale fishermen extensively use longlines since shellfish production has dropped. In summer, gillnets are set for bonito and cojinova, resulting in most of the annual mortality of small cetaceans. On a three hour beach survey south of the port a single skull of *P. spinipinnis* was found. Locals said the animal had stranded about a month ago and its meat had been used for bait. Remains of an as yet unidentified balaenopterid whale were found south of Ilo. Allegedly the whale was hauled onto the beach when it entered very shallow water and locals started butchering it before it died.

Meca-Ite (17°54′S, 70°58′W)
This beach-head has about ten inshore fishing boats. In summer, boats from Ilo are said to operate in the area. Local fishermen reported occasional entanglements of porpoises and bottlenose dolphins in their nets. A weathered skull of *P. spinipinnis* was found along the shore and bones of an unidentified whale were found along the rocky beach of Punta San Pablo.

Vila-Vila (18°08′S, 70°36′W)
Longlines are set principally between October and January. Some 27 boats were counted on our visit, including 15 equipped with compressors for gathering shellfish by divers. In three days, two *P. spinipinnis* were reportedly entangled in inshore gillnets, but the animals were not seen by the CEPEC observers. The broken skull of a large whale was found at Boca del Rio but no other cetacean material was discovered.

CHARACTERISTICS OF POST-BAN CETACEAN EXPLOITATION

Species composition
The species composition of cetacean catches for northern, central and southern Peru in the post-ban period is summarised in Table 5. Off northern Peru, most of the mortality comprises Burmeister's porpoises (about 50%) and long-beaked common dolphins (44%). The virtual absence of dusky dolphins off northern Peru is consistent with known distribution limits (Van Waerebeek, 1992a; b) and the two dusky dolphin skulls found by A. García-Godos and J. Alfaro (CEPEC) in Salaverry (08°14′S), currently represent the most northerly record of the species. In central Peru, dusky dolphins (53%) and long-beaked common dolphins (32%) are the most important species. The sample from southern Peru is too small to allow comparison with other areas and the absence of *D. capensis* in the present sample is probably an artifact. Combined landings of the lesser beaked whale, short-finned pilot whale, short-beaked common dolphin (*D. delphis*), Risso's dolphin, southern right whale dolphin, Cuvier's beaked whale and southern minke whale account for only a few percent of the total Peruvian take and can be considered as a true incidental catch.

Table 5

Species composition of post-ban cetacean kill in Peru per coastal region. Standard error (SE) and lower and upper 95% confidence intervals (CI) are indicated.

Coastal region		*L. obs.*	*D. cap.*	*P. spi.*	*T. tru.*	Other	Total
North	No. specimen	1	187	215	20	5	427
	%	0.2	43.8	50.4	4.7	1.2	100
	SE(%)	0.2	2.4	2.4	1.0	0.6	-
	Lower CI	0	39.1	45.6	2.7	0.2	-
	Upper CI	0.7	48.5	55.1	6.7	2.2	-
Central	No. specimen	1,069	642	246	62	2	2,021
	%	52.9	31.8	12.2	3.1	0.1	100
	SE(%)	1.1	1.0	0.7	0.4	0.1	-
	Lower CI	50.7	29.7	10.7	2.3	0	-
	Upper CI	55.1	33.8	13.6	3.8	0.2	-
South	No. specimen	12	0	5	2	0	19
	%	63.2	0	26.3	10.5	0	100
	SE(%)	11.1	0	10.1	7.0	0	-
	Lower CI	41.5	0	6.5	0	0	-
	Upper CI	84.8	0	46.1	24.3	0	-

The worrying decline in the percentage of dusky dolphins in landings over time (Figs 2 and 3) is discussed by Van Waerebeek (1994) who suggested that this may reflect an increase in the relative abundance of *D. capensis* of central Peru.

Total annual take
Ironically, since small cetaceans acquired legal protection, it has become even more difficult to accurately estimate total annual takes. Based on the best available evidence for each Peruvian port, we have tried to categorise them in terms of their post-ban landings below.

Category A: Chimbote (1,825 for 1993); Pucusana (1,651 for 1990); Cerro Azul (1,927: mean catch of 1992/1993); Ancón (1,740: mean catch of 1991/1992). Estimated combined annual take: 7,140.

Category B: (mean = 1,000 p.a.): Santa Rosa, San José, Culebras, Huarmey, Chancay. Extrapolated take p.a.: 5,000.

Category C: (mean = 275 p.a.): Máncora, Paita/Yacila, Los Organos, Talara, Supe, Pacasmayo, Salaverry, Coishco, Los Chimus, Casma, Chicama, Huacho, Callao (?), San Andrés (470 for 1992), Tambo de Mora, San Juan de Marcona, Lomas. Extrapolated take p.a.: 4,870.

Category D: (mean = 25 p.a.): Puerto Pizarro, Zorritos, Cáncas, Parachique, Pimentel, Eten, Santa, Puerto Chico, Vidal, Chorrillos, Laguna Grande, Chala, Ocoña/La Planchada, Matarani, Ilo, Meca/Ite. Extrapolated take p.a.: 400.

Category E: (0 take): La Cruz, Punta Mero, Acapulco, Negritos, Matacaballo, Caleta Constante, Besique, Tortugas.

By combining the category totals (17,400), we estimate the total yearly take for Peru in the period 1990–93 to range between 15,000–20,000 small cetaceans, i.e. higher than the estimated peak catch for 1989 (14,100 animals) based on MIPE data (1,093 tonnes, Ramírez and Zuzunaga, 1991). Landings at Pucusana in 1990 were lower than in preceding years but landings at Cerro Azul have greatly increased (see Read *et al.*, 1988; Van Waerebeek and Reyes, 1990a; b; 1994a). No comparisons can be made for other ports due to lack of information for earlier years.

In the absence of abundance data and reliable stock delineation, assessing the impact of catches is impossible: sighting surveys are urgently needed. However, the high levels of mortality are already a cause of concern in many cases. IWC (1994) states that removals of the southeastern Pacific dusky dolphins are probably not sustainable. Similar concerns seem warranted for *D. capensis* and *P. spinipinnis*.

Fisheries and attitudes

Artisanal fishermen are surprisingly mobile and frequently travel along the coast in search of the best fishing grounds. Due to the proximity of Chancay and Ancón, for instance, fishermen of both towns often operate from each other's home port. A similar pattern is observed at Pucusana and Cerro Azul.

With a few obvious exceptions, interview feedback from fishermen agreed well with our view obtained from monitoring and beach surveys. In general, fishermen from northern Peru were more communicative than those from central and southern coasts and showed no reticence to talk about dolphin catches. We found that virtually all fishermen were aware that small cetaceans are protected but very few were receptive (and those almost certainly out of politeness) when we explained why the ban must exist. Although they routinely cited 'economic difficulties' to justify killing cetaceans, rarely are those difficulties as acute as claimed. Their view rather reflects a general sense of uncertainty about their short-term future due to the genuine unpredictability of harvest and dangerous working conditions and, it seems to us, a refusal to plan ahead. The opportunistic approach of small-scale fishermen reflects the short-term view that prevents many artisanal fishermen from investment or taking decisions which would be to their clear benefit in the medium or longer-term. Unless this attitude can be changed by improving their real (and, more importantly, perceived) security, ecological arguments will remain irrelevant and cooperation unlikely. This will require a dedicated and thoughtful policy towards artisanal fishermen and much patience.

The apparent unwillingness/inability of MIPE to enforce the ban, in part reflects the truly complex nature of the problem and in part the unfortunate but widespread perception of environmental issues as low-priority. It also must be said that the poor level of education of policing personnel and the armed forces, combined with economic factors such as insufficient pay which render them susceptible to bribery, certainly compound the problem.

However, short of a fully enforced, outright ban of all gillnet and harpoon fisheries and strict control of purse-seine operations, neither of which can be achieved overnight (if ever), there is no practical panacea to this problem (see also Jefferson and Curry, 1994). Unfortunately, time may be short for several stocks of Peruvian small cetaceans and some measures that can be expected to significantly mitigate mortality rates are discussed in the recommendations section.

One possible longer term solution concerns the changing of fishing techniques. A 1992–1993 IUCN/WDCS study has shown the high potential of fish-baited longlines to partly replace gillnets in the shark and ray fishery, and thus reduce cetacean mortality (Reyes, 1993). Additional data collected at Pucusana further confirms the feasibility of longline fishing. During six fishing trips (four in November and two in December 1993) one boat equipped with a small longline (150 hooks) reportedly caught, on average, about 300kg (200–400 kg) blue sharks and 118kg (80–200 kg) mako shark, using a variety of low-value fish species as bait. In the December trips, an additional 175kg of dorado (*Coryphaena hippurus*) was also caught. The mean net income after subtraction of all costs (fuel/subsistence) was about $153 per two-day trip. This amount is customarily divided between the two fishermen (each 25%), and the owners of the boat and longline (each 25%), often the fishermen themselves. These earnings compare favourably with the minimum guaranteed monthly wage in Peru of US$61 and typical labourer/employee monthly wages of US$90–140.

However, should the use of longlines be promoted, the process should be supervised to ensure no unforeseen and counterproductive results arise. For example, uncontrolled South American longline fisheries in Venezuela, French Guiana and southern Ecuador have used dolphin meat as bait (Agudo and Romero, 1990; Van Waerebeek, 1990; Felix and Samaniego, pers. comm., February 1994). Although the present price of dolphin meat in Peru is too high for its use as bait, increased demand might encourage fishermen to harpoon additional animals when out fishing. Dolphin offal such as blubber and intestines from the dolphin fishery is not used as it is alleged to be ineffective. Long-line interactions with non-target species do occur but apparently are rarely lethal. During test sets, South American fur seals *Arctocephalus australis* and an unidentified albatross became hooked when trying to steal bait, but escaped without much harm (Reyes, 1993). No cetacean mortality has been reported in longlines off Peru, although the stealing of the catch from the hooks by marine mammals can lead to directed kills by fishermen.

Problems of humane killing

The principal cause for concern with respect to humane killing is the live-landing of animals, especially by industrial purse seine vessels, and the use of hand-held harpoons to catch bottlenose, dusky and common dolphins; harpooning is particularly prevalent off central and northcentral Peru. One of the worst recorded infractions occurred in November-December 1992 when over a 23-day period, 178 harpooned common and dusky dolphins were landed (besides netted ones) at the wharf of Ancón. Visiting fishermen from Callao (5 boats) and Chorrillos (1 boat) were mostly responsible for the harpooning, although one boat from Ancón had also participated (see García-Godos, 1993). When this was drawn to the attention of the Ministry of Fisheries, the only measure taken was an 'interrogation of locals and fishermen' who claimed not to have caught any cetaceans. This illustrates the urgent need for more rigorous control and the application of penalties.

There is sufficient evidence to state that the commercial purse seine fishery for anchovy and sardines off Peru for the fishmeal industry is responsible for large, albeit unknown, kills of dolphins. The most heavily affected species in the Chimbote area is *D. capensis*, but data in Tenicela (1993), as well as its distribution, suggests that *L. obscurus* is also involved off central Peru.

Muchame

Muchame (also known as *Buchami* or *musciame*) is the salt-dried dorsal muscle of small cetaceans prepared according to a recipe of Italian origin. A black market may still exist in northern Italy (G. Notarbartolo di Sciara, Tethys Res. Institute, pers. comm., 13 Nov. 1993) and this raises the question as to whether some Peruvian muchame is illegally exported. Although it has been around for decades in Peru, indications are that in recent years its illegal trade and consumption of *muchame* have increased considerably. A market study in June-July 1993 revealed its wide availability in the shops and supermarkets of Lima and Callao (Van Waerebeek *et al.*, 1994). Ancón, Pucusana, Chincha and Arequipa are other towns where it can be purchased without difficulty. Its availability may well be explained by the huge profit margins: prices range from $7.5 to $35.9 /kg whilst fresh cetacean meat sells for $0.7–2.0 /kg).

RECOMMENDATIONS

It is clear that the 1990 law protecting Peruvian small cetaceans from exploitation was, depending on the locality, only at best partially enforced. Recent field work by CEPEC members suggests that the law of August 1994 is having more effect so far (November 1994). Authorities regularly seize landed cetaceans, at least at some ports, while pressure from impending penalties and public opinion is higher. Despite this, unknown quantities of cetacean meat are still used commercially and there is no direct evidence that the mortality rate is really down. We recommend that a number of measures be taken to further alleviate the situation.

(1) Dolphins accidentally captured in purse seines should be released. Independent observers, backed by new *ad hoc* regulations, should investigate the issue in detail, determine precise circumstances of captures and suggest practical solutions. The Inter-American Tropical Tuna Commission (IATTC), which has long-term expertise with monitoring of large-scale seining operations, should be consulted as an advisory body.
(2) Fishermen should be required to declare bycatches immediately after docking. Port officials should proceed to confiscate and register the animals by species. The consumption of fresh cetacean meat should be permitted if it is derived from such registered animals and the meat is distributed for free among locals and institutions of public utility. Any form of commerce in cetacean products should remain banned.
(3) Inspecting personnel should be trained in the recognition of species and signs of fishery mortality.
(4) Scientists should have priority access to specimens for study and biological sampling.
(5) The use of large-mesh gillnets (*animalero* nets) that cause the highest rates of directed mortality among dolphins, should be phased out as soon as possible.
(6) Small scale long-lines, which are not known to cause cetacean mortality in Peru, should be promoted as a cost-effective and superior alternative to large-meshed gillnets in the Peruvian shark and ray fishery, provided adequate monitoring takes place.
(7) A feasibility study should be carried out to assess the potential of dolphin-watching (ecotourism) as an alternative source of income for some groups of artisanal fishermen in areas of high cetacean density (and high takes).

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A Note on Incidental Fishery Mortality of Southern Minke Whales off Western South America

Koen Van Waerebeek[1,2] and Julio C. Reyes[1,3]

ABSTRACT

The accidental entanglement of two juvenile southern minke whales in artisanal gillnets in 1991 is discussed. They represent the first positive records of this species for Peru. Some biological data are provided and the incidental fishery mortality of these and other large whales off the west coast of South America is reviewed. It is likely that severe underreporting occurs due to vastly inadequate monitoring effort.

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; MINKE WHALE; SPERM WHALE; SOUTH PACIFIC; HUMPBACK WHALE; RIGHT WHALE

INTRODUCTION

The multifilament gillnets used in the Peruvian artisanal fishery are typically set for several species of sharks, rays and schooling fish (e.g. bonito *Sarda chilensis*) and several dolphin species. This fishery has been described in detail by Read *et al.* (1988) and Van Waerebeek and Reyes (1990; 1994b).

This paper reports on two southern minke whales (*Balaenoptera acutorostrata*[4]) incidentally caught off the coast of Peru in 1991. Despite an official ban on small cetacean catches, the minke whales were landed at the local wharf, being too large to be hauled and processed on board the fishing boats. Only the limited data presented below could be collected, because market workers processed the whales quickly for fear of seizure by port authorities.

DETAILS OF THE MINKE WHALES

A juvenile male minke whale (KVW-2298) was landed on 27 September 1991 by artisanal fishermen at Pucusana port (12°30'S) on the central Peruvian coast. The crewmaster stated that the animal had been caught in a drift gillnet set five hours steaming distance from port (estimated no further than 20 n.miles offshore). Several fishermen reported having seen several unidentified 'whales' on the fishing grounds during that period. A second minke whale, a juvenile female (KVW-2299), was landed at the same port on 30 October 1991. It was not possible to ascertain whether it had become entangled in a drift or set gillnet, but sand found in its stomach seemed to confirm one fisherman's assertion that it had been caught nearshore in shallow water.

Specimen KVW-2298

The animal was a juvenile male of 421cm standard length. It had normal body colouration with grey lips and a white throat and tongue. No white patch was present on the dorsal side of the flippers. Some measurements and meristics were taken: length of dorsal fin, 23cm; height of dorsal fin, 14.5cm; fluke span, 95.5cm; length of fluke (insertion to tip), 64cm; width of fluke, 27cm; depth of fluke notch, 4.5cm; anterior length of left flipper (severed, including caput ulni), 70cm; maximum width of left flipper, 15cm; number of ventral grooves, 59; maximum width and height of largest baleen plate, 4.7cm and 11.2mm, respectively; bristles, creamy white; number of baleen plates, left, 301 (the 216 posterior plates had a lead coloured exterior border, each over one fourth to one fifth of baleen width); number of baleen plates, right, 296 (167 posterior plates with lead-coloured exterior border, extending gradually until posterior baleen were entirely lead-grey); one testis weighed 19g, with epididymis 33g; combined weight of kidneys about 5kg. The stomachs contained a reddish liquid with a few unidentified euphausids and two fish eye lenses. No milk was recognised, nor were parasites found. The skull was collected. Photographs were taken.

Specimen KVW-2299

This animal was a neonate female of 325cm. It had normal colouration and the flippers were grey without a white band. Some measurements were taken: anterior length of flipper (left/right) 47/45.5cm; posterior length of flipper (left/right), 34/33cm; width of flipper (left/right), 12/12cm; length of dorsal fin, 25.5cm; height of dorsal fin, 15cm; number of ventral grooves: 49, running some 5cm short of the umbilicus; number of baleen plates (left/right), 261/260; stomach contents included mucus and sand, no parasites and a greenish liquid (presumably digested milk) was seen in the duodenum. Photographs are available.

DISCUSSION

We were unable to locate any references to minke whales from Peruvian waters and therefore conclude that these are the first confirmed records of this species for Peru (see Clarke, 1962; Grimwood, 1969; Ramirez, 1985; 1990; Ramirez and Urquizo, 1985; Stewart and Leatherwood, 1985). It must be stressed, however, that this is not necessarily evidence that minke whales are only exceptional visitors to these waters. At least in part, it reflects the fact that dedicated research on smaller cetaceans (i.e. other than the species of large whales once exploited off the coast of Peru) is a recent exercise. Ten

[1] *Centro Peruano de Estudios Cetológicos (CEPEC), casilla 1536, Lima 18, Peru.*
[2] *Institut Royal des Sciences Naturelles de Belgique, Bruxelles, Belgium.*
[3] Present address: *Casilla 392, Talcahuano, Chile.*
[4] Although under review, the IWC currently only recognises one species of minke whale, *Balaenoptera acutorostrata*. However, some authors consider (and we concur) that the Southern Hemisphere minke whale is a separate species, *Balaenoptera bonaerensis*.

species of odontocetes, including the newly described *Mesoplodon peruvianus*, and one mysticete, the southern right whale (*Eubalaena australis*), have been reported for the first time in Peruvian waters between 1985 and 1991 (Van Waerebeek and Reyes, 1988; Van Waerebeek *et al.*, 1988; 1992; Reyes, 1990; Reyes *et al.*, 1991).

Previous cases of incidental kills of large whales off the west coast of South America

Baleen whales

Only a few well-documented cases of incidental kills of minke whales or other large cetaceans exist for the west coast of South America. Guerra *et al.* (1987) reported that a minke whale drowned in 1979 in a purse seine net set on anchoveta (*Engraulis ringens*) by an industrial vessel in the Bay of Mejillones (at 23°S), Antofagasta (northern Chile); a photograph was taken by the captain of the ship.

In October 1988, a humpback whale (*Megaptera novaeangliae*) was netted alive and, after the fishermen were assured of repair cost compensation if they cut their nets, was subsequently released at Punta San Juan (15°22'S) in southern Peru (Majluf and Reyes, 1989).

A southern right whale calf was killed and subsequently stranded after receiving severe propeller cuts from a personnel boat shuttling back and forth between shore and *Gracilaria* algae culture floats in the Gulf of Arauco, southern Chile, in August 1989 (Canto *et al.*, 1991).

Sperm whales

Two sperm whales (*Physeter macrocephalus*) died in drift gillnets for dorado (*Coryphaena hippurus*) and bonito (*Sarda chilensis*) in Ecuador: an 11.4m animal about one mile off Engabao, Guayas, on 7 May 1991 after five days of being entangled (Félix, 1991) and a 10.8m animal, west of Isla de la Plata, Manabí, in June 1991 (Haase, 1991b). In addition a 12.6m female sperm whale that stranded in Punta Carnero on 15 August 1991 may have been a victim of the local gillnet fishery although it might have died after being hit by a large ship because the maxillary part of the skull was fractured (Haase, 1991a); a post-mortem collision obviously cannot be excluded.

From 18 sperm whale strandings on the Ecuadorean continental coast between 1987 and 1993, evidence of interaction with some type of fishing gear (mostly gillnets) was available in eight cases (Félix *et al.*, 1994). One 13.6m male was killed after entanglement in a purse seine net (Prieto and Bravo, 1991).

Sufficient evidence is available to confirm that sperm whales occasionally become entangled off central Chile in the fairly recently developed gillnet fishery for swordfish (Reyes and Oporto, 1994).

General

The increasing frequency of reported cases of incidental kills of large whales (including minke whales) in the Southeast Pacific coastal region raises concern about the true magnitude of the problem and the possible impact on populations. The area supports a vast number of often unregulated artisanal and industrial fisheries as well as rapidly expanding inshore mariculture activities (e.g. Cushing, 1982; Wosnitza-Mendo *et al.*, 1988; Reyes and Oporto, 1994; Van Waerebeek, pers. obs.) all of which negatively interfere with marine mammals.

Severe underreporting of incidental cetacean mortality is likely, given the small number of cetologists covering this vast area and the fact that they are limited by inadequate funding and infrastructure.

Stock identity

Very little is known of the stock identity of minke whales in Peruvian and Chilean waters. A recent review of published literature could identify only 15 positive records of minke whales off western South America (Van Waerebeek and Reyes, 1994a). There is no minke whale material in Chilean and Peruvian collections (e.g. see Sielfeld, 1983) but given the opportunistic nature of such collections, this is perhaps not surprising.

In the most recent reviews of the stock identity of Southern Hemisphere minke whales (Donovan, 1991; IWC, 1991a; b) it was clear that information from breeding areas is very limited and that information from feeding grounds suggests no clear stock boundaries. The hypothesis put forward for management purposes (IWC, 1991b) assumed five breeding grounds (including one in the southeastern Pacific, between 10–20°S and 110°-120°W, based on limited sightings data from Japanese scouting vessels; Kasamatsu and Nishiwaki, 1990) and overlapping feeding areas (IWC, 1991a, fig. 1). However, the probable existence of two species of minke whales in the Southern Hemisphere (see Mitchell, 1993), further complicates rational conservation efforts. We concur with the view that considerable effort should be put into examining stock structure in lower latitudinal waters, with the emphasis on molecular genetic techniques (e.g. IWC, 1993).

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SC/46/SM26

A Note on the Status of the Dusky Dolphins (*Lagenorhynchus obscurus*) off Peru

Koen Van Waerebeek

Centro Peruano de Estudios Cetológicos (CEPEC), Casilla 1536, Lima-18, Peru and Institut Royal de Sciences Naturelles de Belgique, Brussels, Belgium

ABSTRACT

This paper briefly examines the cetacean catch composition by species in Peruvian fisheries between 1984 and 1993. Despite a number of difficulties in interpreting the data, there is a significant decline in the proportion of dusky dolphins recorded between 1985–90 (77.5%) and 1991–93 (52.8%). During the same period the proportion of long-beaked common dolphins increased from 6.7% to 31.8%. Possible reasons for this are discussed. One possibility is that this reflects a true decrease in the abundance of dusky dolphins in response to exploitation. It is argued that the precautionary principle requires that effective conservation measures are implemented as a matter of urgency. In addition, studies should be carried out to determine the true reason for the change in proportions.

KEYWORDS: SOUTH PACIFIC; INCIDENTAL CATCHES; FISHERIES; MANAGEMENT; DUSKY DOLPHINS; LONG-BEAKED COMMON DOLPHINS; BURMEISTER'S PORPOISE; BOTTLENOSE DOLPHINS

The Peruvian Centre for Cetacean Research (CEPEC) initiated the scientific monitoring of cetacean landings in central Peru in 1984 and since that time the dusky dolphin, *Lagenorhynchus obscurus*, has been the most heavily exploited small cetacean in Peruvian waters; in some ports it comprised 80–99% of total takes (Read *et al.*, 1988; Van Waerebeek and Reyes, 1990; 1994a). Other commonly landed species included Burmeister's porpoise, *Phocoena spinipinnis*, the long-beaked common dolphin, *Delphinus capensis* (nomenclature see Van Waerebeek *et al.*, 1994; Heyning and Perrin, 1994; IWC, 1995), and the bottlenose dolphin, *Tursiops truncatus*.

A craniometric study and analysis of body size demonstrated the existence of a discrete eastern South Pacific dusky dolphin stock (Van Waerebeek, 1992). Some cranial differences also suggested separation of dusky dolphins from central Peru and northern Chile but a greater sample size from Chile is required to confirm or refute this (Van Waerebeek, 1992; 1993). Repeated concern has been expressed that removal rates of dusky dolphins off western South America may not be sustainable (Read *et al.*, 1988; IWC, 1994; Van Waerebeek and Reyes, 1994b; Van Waerebeek *et al.*, 1994). However, in the absence of abundance estimates and reliable estimates of either direct (large-mesh, gillnet and harpoon fisheries) or incidental kills, the impact of such mortality has not been assessed for any Peruvian small cetacean species. As a response to the concern expressed, a ban on small cetacean takes was decreed by the Ministry of Fisheries in 1990 but this has been largely ignored and the annual total kill in Peru was estimated at between 15,000 and 20,000 animals for the period 1991–93 (Van Waerebeek *et al.*, 1994; Van Waerebeek and Reyes, 1994b).

In this note I examine the species composition of the cetacean catch off central Peru (from Huarmey (10°04'S) to Laguna Grande (13°55'S) in the Paracas National Reserve) over a long-term period in order to try and identify any possible shifts in relative abundance. The catch data are obtained from freshly landed animals and cranial remains collected in refuse dumps and beaches around ports. Most animals were killed in gillnets or by hand-held harpoons and were landed at Pucusana, Cerro Azul or Ancón, the ports most intensively monitored throughout the study period. The recorded catches by species are given in Table 1. Unfortunately, the datasets for southern and northern Peru are too small to allow similar comparisons.

During the 1991 sampling effort of the Ancón wharf, García-Godos (1993) noted more common dolphins and fewer dusky dolphins being landed than usual, a trend that seemed to consolidate itself in other ports and in subsequent years (see Table 1). To minimise possible effects caused by short-term fluctuations in ecological conditions, which may influence species composition, I have defined two broad sampling periods with 1991 as the dividing line: 1985–1990 ($N_1 = 6,308$) and 1991–1993 ($N_2 = 2,022$). Significance was verified by contingency tests ($\alpha = 0.05$) and 95% confidence intervals (CI) of sample proportions were calculated according to the normal approximation method.

The percentage of dusky dolphins decreased significantly ($chi^2 = 457$, df 1, $P < 0.0001$) from 77.5% (CI 76.5–78.5%) in 1985–90 to 52.8% (CI 50.6–55.0%) in 1991–93, while that of common dolphins increased ($chi^2 = 858$, df 1, $P < 0.0001$) from 6.7% (CI 5.5–7.9%) to 31.8% (CI 29.8–33.8%). The proportions of the other main species, the Burmeister's porpoise and bottlenose dolphin did not differ significantly between the two periods (respectively $chi^2 = 0.54$, df 1, $P = 0.46$ and $chi^2 = 3.76$, df 1, $P > 0.05$).

In the absence of information suggesting that either fishing practices or fishing grounds have changed significantly over the period, I believe it is most likely that the observed changes in the relative rates of dusky and long-beaked common dolphins reflect true shifts in their relative abundance off central Peru. Both species primarily feed on Peruvian anchovy, *Engraulis ringens* (McKinnon, 1988; Van Waerebeek and J.C. Reyes, unpublished data) and have a neritic distribution. They are often entangled side by side in gillnets, suggesting that they intermingle, as is claimed by local fishermen. Sightings of two mixed schools during a boat survey in April 1994 (Van Waerebeek, unpublished data) support this view.

Table 1

Species composition of small cetaceans captured in coastal fisheries off central Peru from 1985-1993. Numbers are actually recorded individuals and are based on fresh (F) or cranial (C) specimens. They are not measures of total annual catches because sampling coverage was partial and unequal between both periods. Although more than 99% of *Delphinus* in Peru belong to *D. capensis*, a few *D. delphis* are also included in the statistics.

			L. obscurus		*Delphinus* spp.		*P. spinipinnis*		*T. truncatus*		Other species		Total	
Year	Locality	Type	N	%	N	%	N	%	N	%	N	%	N	Source
1984-85	Pucusana	C	35	41.7	5	6.0	18	21.4	21	25.0	5	6.0	84	Read *et al.* 1988; CEPEC files
1985	Pucusana	F	60	55.0	4	3.7	26	23.9	12	11.0	7	6.4	109	Read *et al.* 1988; CEPEC files
1985	Ancon	F	379	99.2	2	0.5	1	0.3	0	0.0	0	0.0	382	Read *et al.* 1988; CEPEC files
1985	Huacho	F,C	50	98.0	0	0.0	1	2.0	0	0.0	0	0.0	51	Read *et al.* 1988; CEPEC files
1985-86	San Andres	F,C	3	10.3	1	3.4	18	62.1	7	24.1	0	0.0	29	Read *et al.* 1988; CEPEC files
1986	Pucusana	F	455	87.8	4	0.8	20	3.9	33	6.4	6	1.2	518	Read *et al.* 1988; CEPEC files
1986	Cerro Azul	F	192	81.4	0	0.0	40	16.9	1	0.4	3	1.3	236	Read *et al.* 1988; CEPEC files
1987	Pucusana	F	623	64.5	230	23.8	77	8.0	29	3.0	7	0.7	966	Van Waerebeek and Reyes, 1990
1987	Cerro Azul	F	6	54.5	1	9.1	3	27.3	1	9.1	0	0.0	11	CEPEC files, unpublished
1988	Pucusana	F	1,224	75.3	110	6.8	272	16.7	13	0.8	6	0.4	1,625	Van Waerebeek and Reyes, 1994a
1988	Cerro Azul	F	51	92.7	3	5.5	1	1.8	0	0.0	0	0.0	55	Van Waerebeek and Reyes, 1994a
1989	Pucusana	F	1,060	82.6	21	1.6	175	13.6	23	1.8	5	0.4	1,284	Van Waerebeek and Reyes, 1994a
1990	Pucusana	F	750	78.3	44	4.6	139	14.5	21	2.2	4	0.4	958	Van Waerebeek *et al.* 1994
1984-90	Central Peru	F,C	4,888	77.5	425	6.7	791	12.5	161	2.6	43	0.7	6,308	
1991	Ancon	F	358	58.9	168	27.6	82	13.5	0	0.0	0	0.0	608	Garcia-Godos, 1993; Van Waerebeek *et al.* 1994
1992	Ancon	F	102	44.2	113	48.9	11	4.8	5	2.2	0	0.0	231	Van Waerebeek *et al.* 1994
1992	Cerro Azul	F	117	51.3	89	39.0	15	6.6	7	3.1	0	0.0	228	Van Waerebeek *et al.* 1994
1992	S. Andres, Laguna Grande	F,C	12	11.4	35	33.3	40	38.1	17	6.2	1	1.0	105	Tenicela, 1993; Van Waerebeek *et al.* 1994
1992	Pucusana	F	34	57.6	17	28.8	5	8.5	3	5.1	0	0.0	59	Van Waerebeek *et al.* 1994
1992-93	Chancay	F,C	46	52.3	31	35.2	8	9.1	3	3.4	0	0.0	88	Van Waerebeek *et al.* 1994
1992-93	Huarmey, Supe, Huacho	F,C	4	23.5	12	70.6	0	0.0	1	5.9	0	0.0	17	Van Waerebeek *et al.* 1994
1993	Cerro Azul	F	395	57.6	177	25.8	80	11.7	32	4.7	2	0.3	686	Van Waerebeek *et al.* 1994
1991-93	Central Peru	F,C	1,068	52.8	642	31.8	241	11.9	68	3.4	3	0.1	2,022	

One possible explanation for the change is that a partial niche vacuum created by high removal rates of dusky dolphins by coastal fisheries is being filled by an ecologically close species such as the long-beaked common dolphin; the roughly 25% relative reduction in landings of the former species is compensated by a 25% relative increase of the latter. Of course, in the absence of detailed knowledge of the natural history, distribution and abundance of these species, any number of ecological factors might be invoked to explain the observed changes. For example it may be a natural cyclic phenomenon whereby common dolphins move inshore, probably from the north or offshore. In this case a restoration of the 'normal' *Lagenorhynchus/Delphinus* proportion should ultimately be expected. Alternatively, it could be due to a combination of both a natural and a fisheries-caused ecological disturbance. Continued monitoring and an extension of the research programme to include a greater area will be needed to find out.

Despite the uncertainty, I believe that in accordance with the precautionary principle, it is important that effective conservation measures are implemented and that existing legislation is enforced as a matter of urgency (Van Waerebeek and Reyes, 1994b; Van Waerebeek *et al.*, 1994). In that sense I applaud the ministerial resolution of 5 August 1994 (No. 321–94-PE) which reiterates the prohibition of small cetacean exploitation in Peruvian waters, if this means that enforcement will be given new impetus.

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An Investigation of Incidental Catches of Large-Mesh Driftnet Fisheries from the South Pacific and North Atlantic

Michael Earle

Greenpeace International, Rue Cochetay 54, 4140 Gomze-Andoumont, Belgium

Thomas H. Woodley

Department of Zoology, University of Guelph, Guelph, Ontario, Canada N1G 2W1[1]

and

Michael Hagler

Greenpeace New Zealand, Private Bag, Wellesley St, Auckland, New Zealand

ABSTRACT

Driftnet fishing on the high seas for tuna and swordfish has expanded rapidly in recent years, yet little information is available on mortality levels for either target or non-target species. This paper documents catch rates of target and non-target species from a few observed operations and briefly describes the fishing operations of vessels from three areas: the American swordfish fishery in the Northwest Atlantic; the Japanese and Taiwanese fishery for albacore tuna in the Tasman Sea; and the French fishery for albacore tuna in the Northeast Atlantic. Observed incidental catches of cetaceans included common dolphins in all three fisheries, a southern bottlenose whale in the Tasman Sea fishery and striped dolphins in the Northeast Atlantic. The catch rate in the Tasman Sea fishery in 1990 was 0.080 cetaceans per km of netting, whereas 0.18 cetaceans per km of netting were recorded for the French albacore fishery in 1991. Although it is not known whether incidental catches of cetaceans by these fisheries are reducing the populations, these estimates indicate that large numbers could be killed annually.

KEYWORDS: INCIDENTAL CAPTURE; NORTH ATLANTIC; SOUTH PACIFIC; FISHERIES; COMMON DOLPHINS; BOTTLENOSE WHALE; STRIPED DOLPHINS

INTRODUCTION

Driftnet fisheries for tuna (*Thunnus* sp.) and swordfish (*Xiphias gladius*) have recently developed on the high seas in many regions of the world. High seas driftnets characteristically catch a wide range of species incidental to the fishing operation (FAO, 1990a; b; Northridge, In press). In most cases, estimating the impact of these fleets on non-target marine species is virtually impossible due to the lack of data on catch rates and on population sizes and dynamics of those species. We examined three driftnet fisheries: a fishery for swordfish in the northwest Atlantic and two others for albacore (*Thunnus alalunga*) in the northeast Atlantic and South Pacific.

The swordfish fishery in the northwest Atlantic occurs along the edge of the American continental shelf in the region of Georges Bank. By 1989, about 13 vessels were using driftnets in this fishery (Read, 1994; Matthew Gianni, pers. comm.).

Japan began a driftnet fishery for albacore in the South Pacific during the austral summer of 1983/84; by the 1988/89 season, up to 196 vessels from Japan, South Korea and Taiwan were operating. Following strong regional protest and diplomatic pressure, South Korea and Japan withdrew their driftnet vessels following the 1988/89 and 1989/90 seasons, respectively. Eleven Taiwanese driftnet vessels operated during the 1990/91 season (Anon., 1991).

In the northeast Atlantic, French fishermen began experimenting with driftnets and pelagic pair trawls for albacore in 1986. By 1991, over 40 vessels from France, 2 from Ireland and 3 from the UK were operating.

In order to obtain some of the information necessary to estimate the impacts of these driftnet fisheries on non-target species, we observed their fishing operations for four periods between 1989–1991. Our objectives were to provide estimates of species composition and catch rates for non-target species and to briefly describe their fishing operations.

METHODS

Observations were made of the following fleets: the northwest Atlantic swordfish fishery (13–15 August 1989), the Tasman Sea albacore fishery (11–21 January 1990) and the northeast Atlantic albacore fishery (18–19 June 1990 and 20–28 June 1991). Information was collected on fishing locations, gear deployment practices, net design and catches of target and non-target species.

Net lengths were estimated in one of two ways. In the Tasman Sea, the length of a tan (individual section of netting) was measured and then multiplied by the total number of tans deployed. In other cases, lengths were estimated directly from the latitude and longitude coordinates of both ends of the net following deployment, as determined by a *Magellan* GPS NAV 1000 satellite navigation system. The distance between these coordinates was calculated as the length of the net. Where possible, these lengths were verified with a *Furuno* FR1505DA radar system.

Catch composition and numbers were recorded by observers in a small inflatable boat stationed near the point where the net was hauled on board the driftnet vessel. The inflatable was deployed from the Greenpeace mother ship. Animals were identified to the lowest taxonomic level possible. Occasionally, when weather conditions

[1] Present address: *International Marine Mammal Association, 3 Paisley Street, PO Box 515, Guelph, Ontario, Canada, N1H 6K9*

precluded launching the inflatable, observations were made using 7x50 binoculars from the bridge of the mother ship at distances of 50–100m.

For nets surveyed during retrieval that were of known length, catch rates were calculated for target and non-target species as the number of individuals per km of net. Since net length varied from vessel to vessel, mean catch rates (M) for each species were obtained by weighting the catch of each net by the length of net examined:

$$M = \frac{\sum_i n_i}{\sum_i L_i}$$

where n_i is number of individuals of a species caught in net i and L_i is the length of net i in km. The standard error of this mean was calculated as

$$SE = \sqrt{\frac{1}{(N\text{-}1)}\left[\frac{\sum_i n_i^2/L_i}{\sum_i L_i} - M^2\right]}$$

where N is the number of nets observed.

Nets were observed underwater for details of construction. In some cases, divers also observed the nets to provide information on species composition of the catch, although these data were not appropriate for catch rate calculations.

RESULTS

USA East coast swordfish fishery

Three American vessels were observed driftnetting in 460–920m of water along the outer edge of Georges Bank, 16km southwest of the Canadian/USA boundary for three days in August 1989. Sets ranged from 1.8–2.7km in length, with a 56cm stretch mesh size. They were deployed at dusk and floated 6m below the surface. Ships remained attached to their nets throughout the night, and nets were retrieved at dawn. Netting was made of braided nylon twine.

Catches of three sets were observed during retrieval operations, two in their entirety and about one half of the third for a total of 6.5km. The combined catch was 26 swordfish, 2 bigeye tuna (*T. obesus*) and 4 common dolphins (*Delphinus delphis*). These few data provide a catch rate estimate of 0.62 (SE = 1.64) cetaceans per km of netting.

Tasman Sea albacore fishery

Nine driftnetting vessels of the Japanese and Taiwanese albacore fleets were monitored in the Tasman Sea (37°-42°S, 156°-161°E) in waters of about 4,500m depth for 11 days in January 1990. Nets were usually deployed along a near north/south axis, across the expected easterly migration path of the tuna. Up to eight vessels deployed nets in a parallel formation about 3km apart.

The Japanese and Taiwanese driftnets differed somewhat in design, although total length per set was about 40km for both fleets. Japanese sets consisted of eight individual nets, 5km in length, deployed end to end. Nets consisted of 124 tans that were 39m long and 10m deep. They had a stretch mesh size of 180mm. The Taiwanese vessels, however, deployed sets of five nets that were 8km long. Each net consisted of 200 tans that were 39m long and 15m deep. They were constructed of multi-monofilament twine with a stretch mesh size of 200mm. Both fleets deployed the driftnets at the surface and attached radio beacons to both ends of each net. A gap of about 60m separated individual nets. Deployment began at about 1600 hrs (local time) and retrieval began between 0135 and 0900 hrs the following morning.

A total of 87.5km of netting from 18 nets, deployed during five sets, was observed during retrieval operations. The present analysis differs slightly from the preliminary report of Coffey and Grace (1990), because they used data collected during underwater observations for estimating catch rates and did not use weighted means. The total catch included 898 tuna (albacore and skipjack, *Katsuwonus pelamis*), 4 sunfish (*Mola mola*), 5 sharks, 3 billfish (Istiophoridae) and swordfish, 7 common dolphins and 24 bream (*Brama* spp.) (Table 1). No birds or turtles were observed in the nets.

Table 1

Catch records of albacore driftnet vessels in the Tasman Sea, 15-21 January 1990. Weighted means are per km.

Date	Net length (km)	Tunas	Ocean sunfish	Sharks	Billfish and Swordfish	Common dolphins	Bream
15	5.0	105	0	1	0	1	0
16	5.0	98	1	0	0	0	0
16	5.0	140	0	0	0	0	0
16	5.0	70	0	0	1	0	0
16	5.0	96	0	0	0	0	0
16	5.0	31	0	1	0	0	0
16	5.0	94	1	0	0	1	0
16	5.0	77	0	1	0	0	1
16	5.0	86	1	1	0	1	3
18	5.0	6	0	1	0	2	0
18	5.0	13	0	0	0	0	0
18	5.0	18	1	0	0	1	0
18	5.0	8	0	0	0	0	0
18	5.0	6	0	0	0	0	0
18	5.0	22	0	0	1	0	2
20	5.0	9	0	0	0	0	2
21	2.5	10	0	0	1	1	1
21	5.0	9	0	0	0	0	12
Totals	87.5	898	4	5	3	7	21
Weighted means		10.263	0.046	0.057	0.034	0.080	0.240
SEs		2.102	0.020	0.022	0.022	0.031	0.137

The catch rate for common dolphins was 0.080 (SE = 0.031) per km of netting. Estimated catch rates for other species are given in Table 1. Additionally, divers observed a southern bottlenose whale (*Hyperoodon planifrons*) in a net and released it alive.

Northeast Atlantic albacore fishery

A preliminary investigation of the French driftnet fleet in 1990 recorded a total catch of 84 albacore, 10 blue sharks (*Prionace glauca*), 2 bream and 1 common dolphin during underwater observations of four sets over three days in June. Nets ranged from 5–20km in length (as measured by radar).

In 1991, the operations of six French vessels were observed in the region of 43°-45°N, 17°-19°W in depths of 4,000m over a period of nine days. The vessels were estimated to be 20–23m in length with crews of seven to eight. Nets were suspended from the surface, ranged from 15–20m in height and had a stretch mesh size of about 160–170mm. They were constructed of multifilament nylon. Sets consisted of one or two nets, depending on the vessel, and had a total length of 5.7–8.5km (mean=6.8km, n=5). Deployment began between 2100–2200 hrs (local time) and retrieval began about 0530 hrs the following morning. Since it was not possible to observe all deployments, length estimates could not be obtained for all nets.

The total catch of 12 nets from eight sets included 2,144 albacore (including 55 that fell from nets and were lost), 130 sharks (mostly blue sharks), 82 bream, 4 swordfish, 3 common dolphins, 2 striped dolphins (*Stenella coeruleoalba*) and several other species (Table 2). The cetacean bycatch comprised a dolphin calf of about 1m, three dolphins that appeared to be immature and an adult of just over 2m.

Length estimates were obtained for seven of the twelve nets surveyed in 1991, totalling 28.1km (Table 2). The catch rates derived for these nets for common and striped dolphins were 0.11 (SE = 0.09) and 0.07 (SE = 0.05) per km of netting, respectively, or 0.18 (SE = 0.12) cetaceans per km of netting. A complete list of catches, net lengths and catch rates for the 1991 observations is provided in Table 2.

DISCUSSION

The present study provides some of the first estimates of catch rates of target and non-target species in large-mesh driftnet fisheries, although the surveys were of small sample sizes. The estimated catch rates of cetaceans (0.080 cetaceans per km in the Tasman Sea albacore fishery; 0.18 per km in the northeast Atlantic albacore fishery and 0.62 per km in the northwest Atlantic swordfish fishery), suggest that total cetacean mortality during the fishing season may be substantial given the number of sets made each year; the non-cetacean bycatch may also be substantial.

Data are also available from fisheries observers in these three fisheries. For the swordfish fishery, data were available on catches from 54 sets by nine vessels between 16 August and 14 November 1989 and 69 sets in 1990 (Anon., 1990; Read, 1994). In addition to swordfish, 33 species were observed caught during the two years. This included eight species of marine mammals with 43 common dolphins, 18 long-finned pilot whales (*Globicephala melaena*), 17 Risso's dolphins (*Grampus griseus*), 16 bottlenose dolphins (*Tursiops truncatus*), 13 unidentified beaked whales (Ziphiidae), 7 spotted dolphins (*S. frontalis*), 5 striped dolphins, 1 sperm whale (*Physeter macrocephalus*) and 1 unidentified dolphin (Delphinidae) (Anon., 1990; Read, 1994). Leatherback (*Dermochelys coriacea*) and loggerhead (*Caretta caretta*) turtles were also caught in the nets. The fewer species observed in our study presumably reflects the much smaller sample size.

Although the data released on the American swordfish driftnet fishery did not include lengths of the nets observed (Anon., 1990; Read, 1994), if a length of 2.7km is assumed (the maximum length allowed under US domestic law; see also Read, 1994) catch rates can be estimated. The total catch of 54 cetaceans reported from 54 sets in 1989 results

Table 2

Catch records of French albacore driftnet vessels in the northeast Atlantic, 21-28 June 1991. Weighted means are per km.

Day of June for the set	Surveyed portions of nets (km)	Albacore tuna	Shark	Bream	Jellyfish	Squid	Swordfish	Sea Bass	Common Dolphin	Striped Dolphin	Leather-jacket	Unidentified fish
20	NA	168	5	5	0	1	0	0	0	0	0	6
21	3.0	203	7	1	0	1	2	1	0	0	0	5
21	NA	41	2	2	0	0	0	0	0	0	0	3
22	NA	124	3	5	0	0	0	0	0	0	0	1
22	NA	148	19	7	0	2	0	0	0	0	0	5
23	3.7	221	15	2	0	0	1	0	0	0	1	0
23	3.2	233	8	4	0	1	0	0	0	1	0	1
24	3.9	300	25	12	0	2	0	0	0	0	1	0
24	NA	118	2	1	0	0	1	0	0	0	0	0
25	3.9	254	23	2	0	0	0	0	0	0	0	0
26	4.7	221	8	1	0	2	0	1	0	0	0	2
27	5.7	113	13	40	34	2	0	1	3	1	0	0
* Total A	NA	2,144	130	82	34	11	4	3	3	2	2	23
** Total B	28.1	1,545	99	62	34	8	3	3	3	2	2	8
** Weighted means		54.98	3.52	2.21	1.21	0.28	0.11	0.11	0.11	0.07	0.07	0.28
** SEs		8.08	0.72	1.06	0.98	0.07	0.09	0.05	0.09	0.05	0.05	0.21

* Calculated from all nets surveyed.
** Calculated only from nets where a known portion was surveyed.

in an estimate of 0.37 cetaceans per km while the total catch of 67 cetaceans caught in 69 sets provides an estimate of 0.36 cetaceans per km in 1990. These values are lower than the estimate of 0.62 cetaceans per km derived from our small sample.

A New Zealand government observer surveyed the operations of the Japanese experimental albacore driftnet vessel RV *Shin-Hoyo Maru* in the Tasman Sea during the same fishing season as the present study (Sharples *et al.*, 1990). A total of 41 species was observed in 22 sets, including three leatherback turtles and two Westland black petrels (*Procellaria westlandica*). The marine mammal catch consisted of 45 common dolphins, 10 striped dolphins, 1 short-finned pilot whale (*Globicephala macrorhynchus*) and 1 southern bottlenose whale. The number of species reported is again greater than in our study, probably reflecting the larger sample size. All except the bottlenose whale were dead upon retrieval, and that animal was released but carried a section of netting with it. The 57 cetaceans were caught in 22 sets totalling 698.4km, providing a weighted mean catch rate of 0.082 (SE = 0.022) cetaceans per km. This figure is similar to the estimate of 0.080 cetaceans per km derived in the present study.

In the northeast Atlantic, the IWC (1992) reported catch rates of 0.03–0.08 cetaceans per km of netting for the French albacore driftnet fishery for 1989 and 1990, based on data in Antoine (1990). These bycatch estimates are somewhat lower than the 0.18 per km reported here.

Few other estimates of cetacean catch rates in tuna and swordfish driftnet fisheries are available. An observer aboard the *Shin-Hoyo Maru* in the Sub-Tropical Convergence, to the south of French Polynesia, recorded catches from 14 sets in 1990. Eight common dolphins and 1 Risso's dolphin were caught in 408km, which results in a weighted mean of 0.022 cetaceans per km. FAO (1990a) provided a figure of 0.058 cetaceans per km for the 'North Pacific tuna driftnet fishery', although no source is credited for the estimate. Data reported from an observer programme for the swordfish driftnet fishery off the coast of California result in a catch rate of 0.046 cetaceans per km (Lennert *et al.*, 1994).

Bycatch rate estimates provided here can be used with data on fishing effort to provide annual catch estimates for the relevent driftnet fisheries. Such estimates would have to be treated with caution, because they are based on relatively small sample sizes. Clearly, the collection of more extensive data on catch rates of incidentally caught species, and the other information (estimates of population size and fishing effort) required for proper assessments of the impact of driftnet fishing on non-target species is required to refine these figures.

Overall, our observations of driftnet fisheries in the South Pacific and North Atlantic indicate substantial cetacean bycatches. Indeed, it seems that wherever cetacean distributions overlap with driftnet fisheries, cetaceans will inevitably be caught, sometimes in large numbers (IWC, 1992).

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Causes and Solutions

SC/O90/G50

How Many Did You Catch? The Effect of Methodology on Bycatch Reports Obtained from Fishermen

Jon Lien

Ocean Sciences Centre and Department of Psychology, Memorial University of Newfoundland, St. John's, Newfoundland, A1C 5S7, Canada

G.B. Stenson

Science Branch, Fisheries and Oceans, St. John's, Newfoundland, Canada

Sue Carver

Whale Research Group, Memorial University of Newfoundland, St. John's, Newfoundland, A1C 5S7, Canada

and

John Chardine

Canadian Wildlife Service, St. John's, Newfoundland, Canada

ABSTRACT

Reports of fisheries bycatches are obtained from fishermen by various methods and often presented without evaluating the reliability of the reports. We examined the effects of method of obtaining estimates of small cetacean and seal bycatch on reports by inshore fishermen in Newfoundland and Labrador during 1990. Fishermen were phoned and questioned about incidental catches. Responses were examined for effect of the interviewer's agency and sex. About 15% of fishermen interviewed were re-phoned and re-questioned. Fishermens' ability to recall well documented numbers of animals caught a decade earlier was evaluated. *In situ* interviews were conducted and logbooks examined in a manner that permitted comparisons among data obtained by different methods. Differences in reports caused by different motivations were examined by paying a sub-sample of fishermen.

Results indicate that bycatch estimates are influenced by methodology used to obtain reports from fishermen. Fishermen are influenced by interviewers. Bycatch estimates were markedly skewed. In most studies variance of estimates of bycatch within and between fishermen were positively correlated with size of reported catches; fishermen tend to count '1 – 2 – 3 – 4 – 5 – dozens – hundreds – thousands'. We conclude that investigations without assessments of their methodology for obtaining their bycatch reports cannot be evaluated or interpreted. Scaling corrections and improvements of survey methodology are discussed.

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; METHODOLOGY; NORTH ATLANTIC

INTRODUCTION

Incidental entrapment of non-target species in fishing gear (bycatch) is a worldwide phenomenon of major concern to resource managers. For example, in Newfoundland and Labrador, some 30,000 inshore fishermen employ substantial amounts of fishing gear, several kinds of which catch individuals of a wide variety of target and non-target species. The levels of bycatch are very difficult to determine, especially in areas such as Newfoundland, which is geographically large and intensively fished. Historically, data on incidental catches have been based upon reports obtained from fishermen through phone interviews, mailed questionnaires, or *in situ* interviews. In reports of such data it has been assumed that there was no systematic bias in reporting and that catches were counted more-or-less accurately. Few, if any, studies have incorporated procedures to test these assumptions (Lien *et al.*, 1989).

Studies based on reports from fishermen can suffer from numerous problems. The first is inconsistency in reliability of reports from fishermen (Lien, 1987). Numbers may be inaccurate and change depending upon the interviewer and when and how questions are asked. Problems such as these make it virtually impossible to correct estimates to quantify catches accurately.

The second is determining bias in estimated catches reported by fishermen. For example, examination of data obtained in most studies indicates that variance of estimates of bycatch, both within and between fishermen, are correlated with size of catches. Fishermen tend to count '1 – 2 – 3 – 4 – 5 – dozens – hundreds – thousands' (Lien *et al.*, 1989).

Finally, although there are strong indications that bycatch estimates are influenced by the methods used to obtain data (Lien, 1980), there has been no effort to quantify effects of differences in methodology, motivation or interviewer.

Like other investigators, we have attempted to obtain reliable, useful estimates of numbers of animals incidentally taken and their geographic and seasonal variation. This paper presents findings on how method affects bycatch estimates.

METHODS

Five techniques for obtaining bycatch reports from fishermen were examined: (1) phone interviews; (2) *in situ* interviews; (3) log books; (4) recall of past catches; and (5) payment for samples.

(1) Phone interviews

A total of 350 fishermen from Newfoundland and Labrador were phoned in May 1990 and asked about incidental catches during the immediately previous (1989) fishing season. Fishermen were selected randomly from a list of chairmen of local 'fishermens' committees'; such individuals are typically among the most successful

fishermen and are active in organising local fishery-related activities.

Fishermen were assigned randomly to one of four experienced interviewers (two male; two female). Two interviewers were fishermen; two were fisheries technicians. Each interviewer identified himself/herself as calling on behalf of either a government fishery agency or a university (Science Branch, Fisheries and Oceans or the Whale Research Group of Memorial University). A maximum of six attempts was made to reach an individual before he/she was dropped.

Each fisherman was asked to describe the types of gear used in 1989 and for each gear type to summarise information on fishing effort (amount used and duration of fishing). Questions were asked on fish catches and on incidental catches of non-teleost species (cetaceans, pinnipeds, birds, sharks and turtles) in each type of gear. The various local names fishermen used for non-target species were collapsed into unified categories: 'seals', 'small cetaceans', 'whales' and 'seabirds'. Interviewers asked fishermen if they would be willing to continue reporting bycatch and rated their 'cooperativeness' as uncooperative, helpful or very helpful.

Approximately two to three weeks after the initial phone survey was completed, 15% of the fishermen contacted were phoned by a different interviewer and asked again about their 1989 bycatch. During this second interview questions were restricted to bycatches in groundfish gillnets.

(2) In situ interviews concerning immediately previous season

Interviewers travelled to convenient fishing communities on the southern shore of the Avalon Peninsula and on the northeast coast of Newfoundland and conducted *in situ* interviews with 37 crew skippers regarding bycatch. They were interviewed in the presence of their crews. Questions were identical to those asked in the phone interviews.

(3) Examination of logbooks

Forty five fishermen were phoned in 1989 and asked to participate in a monitoring program by reporting fishing effort, fish catches and marine mammal bycatches. Log books were returned at the end of each month from April through August. Participants were paid $50 at the end of the fishing season when they had returned all completed log books.

(4) Phone interviews concerning catches from a previous decade

A phone survey of 100 chairmen of fishermens' committees regarding small cetacean bycatch by inshore fishermen was conducted in 1980 (Lien, 1980; 1987). We phoned these fishermen again in June 1990 and asked about their 1980 catches, their 1989 bycatch and asked them to estimate changes in the magnitude of bycatch.

(5) Phone interviews with payment for samples

To examine effects of motivation on tendency to report, 56 fishermen who had been contacted in the 1990 phone survey and indicated a willingness to participate further in bycatch studies were formed into four groups: (1) fishermen who volunteered to collect and save specimens for scientists (n=5); (2) those who had stated they would participate in further monitoring of bycatch and were later called and asked specifically to collect and save specimens; they received no payment for reports (n=20); (3) those as in (2) but given $10 for each reported bycatch animal collected; and (4) those as in (2) but given $25 for each by-caught animal reported and collected.

At the end of the season fishermen in all groups were called, thanked for their participation in the program, and questioned again about their total bycatch of small cetaceans, both reported and unreported.

RESULTS

Results are presented below by method; comparisons among methods are made in the discussion.

Phone interviews concerning the immediately previous season

Only 235 (67%) of the fishermen selected were successfully reached by phone. Nearly all interviewed were rated as 'very helpful' (81.6%) or 'helpful' (17.0%) by interviewers.

Mean reported bycatches of small cetaceans (Table 1) and seals (Table 2) were highest in groundfish gillnets. Although the percentage of fishermen who reported catching at least one small cetacean (12.6%) in groundfish gillnets was similar to those reporting at least one bycatch in salmon gillnets (10.7%), mean catches were much higher for groundfish (0.91 animals/fisherman) than for salmon (0.27 animals/fisherman) gillnets. Mean numbers of animals caught were heavily influenced by very high catches, especially of seals, reported by some fishermen (Tables 3 and 4).

Table 1

Results of 1990 phone survey to monitor bycatch of small cetaceans. (n = 235 fishermen).

Gear type	Number of fishermen using gear	Bycatch of small cetaceans: Mean catch/ fisherman	SD	% of fishermen with some bycatch
Groundfish gillnets	190	0.91	3.57	12.6
Salmon gillnets	74	0.27	0.89	10.7
Lumpfish gillnets	109	0.05	0.40	2.8
Codtrap	135	0.01	0.08	1.1
Capelin traps	94	0.00	0.0	0.0

Table 2

Results of 1990 phone survey to monitor bycatch of seals. (n = 235 fishermen).

Gear type	Number of fishermen using gear	Bycatch of small cetaceans: Mean catch/ fisherman	SD	% of fishermen with some bycatch
Groundfish gillnets	190	5.56	18.55	24.2
Salmon gillnets	74	0.36	2.09	1.4
Lumpfish gillnets	109	6.20	13.61	38.5
Codtraps	135	0.03	0.28	14.8
Capelin traps	94	0.01	0.10	1.1

Table 3

Frequency of small cetacean groundfish gillnet bycatch reported in 1990 phone survey (n = 235 fishermen).

No. of small cetaceans reported caught in 1989	Frequency	% of Interviewees	Cumulative %
0	159	83.7	83.7
1	10	5.3	88.9
2	7	3.7	92.6
3	2	1.1	93.7
4	4	2.1	95.8
6	1	0.5	96.3
12	3	1.6	97.9
15	2	1.1	98.9
25	1	0.5	99.4
30	1	0.5	100.0

Table 4

Frequency of seal groundfish gillnet bycatch reported by 235 fishermen in 1990 phone survey.

No. of seals reported caught in 1989	Frequency	% of Interviewees	Cumulative %
0	769	88.0	88.0
1	19	2.2	90.2
2	7	0.8	91.0
3	14	1.6	92.6
4	4	0.5	93.0
5	3	0.3	93.4
6	6	0.7	94.1
7	3	0.3	94.4
8	4	0.5	94.9
9	1	0.1	95.0
10	10	1.1	96.1
11	1	0.1	96.2
12	4	0.5	96.7
15	4	0.5	97.1
17	2	0.2	97.4
20	7	0.8	98.2
22	1	0.1	98.3
25	2	0.2	98.5
30	2	0.2	98.7
40	1	0.1	98.9
50	7	0.8	99.8
96	1	0.1	99.9
100	1	0.1	100.0

The effect of interviewer's affiliation was not significant but the sex of the interviewer was. Female interviewers more frequently were given reports of 'whales' ($p<0.0002$) or 'porpoises' ($p<0.013$) than were male interviewers. This reflects terms used by interviewers and did not, in this case, affect frequency in the final categories. The two interviewers with fishing experience were given higher estimates of small cetacean bycatch and fish landings than were interviewers without fishing experience.

We were unable to reach 28% of the fishermen designated for a second interview; thus there were only 25 recall interviews.

When asked about their bycatch in groundfish gillnets a second time, these 25 fishermen changed reports fairly frequently; 16 out of 25 (64%) changed answers in at least one of four categories (Table 5). Fishermen who reported a low bycatch in the first phone interview made relatively few changes in all categories. Only 8.2% made changes in their second bycatch reports if on the first report numbers were 0–2; 84.6% of fishermen made changes in bycatch reports on the second call if they had estimated bycatch of three or more on the first call. The direction of changes was random (52.6% up; 47.4% down). If fishermen changed their estimate of 'seabirds' between calls (n=11) and reported some bycatch in other categories (n=5), they also tended to change their estimates in at least one of the other category (80%).

Table 5

Bycatch reports of whales, dolphins, seals and seabirds: Changes between two phone calls in the same fishing season. Total fishermen = 25; number that change answer in at least one category on the second call = 16.

No. animals reported on first call	No. fishermen reported	No. fishermen that changed	Change to
'Whale/dolphin'			
0	24	0	
2	1	0	
'Small whale'			
0	22	0	
1	2	0	
15-20	1	1	60-70
90	1	1	12
'Seals'			
0	17	3	12; 2-3
3-4			
1	1	0	
2	1	0	
2-3	1	0	
6	1	1	12
8	1	1	6-7
12-15	1	1	12
200	2	2	50-50; 100
'Seabirds'			
0	13	2	'few' 15-6
'few'			
1	1	0	
2	2	2	0; 10-12
12-15	1	1	6-12
12-200	1	1	40-50
25	1	1	100
100	2	1	70

There were substantial differences among interviewers in the numbers of changes of estimates which occurred when they were involved in the second interviews. Ratios of changed estimates on second interviews conducted were 2/6 (33%), 8/9 (89%), 4/7 (57%) and 2/3 (67%) for the four interviewers.

In situ interviews concerning the immediately previous season

Results of *in situ* interviews with 37 fishermen are presented in Table 6. All fishermen approached for an interview agreed and were scored by the interviewer as 'very helpful'. Most of these interviews were conducted in the presence of other fishermen; frequently fishermen, usually crewmen, present during the interview added or corrected information given by the interviewee.

Examination of logbooks

Initially, 45 fishermen contacted agreed to maintain log books of fishing effort, fish catches and marine mammal bycatch; 22 (49%) actually returned their log books monthly during 1990. Analysis of log book records of bycatch is presented in Table 7.

Table 6

Bycatches of small cetaceans and seals reported in *in situ* interviews (n = 37 fishermen).

Gear type	No. of fishermen using gear	Mean no. small cetaceans	% fishermen reporting any catch	Mean no. seals	% fishermen reporting any catch
Groundfish gillnets	28	1.07	35.7	16.9	46.4
Salmon gillnets	10	0.30	30.0	0.0	0.0
Salmon gillnets	12	0.50	16.7	5.4	33.3
Codtraps	16	0.06	6.0	0.1	6.0

Table 7

Bycatch of marine mammals reported in groundfish gillnets in 1990 by logbooks. (n = 22 fishermen).

Animals	Total no. reported bycatch	Mean bycatch per fisherman	% of fishermen reporting any catches
Small cetaceans	22	1.0	31.8
Seals	115	5.23	59.0

Phone interviews concerning catches from a previous decade

Participants in the 1980 study of bycatch were difficult to re-contact. Of 100 in the initial sample only 62% had current phone numbers. Of those, 14.5% were not successfully contacted; 19.3% were either retired or dead; 17.7% had left fishing. Twenty-nine were successfully re-contacted and interviewed. In 1980 these 29 individuals had reported a mean catch of 5.4 small cetaceans; 55% of them had reported catching at least one small cetacean in 1980.

When asked in 1990 to recall their 1980 bycatch, 11 fishermen (37.9%) could not remember and would not guess while 18 (62.1%) gave estimates. Typically fishermen who had reported high estimates of bycatch in 1980 were the individuals who in 1990 could not remember or would not give estimates. Of fishermen that did recall 1980 catches, 24% recalled reported catches without changes, 21% made lower estimates and 17% made higher estimates in 1990. The recalled mean estimate of 1980 catches was 1.3 small cetaceans; 39% of the fishermen reported catching at least one small cetacean.

When asked to give their impression whether bycatches of small cetaceans were 'up' or 'down' 21% indicated they 'couldn't tell', 3% said the 'catches were up', 10% said catches were 'about the same', and 62% said 'catches were down'. These estimates generally agreed with reported 1990 catches (average 1.1 small cetacean); 27% of these fishermen reported catching at least one small cetacean in 1990.

Phone interviews with payment for samples

Overall, the mean bycatch of small cetaceans reported by fishermen participating in the payment for samples experiment was 0.34 during the 1989 season. When the numbers are corrected to include catches not reported initially but were discovered by later phone interviews, mean catch was 0.48; 19.6% of fishermen in the sample caught at least one small cetacean.

Comparison of the groups (Table 8) indicate that the highest catches of small cetaceans were reported by individuals who received $25 for reporting each catch. Their catches were substantially higher than those of fishermen receiving lower remuneration. However, when fishermen in all groups were questioned in phone interviews at the end of the season about reported and unreported bycatch, the effects of motivational differences which could account for reported vs unreported catches were not clear. Fishermen in the $25 group had both the highest number of reported and unreported catches.

DISCUSSION

Bycatch monitoring methods

Methods used to obtain data to estimate bycatches in groundfish gillnets in 1989 are compared in Table 9. Differences cannot be simply explained.

Some variation may have resulted from the relatively small samples of some methods and a site bias – some areas had higher sample density than others. Differential distribution of seals and small cetaceans might explain the higher catches reported in *in situ* interviews. In phone interviews, where the sample size was larger and data could be clustered by regions, there were large differences in bycatches reported from different areas. We believe that some of these differences reflect relative abundance of animals in the areas. However, in other regions our sample size is too small to make comparisons. Methods to estimate bycatch should be carefully checked for potential site bias.

Fishermen who reported large numbers of animals as bycatch were the same individuals who were most likely to change their estimated catches. They tended to change consistently in that if they changed estimated catches of one species group, they were likely to change estimated catches of other species.

Information obtained by re-phoning fishermen to verify their reports bycatches given a decade earlier shows a similar pattern. It was the fishermen that reported large bycatches that could not recall earlier bycatch numbers and changed them in the 1990 interview. In these interviews it is interesting that the fishermens' impressions of changes in bycatch agree with the trend in the numerical data they provided.

The 'pay for samples' approach may be considered the most reliable method for obtaining reliable estimates of bycatch, although totals may have been affected by animals caught but not reported; 7 of 26 (26.9%) small cetaceans were not reported because fishermen released them alive, they dropped out of the net before recovered, or they were rotten on discovery. However, the percentage of fishermen catching at least one animal did not change much following end-of-season phone interviews. This method gave lowest bycatch estimates.

Data obtained in a social context, as in the *in situ* interviews seemed to have the advantage of several individuals verifying and correcting estimates of bycatch made by the principal interviewee. Interviewers agreed

Table 8

Small cetaceans reported by fishermen in program monitoring bycatch with different incentives. All participants were Newfoundland inshore fishermen who agreed to report and save dead small cetaceans during 1990 (June - Sept.). *Participants were called in October 1990, thanked for their participation and asked by interviewers how many animals they had actually captured during the season.

Classification Interviewees	No. interviewed	Sm. cetaceans reported caught	% fishermen that caught at least 1	Actual no. caught*
Volunteer	5	2	20	none
No pay	20	0	0	2
$10/catch	10	1	10	none
$25/catch	21	16	30	5

Table 9

Mean number of seals and small cetaceans reported caught in groundfish gillnets and percentage of fishermen that reported catching them: comparison of different monitoring methods used during 1990.

	No. fishermen interviewed	Mean no. seals caught/ fishermen	% fishermen reporting any seal catches	Mean no. small cetaceans caught/ fishermen	% fishermen reporting any cetacean catches
Phone interview	190	5.56	12.0	0.91	12.6
In situ interview	28	16.96	46.4	1.07	35.7
Logbooks	22	5.23	59.0	1.00	31.8
Payment experiment	56	-	-	0.48	19.6

that face-to-face contacts with fishing crews who were known from past contacts resulted in the most reliable, comprehensive estimates of bycatch. Maintenance of log books by volunteers, followed by end-of-season *in situ* interviews is probably the best monitoring method. However, only about one-half of our log book volunteers, paid $50 for their efforts, completed books and returned them. Perhaps more would be returned for higher pay. The high investment of time, and perhaps money, and the relatively low return make costs of this method a major disadvantage.

It is not clear that any single method is best. Each had problems with reliability of reports and potential sample bias. Costs in time and money to conduct such investigations, as well as practical situational factors, may be reasonable basis for selecting any particular method.

However, incorporating reliability checks into each method does give a basis for evaluating estimates of bycatches. Whether the reliability check is a social one where fishermen report their catches in the presence of peers, motivational, double checking numbers with second interviews or requiring the proof of a dead body, some procedure is necessary to evaluate the adequacy of the method.

Bycatch counting and distribution

Reports from fishermen using various methods resulted in distributions which were markedly skewed. Most fishermen reported catching no or few animals. When re-interviewed these numbers were reliably recalled. A few fishermen reported higher catches but their estimates used scales which were not continuous or linear; recall of higher estimates was more variable. Mean sizes of reported bycatches generally appeared correlated with variability of reports.

Distributions with such characteristics are difficult to summarise. Arithmetic means fail to adequately characterise them; means inordinately reflect the less reliable high estimates of fishermen. Mathematical transformations might be useful so that bycatch data can be adequately described statistically, but it is not clear which type of transformation is best.

Conclusions

We conducted these investigations of bycatch methodology to help us obtain the most reliable data possible on bycatches of about 30,000 inshore fishermen scattered along 17,000km of coastline. While we have not found a single monitoring methodology which is clearly best, the studies have allowed us to reach the following conclusions:

(1) numerical estimates of bycatch are, at least in part, a function of methodology used;
(2) interviewer and motivational variables influence estimates of bycatch which fishermen provide;
(3) to understand the adequacy of any methodology it is necessary to check the reliability of estimates on bycatch in order to interpret them;
(4) counting scales of fishermen are not continuous or linear. Higher bycatch estimates are more variable than lower ones. Mathematical transformations are necessary.

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Is There Common Cause for Dolphin Capture in Gillnets? A Review of Dolphin Catches in Shark Nets off Natal, South Africa

V.G. Cockcroft

Centre for Dolphin Studies, Port Elizabeth Museum, P.O. Box 13147, Humewood 6013, Republic of South Africa

ABSTRACT

Biological, environmental and physiographic data pertaining to the capture of common (*Delphinus delphis*), bottlenose (*Tursiops truncatus*) and Indo-Pacific hump-backed (*Sousa chinensis*) dolphins captured in shark gillnets set off Natal, South Africa, between January 1980 and December 1988 were analysed. Examined individually, these data provide insights into the social organisation and biology of the three species and suggest a number of reasons why each dolphin species may be incidentally captured in gillnets. There were, however, few commonalities when comparing data for the different species. Generally, this indicates that dolphins occurring around nets are prone to capture. The implications of this for capture prevention or reduction and the modification of gear are discussed. Recommendations regarding the continued deployment of shark nets off Natal and the management and conservation of small cetaceans elsewhere are proposed.

KEYWORDS: INCIDENTAL CAPTURE; INDIAN OCEAN; COMMON DOLPHIN; BOTTLENOSE DOLPHIN; INDO-PACIFIC HUMP-BACKED DOLPHIN; BEHAVIOUR; MANAGEMENT; OCEANOGRAPHY; FEEDING; MOVEMENT

INTRODUCTION

The incidence of small cetacean capture in gillnets and traps, in both high seas and coastal waters, is diverse and widespread in all oceans (Beverton, 1985) and can be viewed as the greatest single cause of their mortality (IWC, 1994). Consequently, the elimination or reduction of such catches is of prime importance in the management and preservation of existing stocks. Unfortunately, there has been little progress in perfecting methods of preventing or reducing captures, particularly where socio-economic realities conflict with management and conservation.

The results of experiments to modify either the setting of nets, such as sub-surface placement, or their acoustic properties have been equivocal at best (e.g. Murison, 1986; Peddemors *et al.*, 1990). With hindsight, the failure of these attempts, particularly the latter, was to be expected. The assumptions on which much of this research was based were unfounded and little fundamental research into the causes of incidental capture was undertaken prior to the commencement of most of these studies. As a priority therefore, establishing the causes of and sequence of events leading to incidental capture are fundamental in formulating methods of capture prevention or reduction.

Off Natal on the east coast of southern Africa (Fig. 1), numbers of small cetaceans are caught incidentally in non-commercial gillnets set off beaches frequented by tourists. These nets are set to catch sharks and reduce the probability of shark/bather interaction. Incidental catches of dolphins in these nets commonly include three species, common dolphin (*Delphinus delphis*), Indo-Pacific hump-backed dolphin (*Sousa chinensis*) and Indian Ocean bottlenose dolphin (*Tursiops truncatus*) (Cockcroft, 1990). Assessments of population numbers of the latter two species in Natal waters suggest that their continuing incidental mortality may lead to their decline in the Natal region (Ross *et al.*, 1989; Cockcroft, 1991; Cockcroft *et al.*, 1992a; 1992b). Concern for this decline prompted the initiation of an experimental programme into methods of preventing dolphin capture (Peddemors *et al.*, 1991) and an assessment of biological, environmental and physiographic factors implicated in the capture of bottlenose dolphins (Cockcroft, 1992).

This paper examines these parameters for common and hump-backed dolphin catches and re-examines those pertaining to bottlenose dolphin captures (Cockcroft, 1992). Firstly, this is done in an effort to determine which of these factors may be important in the capture of the individual species. Secondly, it is an attempt to compare the apparently pertinent factors for each species to ascertain which, if any, may be common to more than one species.

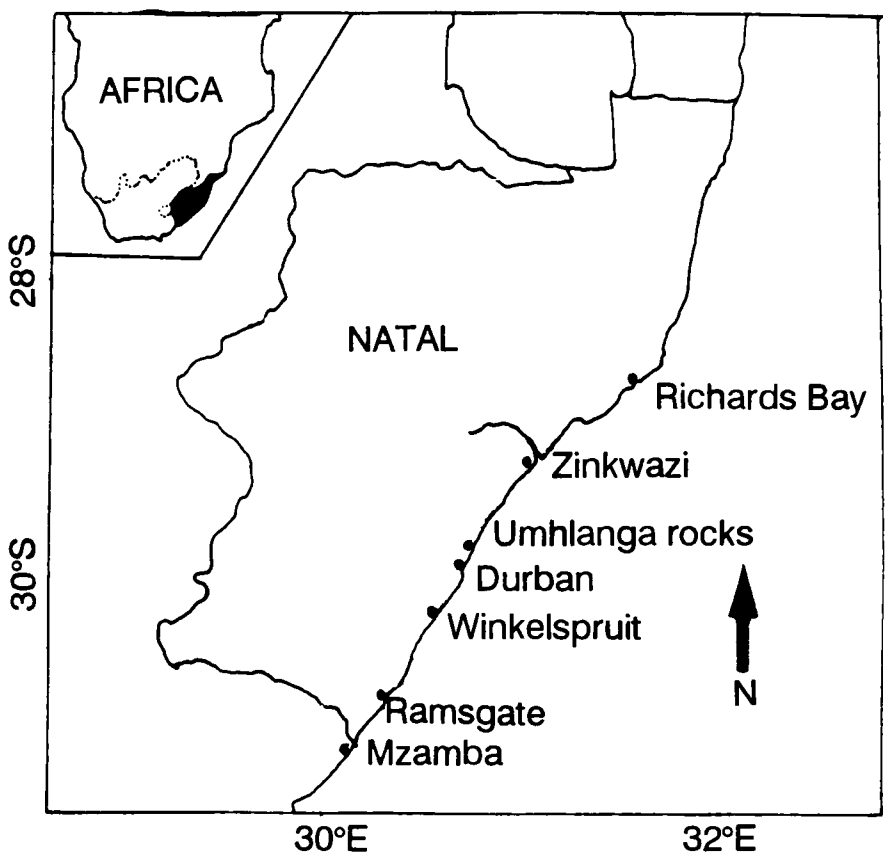

Fig. 1. Natal on the east coast of southern Africa. Shark gillnets, to catch and reduce the populations of sharks, are positioned some 500m off-shore at 44 bathing beaches between Richards Bay and Mzamba.

STUDY AREA, MATERIALS AND METHODS

The locality, distribution and specifications of all Natal Sharks Board (NSB) net installations off Natal, South Africa (Fig. 1), are provided by Cockcroft (1990). Necropsies performed on all dolphins retrieved from the nets between 1980 and 1988, inclusive, provided biological data, such as length, weight and sex. Additionally, the proportional fullness of the stomach was estimated from the weight of solid food remains in the stomach as a proportion of the estimated maximum weight of prey the stomach could hold. This was assumed to be equal to the maximum fluid volume of the stomach (*sensu* Cockcroft and Ross, 1990), but slightly modified from this previous assessment in that all liquid was removed from stomachs before fluid volume estimates were made.

Environmental parameters for each capture were taken from daily records of sea temperature, water visibility, wave height and current direction, all routinely collected by NSB staff during daily net inspections of each netted beach. The physiography of each net installation was obtained from underwater surveys undertaken by staff of the NSB. Thus, for each species a serial matrix containing biological, environmental and physiographic data for each captured dolphin was constructed.

The data matrix (Table 1) for each dolphin species consisted of both ordinal and nominal data, of different measurements and scales and was analysed using both univariate and multivariate statistical techniques. The latter analyses were found to be unsuitable because of the mixture of ordinal and nominal data and the serial nature of the matrices, which, importantly, contained data only for captured dolphins. Consequently, the individual matrices were analysed separately, such that each factor field within the matrix was examined for serial randomness and skewness. Where either of these tests showed significant patterns, this was taken to be an indicator of the significance of that factor field.

Table 1

Variables included in the matrix of biological, environmental and physiographic parameters examined to determine factors contributing to the catch of dolphins in shark gillnets off Natal.

1. Locality of capture.
2. Year of capture.
3. Month of capture.
4. Day of capture.

Biological characteristics

5. Sex (male or female).
6. Age/Maturity class (calves, juvenile males, juvenile females, resting females, pregnant females, lactating females, mature males).
7. Weight (kg).
8. Length (cm).
9. Age (GLGs).
10. Number of animals caught simultaneously.
11. Percentage fullness of stomach.

Environmental characteristics

12. State of the tide (two days either side of spring tide, two days either side of neap tide, mid tide).
13. Water visibility on day before capture (m).
14. Water visibility on day of capture (m).
15. Difference between 13 and 14.
16. Temperature on the day before capture (°C).
17. Temperature on the day of capture (°C).
18. Difference between 16 and 17.
19. Current direction (northerly, southerly, offshore).
20. Swell height (m).

Physiographic characteristics

21. Net in which caught (locality specific).
22. Channel at the net.
23. Reef under the net.
24. Reef in the net area other than under net.
25. Type of reef (bare rock, flora covered).
26. Substratum type (rock, rock+algae, rock+sand, sand, mud).
27. Distance of net from shore (m).
28. Depth of water at net (m).

RESULTS

Between January 1980 and December 1988, 250 bottlenose, 290 common and 53 hump-backed dolphins were retrieved from the Natal shark nets (Cockcroft, 1990). The geographic distribution and length and sex composition of these dolphins have been previously described (Cockcroft, 1990) and these results are not presented again here. Where variables within either the common or hump-backed dolphin capture matrices appeared significant, they are presented here. Additionally, those variables apparently significant in bottlenose dolphin capture (Cockcroft, 1992) were analysed for common and hump-backed dolphins and the results are presented here.

Biological characteristics (variables 5 to 11 – Table 1)

Stomach fullness

The degree of stomach fullness of captured bottlenose dolphins was assessed by Cockcroft (1992), but is re-assessed here for comparison with common and hump-backed dolphins.

Regressions for plots of measured stomach fluid volume against dolphin weight are given for all three species (Table 2) and have the form:

$$\text{Stomach volume} = a + b \times \text{dolphin weight}$$

All three species showed a high correlation between the measured fluid volume of the stomach and body weight. Mean common dolphin stomach fullness was calculated as 16.3%, with a modal value of about 12%. The values for hump-backed dolphins were 11.7% and 9.8%, respectively. A re-calculation of these values for bottlenose dolphins show that mean stomach fullness was 35.7%, while modal fullness was 23.7%. The latter mean fullness figure is some 30% less than that calculated for bottlenose dolphins by Cockcroft (1992), but reflects the proportion of solid remains in the stomach once all liquid was removed, whereas the original estimates were made without removing residual liquid.

Table 2

The relationship and correlation between the measured maximum fluid volume of a dolphins stomach and its weight (cf. text). Regressions have the form: Stomach volume = $a + b$ x dolphin weight.

	a	*b*	*r*	*n*
Common dolphin	-2456.75	58.00	0.86	29
Bottlenose dolphin	-1017.92	39.79	0.72	32
Humpback dolphin	0	61.38	0.91	16

Group capture

Captures retrieved from the same net on the same day were considered to be group or multiple captures and treated as single events, although the precise time of any capture was unknown.

Of the 250 bottlenose dolphin captures, 186 (74.4%) were single captures, while on 32 occasions (64 dolphins – 25.6%) two dolphins were captured in the same net and on the same day (Cockcroft, 1992). Of the 32 double captures, 25 (50 dolphins – 20% of total catch) were apparently of mother and calf pairs. The relationship of one of these pairs and three others captured subsequently has been verified electrophoretically (Durham *et al.*, In press).

Of the 216 common dolphin captures for which accurate capture dates are available, single captures occurred on 104 (48.1%) occasions. Multiple captures accounted for 112 (51.9%) captures; 29 (58 dolphins) double captures, three of three dolphins, one of four dolphins, three of five together, two of six together and two of seven dolphins captured in the same net on the same day. Of the 112 multiple captures, only nine included calves small enough (<155cm) to be considered under maternal care and possibly captured with their mothers.

The date of capture was known only for 43 of the hump-backed dolphin captures. Of these, 37 (86%) were single captures, while in three (six dolphins – 14%) instances mother and calf pairs were captured. The relationship of two such pairs captured during 1989 has been established electrophoretically (Smith, unpublished data).

Environmental characteristics

No correlation patterns were found for the majority of environmental parameters (variables 12 to 20 – Table 1) in either the hump-backed or common dolphin capture matrices. The results of analyses for those factors which appeared of significance in the capture of bottlenose dolphins are, however, presented here.

Current direction

The majority of bottlenose dolphins were captured on days when the current direction was significantly different to that normally prevailing (Cockcroft, 1992).

The majority (82%) of common dolphin captures occurred during the months June through September, inclusive. Consequently, the frequency of current directions at which common dolphins were captured was compared with the frequency of actual current directions for these months only. The distribution of current directions in the common dolphin capture matrix (63.7% southerly and 36.3% northerly) did not differ significantly from the actual distribution in the environmental data (61.4% and 38.6%, respectively) ($Chi^2=0.26$, $p>0.01$).

Over 70% of all hump-backed dolphins were captured at the four northernmost netted beaches (Cockcroft, 1990) and, therefore, current direction distributions in the capture matrix were compared only with those for these beaches. There was a significant difference between current direction distributions in the capture matrix (29% northerly and 71% southerly) and the collected data (51% and 49%, respectively) ($Chi^2=19.5$, $p<0.01$).

Temperature and turbidity

The seasonality of bottlenose dolphin capture showed a direct correlation with seasonal temperature, but not with seasonal water turbidity (Cockcroft, 1992).

A similar correlation was found for common dolphins, where mean monthly water temperatures, but not mean monthly turbidity, were significantly correlated with capture frequency ($r=-0.64$, $p<0.05$ and $r=0.56$, $p>0.05$, respectively). In contrast, hump-backed dolphin captures at the four most northerly beaches were not significantly related to either mean monthly temperatures ($r=-0.23$, $p>0.05$) or mean monthly turbidity ($r=0.14$, $p>0.05$) at these beaches.

Physiographic characteristics of netted beaches

Cockcroft (1992) found that the physiographic characteristics of net installations (variables 21 to 28 – Table 1) where bottlenose dolphin captures occurred, were apparently of no significance in capture.

Similarly, analyses of the beach physiographic parameters in the common and hump-backed dolphin capture matrices indicated no patterns other than the geographic distribution of captures discussed by Cockcroft (1990). Neither hump-backed nor common dolphins were captured in the same nets repeatedly. Although a large proportion of hump-backed dolphin captures occurred at Richards Bay, there was no significant pattern in sequential captures, i.e. dolphins were not consistently captured in the same nets.

Catch rates

Unlike bottlenose and common dolphins, there was no relationship between the number of hump-backed dolphin captures along the entire coast and the number of nets set at any beach (Cockcroft, 1990). However, catches at the four most northerly beaches were significantly correlated with the number of nets set ($r=0.98$, $p<0.05$). Mean annual catch rates/km of net for bottlenose and common dolphins along the entire netted coast are 0.0074 and 0.0086, respectively. The mean annual catch rate/km of net for hump-backed dolphins at the four most northerly beaches only is 0.0146. Mean annual catch rates/km of net for bottlenose dolphins in areas where estimates of population size are available are: 0.0098 for the estimated 520 dolphins between Zinkwazi and Umhlanga (8.6km of net) (Cockcroft *et al.*, 1992b); 0.0065 for the estimated 350 dolphins between Winkelspruit and Ramsgate (13.3km of net) (Cockcroft *et al.*, 1992a) (Fig. 1).

DISCUSSION

An analysis of net catches reveals a number of important features of the animals captured, some or all of which are likely to be directly implicated in their capture. Obviously, seasonal and geographic differences in net catches will reflect the movements and distribution of a particular species, i.e. a dolphin species will only be captured in areas coincident with its occurrence. Presumably, a species inhabits an area because the environmental conditions and oceanographic features of the area are favourable and provide for its biological needs, including its food resources. Environmental and oceanographic conditions and their fluctuations within an area will be of importance because they may influence the localised distribution of dolphins or their prey and, consequently, the probability of dolphin capture. In addition, given a knowledge of mesh dimensions and, thus, any possible net selectivity, the sex and size composition of any catch will reflect that of the dolphins coming into contact with the nets, giving an indication of any distributional differences or age and sex segregations. Of obvious importance in this context is the behaviour of dolphins when in netted areas. For example, they may be attracted to nets, or display net avoidance behaviour.

Examined individually, and in light of the above, the capture matrices for bottlenose, hump-backed and

common dolphins reveal some possible clues for the capture of these species and also some information on the distribution and life history of each species.

Bottlenose dolphin

The majority of captures were of young suckling or just weaned calves and lactating females, with many of these being mother and calf pairs. Captures were slightly seasonal, occurring mainly during the austral winter and spring. Catches were random in netted areas, excluding the most northern netted beach, and catch rates were directly related to the number of nets set. Captures occurred under significantly different current regimes than those normally prevailing and the stomachs of dolphins were apparently fairly full at capture (Cockcroft, 1990; 1992).

These findings led to the conclusion that a combination of several factors is probably implicated in bottlenose dolphin capture (Cockcroft, 1992). Firstly, bottlenose dolphins were captured in all areas where they and nets co-occur. Secondly, lactating females and often mother and calf pairs, were either abundant within the population or were more prone to capture, possibly because they occur more commonly around the nets. This is supported by feeding studies, which indicate some age and sex class segregation within groups, with lactating females and calves feeding preferentially in the inshore region close to the nets (Cockcroft and Ross, 1990). Thirdly, further evidence for the role of feeding in capture is provided by the observation that the stomachs of most adults seemed quite full at capture, implying that the dolphins were feeding or had just fed. Fourthly, captures were in some way linked to current movement, possibly because this influences prey movements.

Hump-backed dolphin

Catches showed a distinct sex and size class bias, the majority were either adolescents or mature dolphins, particularly large males, with very few young calves or lactating females (Cockcroft, 1990). It is possible that, unlike bottlenose dolphins, hump-backed dolphin lactating females and calves occur only infrequently in the inshore netted region and may not forage there preferentially. As multiple captures occurred only infrequently and all were apparently mother and calf pairs, it seems likely that mothers and calves are in close association when in the inshore area. This is supported by observations in Plettenberg Bay, where young hump-backed dolphin calves seldom move about on their own and normally travel only with larger groups (Saayman and Tayler, 1979).

Most captures were single incidents, of either adolescents or mature, larger males, suggesting that these size and sex classes may be more numerous than other size classes. Alternatively, these sex and size classes could be more mobile and forage close inshore, where they come into contact with nets more often. All inferences, however, indicate some form of age and sex class segregation of hump-backed dolphin groups within the areas they inhabit.

The consistently greater hump-backed dolphin catch at the four most northerly netted beaches and the significant correlation between the number of nets set and catch rates at these beaches, indicates these dolphins are probably more numerous in this area than anywhere else along the coast, a conclusion supported by NSB sighting rates (NSB, unpublished data). These facts also suggest that hump-backed dolphins may either be resident here or frequently pass through this area. Interestingly, bottlenose dolphins are seldom caught at the four northerly beaches (Cockcroft, 1990), indicating that these two species have slightly different habitat requirements, possibly related to the different prey species taken (Cockcroft and Ross, 1983).

Unlike bottlenose dolphins, feeding appears to be of little significance in hump-backed dolphin captures, with the stomachs of most dolphins being almost empty at capture. In addition, neither water temperature nor clarity seem to be significant factors in their capture. This is partly supported by other studies of hump-backed dolphin distribution, which showed that water temperature was not a significant factor in determining seasonal occurrence in Plettenberg Bay (Saayman *et al.*, 1972).

The current direction on the day of capture for the majority of hump-backed dolphins was significantly different to that normally prevailing. Interestingly, a similar but opposite situation pertains to bottlenose dolphin captures. More bottlenose dolphins were captured when the current direction was northerly, although southerly currents were most common at the beaches where entanglements occurred. In contrast, a greater proportion of hump-backed dolphins was caught on days when a southerly current was prevalent, though northerly currents were usual at the four most northern beaches. In interpreting the significance of this for bottlenose dolphins, Cockcroft (1992) surmised that because captures of bottlenose dolphins seemed directly influenced by feeding activity, current direction was implicated as it influences the movement and abundance of prey species. However, given the lack of evidence for a connection between capture and feeding in hump-backed dolphins, this does not appear to apply for this species. Thus, the reasons for the significance of current direction are unknown, although, in Plettenberg Bay, Saayman and Tayler (1979) observed the onset of feeding with the rising tide, presumably because this influenced local prey movements and abundance. It is possible that captures of hump-backed dolphins occurred as they moved close inshore with the rising tide at the onset of feeding. Regrettably, the time of capture of dolphins was unknown, although this may be an important parameter in assessing the contribution of tidal and other rhythmic influences on behaviour and capture (Cockcroft, 1991).

Common dolphin

Common dolphins make a northward, seasonal migration into Natal waters during the austral autumn, returning to more southerly waters in the spring and summer (Cockcroft and Peddemors, 1990b). This migration appears closely linked to the movement of the pelagic shoaling Natal sardine (*Sardinops ocellatus*) into Natal waters (Cockcroft, 1990; Cockcroft and Peddemors, 1990a), as this fish constitutes the major prey of common dolphins in Natal waters (Cockcroft and Ross, 1983; Young and Cockcroft, in press). As a consequence and because the presence of common dolphins in the inshore region is probably influenced by the movement of fish shoals, there were no geographical distributional biases in the catch of common dolphins in Natal (Cockcroft, 1990). Given the probable importance of prey in the movements of common dolphins into netted areas, it is unclear why this was not evident in the degree of stomach fullness, particularly as the highest annual dolphin catch occurred in conjunction with the most extensive fish shoal movement inshore (Cockcroft, 1990).

None of the environmental or physiographic factors

seemed of any significance in common dolphin captures. However, there were clear differences in the sex and size classes of dolphins captured. Significantly greater numbers of female than male dolphins were captured, particularly sexually mature females, and also fairly large numbers of older, weaned calves (Cockcroft, 1990). The sex and size class composition of the population are unknown. But, the preponderance of sexually mature females and older calves in the catch may reflect the composition of dolphins partaking in the annual migration. Cockcroft (1990) has suggested that common dolphin females use the plentiful resources provided by the annual fish migration to wean their calves and replenish their energy reserves for the following pregnancy and lactation. Some further evidence for this is provided by data from a mass stranding of 15 common dolphins at Hluleka (31°47'S, 29°18'E) on 6 December 1990 (mid austral summer). Of these dolphins, only one was a mature male, one was a 179cm weaned male calf and 13 were mature females, of which 11 were pregnant (Cockcroft, unpublished data). If the catch is representative of those dolphins making the migration, it suggests that common dolphins have an age and sex class segregation covering a large area of their distributional range off the east coast of southern Africa.

CONCLUSIONS

Although the examination of the individual capture matrices may provide some clues to the capture of individual species, there are few evident common factors when comparing matrices and the subsequent interpretation of individual catch patterns. As a result, the present data offer only a few possible relationships between the captures of all three species.

In view of the apparent influence of food resources on the movements and distribution of dolphins (Norris and Dohl, 1980), the results of attempts to assess whether dolphins were feeding or not at capture, by using estimates of the degree of stomach fullness, were equivocal and unexpected. Although this could be a product of the rather crude assessment method used, the differences among the three species suggest, at least, that feeding activity or its timing play a different role in the capture of each species. An appraisal of the importance of feeding behaviour prior to and during capture of these and other dolphin species in gillnets needs urgent attention in the effort to understand why captures occur.

However, feeding is not the only reason why dolphin groups may move into certain areas or aggregate (Norris and Dohl, 1980). In addition, these movements are likely to occur following specific entrained rhythms (Klinowska, 1986). Thus, the apparent lack of a pattern in the degree of stomach fullness may imply that, at least in some instances and to a varying degree for the different species, dolphin occurrence at the nets and their capture were not related to feeding. In other words, movement around and aggregation at nets may occur for a number of reasons and at various times during the day, all for different reasons. Consequently, one might not expect to find patterns within the existing capture matrices, although in this light, the observed age and sex class biases may be regarded as evidence for short-term rather than long-term segregations. Obviously, observation and recording of captures and the preceding circumstances would clarify this to some extent. Experimentation with captive animals may also provide insights into the precise circumstances surrounding capture.

Interestingly, all three dolphin species captured in the shark nets show some evidence of age and sex class biases, implying some segregation within areas. Although such segregations are relatively well known (e.g. Wells *et al.*, 1980; Kasuya and Jones, 1984; Monami, 1992) and probably play an important role in determining the composition of catches in an area, the reasons for them and their relevance in these three species are as yet unclear. However, the biases in catch composition obvious in the incidental capture of many cetacean species probably reflect only the occurrence of certain classes in netted areas, i.e. it is unlikely that segregation itself causes incidental capture.

A further common factor found is, of course, that all three species occur in the vicinity of some or all the nets at certain times. Although there are no data on the relationship between net expanse, dolphin numbers and catch rates, it seems likely that an increase in either net expanse or dolphin numbers would increase catch rates and *vice versa*. Some support for this is given by the fact that for areas where population estimates of bottlenose dolphins are available, catch rates appear directly proportional to the number of dolphins present. However, this relationship may be complicated by several behavioural factors including attraction or avoidance of nets, epimeletic behaviour and multiple captures.

The differences in the frequency of multiple captures among the three species may reflect their natural history and the reasons for their capture. Only for the common dolphin were more animals caught in multiple than single captures. Very few bottlenose and no hump-backed dolphin multiple captures occurred, other than mother and calf pairs, implying different social organisation and/or feeding strategies. For both species the multiple captures that did occur involved calves with either lactating females, other adults or adolescents, perhaps reflecting epimeletic behaviour among mothers or 'relatives', and calves (Cockcroft and Sauer, 1990). Nevertheless, the occurrence of multiple captures in all three species implies that, unless all multiple captures occur simultaneously, which is unlikely, one of the two or more dolphins caught must be aware of the other's capture, but is nevertheless captured itself.

This leads to the question of possible capture, escape and recapture. Of the 250 bottlenose, 290 common and 53 hump-backed dolphins captured between 1980 and 1988, none appeared, from external examination, to have been captured before. This suggests that either no escapes occurred or that all escapees avoided subsequent capture. However, on 21 August 1990, a heavily lactating female bottlenose dolphin (PEM N1797) recovered from the nets showed distinct and unmistakable net scars at the insertion of her flippers, indicating that sometime previously, she had been captured in a net and escaped (Cockcroft, unpublished data). As she was not accompanied by a calf, epimeletic behaviour was probably not the cause of her capture in this instance. This limited information suggests that escapes are extremely uncommon and that dolphins are unaware of the danger that nets pose, even after an escape from entrapment.

This raises some interesting questions regarding a dolphin's perception and interpretation of nets and whether they pose a threat. These and other considerations must be addressed if active and passive devices are to be used to 'caution' dolphins against nets and prevent their incidental capture. Given the largely unsuccessful results of previous attempts to eliminate captures through such

methods (Hembree and Harwood, 1987), it may be that these are intractable problems and that alternative methods of capture prevention may be necessary.

The apparent lack of common factors implicated in the capture of bottlenose, common or hump-backed dolphins is interesting. It implies that either the data collected and examined did not include the salient parameters, or that there is little or no connection in the reasons for capture between species. Although observations of the circumstances immediately prior to and at the precise moment of capture would provide essential information on the mechanisms of capture, the evidence from this study indicates that capture simply results from the presence of dolphins around nets, for whatever reason. This raises the obvious question, to which we have no single consistent answer, of why dolphins occur around nets? Intuitively, it seems likely that this would be a function of the specific biological needs of the various species, including that to harvest food resources (Beverton, 1985).

If dolphin incidental captures are inevitable wherever they and nets co-occur, how can captures be reduced or prevented? One obvious solution is the removal of all nets where dolphins occur, although for many areas, this may be impractical for socio-economic reasons. Another alternative is net modification.

For shark nets off Natal, Cockcroft (1990; 1992) has suggested that one method of reducing catches of bottlenose dolphins would be to increase the mesh size, because the body dimensions of the smallest dolphins caught were the same as that of the net mesh. This solution would be of no obvious benefit to common and hump-backed dolphins however, where the smallest dolphins captured were substantially larger than the size of the net mesh. For those species, the removal of all shark nets seems warranted. It is unwise to adversely effect the inshore environment (van der Elst, 1979), including the depletion of dolphin stocks, when an annual average of only three shark attacks, of which 0.7 are fatal, occurs along the entire South African coast (Compagno *et al.*, 1989). Unfortunately, the relevant authorities are reluctant to accept this solution, citing the 'fears' of the tourists and the possible loss of tourist income should nets be removed. Given this and the data presented here, selective net removal from certain areas and in specific months, in combination with net modifications, could reduce the overall incidental catch of these three species.

This study suggests that the management of specific 'fisheries' needs to be formulated on a species specific level but that this becomes difficult or almost impossible where dolphin catches are species diverse. Consequently, a compromise may be inevitable, where the marine environment may increasingly suffer the same fate as the terrestrial and be partitioned into conservation or natural areas and exploitable zones. How this could be done given the large migrations of many dolphin species is unclear. It is possible that these reserves could be modelled on defined areas, as terrestrial refuges are, or they may be more liberally defined to encompass isobath boundaries for coastal dolphins or temperature boundaries for oceanic species.

In conclusion, although the examination of the catch and biology of an individual species provides some insight into the reasons contributing to its capture, there appears to be few or no common causal factors, apart from the presence of nets and dolphins in the same area. The incidental entanglement of dolphins, and perhaps other marine mammals, thus appears to be simply a function of their presence in netted areas. The mechanisms and causes of capture may differ or be similar between species. As a consequence, the solution to the problem lies in either the removal or selective removal of all nets or the establishment of areas or boundaries within which fishing is not permitted. In view of the danger gillnets pose many dolphin stocks and species (IWC, 1994), solutions to the problem are urgent.

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A Review of Studies on Attempts to Reduce the Entanglement of the Dall's Porpoise, *Phocoenoides dalli*, in the Japanese Salmon Gillnet Fishery

Yoshimi Hatakeyama, Ken Ishii, Tomonari Akamatsu

National Research Institute of Fisheries Engineering, Ebidai, Hasaki-machi, Ibaraki, 314–04, Japan

and

Hideo Soeda, Tetsuya Shimamura and Takahito Kojima

College of Agriculture and Veterinary Medicine, Nihon University, 3–34–1, Shimouma, Setagaya-ku, Tokyo 154, Japan

ABSTRACT

Dall's porpoises, *Phocoenoides dalli*, were often incidentally caught in the Japanese salmon gillnet fishery in the North Pacific. In order to investigate the reasons for entanglement, their auditory characteristics and capabilities and their responses to gillnets were examined. Dall's porpoises emit short high frequency pulses ranging from 135 to 149kHz, with a pulse width of 50 to 60μs and a source level of 165 to 175dB re 1μPa. When chased toward a gillnet in open sea, they have been observed to change their swimming direction to avoid it by either swimming along it or diving underneath it. They are thus capable of avoiding entanglement. Estimated target strengths of a float, leadline, lead and netting were –25, –33 –39, and –55dB, respectively. Approximate estimates of Dall's porpoise's detection ranges for the leadline and netting were found to be 30 and 8m, respectively. Active and passive acoustic devices were tested with the aim of reducing the incidental catch. Four types of sound generator (SG-1 to 4) in the frequency range of 20 to 150kHz were developed on the basis of the frequency components of clicks and observed responses to sounds. Air-tube threads to increase the net target strength were also used. Incidental catches were monitored on the fishing ground and catch decrease rates (DRs) estimated. The DRs of the sound generators (with the exception of SG-4) were 3–16% and the DR in the case of the gillnet with three air-tube threads in the centre portion was 8–20%. As for SG-4, entanglement was concentrated in the portion of the net where SG-4 was not attached and the sound wave was weak. The target strengths of a rope, vinyl string and blister sheet are much larger than that of the netting. Experimental operations using gillnets equipped with these reflectors were conducted on the fishing ground. The detection abilities of other cetaceans, such as the harbour porpoise (*Phocoena phocoena*), white whale (*Delphinapterus leucus*) and the bottlenose dolphin (*Tursiops truncatus*) were also examined.

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; NORTH PACIFIC; DALL'S PORPOISE; HARBOUR PORPOISE; WHITE WHALE; BOTTLENOSE DOLPHIN; ACOUSTICS; BEHAVIOUR; MORPHOLOGY/ANATOMY; LIVE-CAPTURE; REVIEW.

INTRODUCTION

In the Bering Sea and the North Pacific, marine mammals, particularly Dall's porpoises (*Phocoenoides dalli*), are often incidentally caught in the gillnets used by the Japanese mothership salmon fishery. There are two 'forms' of Dall's porpoise, the *truei*-type and the *dalli*-type (Kasuya, 1978; Miyashita and Kasuya, 1988; Amano and Miyazaki, 1992). Only the latter is taken in the mothership fishery.

The Japanese mothership salmon fishery targetted salmon using driftnets in the North Pacific. From 1978–1986 four fleets operated, each comprising one mothership (7,000 to 9,000GRT) and 43 catcher boats (96 to 127GRT). Each catcher boat used 15km-long gillnets with a net depth of 6m. The fishing season lasted from 1 June to 31 July.

The US Fishery Conservation and Management Act (FCMA) became effective on 1 March 1977. In conjunction with its implementation, the 1972 US Marine Mammal Protection Act (MMPA) was amended and its applicable range was increased from 12 to 200 n.miles from the US coast. It became mandatory for Japanese fishing fleets operating within the US 200 mile zone (EEZ) to obtain a general permit under the MMPA. After several hearings, a permit was issued in June 1977.

Article X of the International Convention for the High Seas Fisheries of the North Pacific Ocean includes a provision concerning scientific research activities with respect to marine mammals incidentally caught in fishing for anadromous species. Japan and the USA signed a Memorandum of Understanding (MOU) on Dall's porpoise in connection with Article X. Thereafter, the MOU was revised and signed twice (on 3 June 1981 and 5 June 1984) corresponding to each renewal of the permit for the incidental take of Dall's porpoises in the mothership salmon fishery in the US EEZ.

The MOU required that studies be conducted on gear modification to reduce the incidental catch rate of marine mammals. In accordance with the 1981 amended MOU, field trials were initiated with modified gear. In addition, the December 1982 amendment to the North Pacific Fisheries Act (NPFA) required that the use of new fishing gear and/or techniques to reduce porpoise mortality should be phased into the commercial operations according to a specified timetable. The amendment also stipulated that the General Permit (1981–3) issued should be extended for three years until 9 June 1987. The number of Dall's porpoise taken by Japanese vessels in the US EEZ was limited to 5,500 per year from 1981 to 1986.

In order to fulfil these requirements, in 1981 the National Research Institute of Fisheries Engineering (NRIFE) began a programme entitled 'Urgent studies on the development of techniques to prevent incidental catch of marine mammals in the salmon driftnet fisheries' (National Research Institute of Fisheries Engineering, 1982). Since 1982, NRIFE has cooperated with Nihon

University and Kamogawa Sea World. In 1989, the Ocean Research Institute of University of Tokyo was commissioned by the Fisheries Agency of Japan to examine the physiology and anatomy of the eyes of the Dall's porpoise.

In addition, the mothership salmon fishery industry organised a 'Marine Mammal Project Team' comprising experts in fishing operations. They conducted field trials from 1981 to 1987. In accordance with the provisions of the MOU and the NPFA, these two groups conducted basic biological and acoustic studies and tested modified gear in fishing operations in order to try to prevent incidental catches of Dall's porpoises.

A Public Hearing was held at Seattle in the US in December 1986 and a general permit was again issued to the fishery in May 1987, reducing the quota to a total of 6,039 between 1987 and 1989. However, after a successful law suit by the environmental conservation groups and Alaskan native peoples against the US Government, the general permit was suspended. Since then, a small number of Japanese catcher boats have operated in a limited area (outside the US and Soviet EEZs).

This report summarises documents submitted to the International North Pacific Fisheries Commission (INPFC) and recent papers in Japanese on the efforts to reduce the incidental catch problem.

ACOUSTIC STUDIES

Until recently, only four acoustic studies of Dall's porpoise had been published. Three reported only low frequency clicks with a peak energy below 10kHz (Ridgway, 1966; Schevill *et al.*, 1969; Leatherwood and Ljungblad, 1979). The fourth, Awbrey *et al.* (1979) described detailed characteristics of the high frequency clicks used for echolocation with peak energy levels of between 120–160kHz; the source level of the clicks was not measured. Those authors also estimated the Dall's porpoise's auditory capability from cochlear morphology. On the basis of an estimation of the target strength of the net and a porpoise's ability to detect echoes from the net, they doubted whether Dall's porpoises could acoustically perceive monofilament gillnets.

Examination of the vocal and auditory abilities of Dall's porpoises and observations of their responses to sound and objects such as gillnets can most easily be carried out on captive animals. To this end, capture experiments were conducted in the winter of 1982/83 along the Sanriku coast near Ozuchi, Iwate Prefecture, and in the summers from 1983 to 1985 in the Sea of Okhotsk foreshore of Utoro, Shari Town, Hokkaido (National Research Institute of Fisheries Engineering, 1982; Taketomi, 1984).

Various methods of entrapment involving harpoons, tailgrabs, hoopnets and drift gillnets were tried. All attempts to live-capture porpoises which approached the vessel were unsuccessful. Furthermore, when three or four vessels tried to chase porpoises towards gillnets, they either scattered or successfully avoided the nets, again resulting in no captures.

On 7 May 1984, three Dall's porpoises from a group of 20 were captured using a mackerel purse-seine 10 n.miles off Hitachi City, Ibaraki Prefecture. Only one was alive on retrieval (a 160cm, 76.5kg, male) and it was put in a pool at the Oarai Aquarium. On 10 May, it was transferred to Kamogawa Sea World where acoustic studies were carried out. However, attempts to feed it with frozen, live or minced fish failed and it died on 19 May (Hatakeyama and Shimizu, 1985).

From 8–13 September 1986, a one-boat purse-seiner fleet (four vessels) chartered by the Japan Marine Fishery Resource Research Centre carried out scouting and capture experiments on Dall's porpoises in the waters off Kushiro, Hokkaido. Three animals were caught on 10 September and five on 11 September with a tuna purse-seine. However, only one (a 220cm male) survived. It was fed for seven days from 10–16 September in a pool in the National Fish Farming Centre for Culture-based Fisheries, Akkeshi Station in which it died. Since it did not beat its tail, two floats were attached to its head so that it could swim slowly by itself (Hatakeyama *et al.*, 1987).

Waveform characteristics of clicks

Dall's porpoises

On 2 June 1982 in calm seas, about 10 Dall's porpoises swam around a stationary salmon research vessel in the Bering Sea. Two to four individuals appeared to be interested in the hydrophone hanging over the port side and repeatedly approached to within 1–2m of it. Recordings were made for about 10 min., during which only the auxiliary engine (310HP) was operating. The results (Hatakeyama, 1983) are listed in Table 1 (No. 1). No low frequency components were found. Data reported by Awbrey *et al.* (1979) are also listed in Table 1 (No. 4) and a comparison with our results shows that: (1) the 'total numbers of clicks' are similar; (2) our maximum 'pulse width' is considerably narrower; (3) the maximum 'interclick intervals' are almost equal; (4) our minimum 'interclick interval' is shorter; and (5) we found that each click consisted of 1 or a series of 2 to 4 pulses whereas Awbrey *et al.* reported that all signals were single or double pulses of constant frequency.

An acoustic study of the animal caught in the mackerel purse-seine off Hitachi City was carried out at the Oarai Aquarium on 9 May and at the Kamogawa Sea World on 10 May 1984. A total of 33 series of clear clicks was obtained during a 72 minute recording. No whistles or clicks with frequencies below 20kHz were found (Hatakeyama and Shimizu, 1985). The analysed results are listed in Table 1 (No. 3). Both frequency and sound pressure were smaller than those measured in the Bering Sea. These differences are probably due to the stress of capture and the small pool environment. The sound pressure of the clicks emitted by the Dall's porpoise was the same as found for a bottlenose dolphin in the pool. The high frequency and the narrow pulse width of the clicks emitted by the Dall's porpoise is advantageous in detecting smaller and finer objects (such as the thread of a net) and estimating distances between objects with greater resolution. However, the narrow beam width due to the high frequency is a disadvantage when searching quickly through a wide area and this may create problems in avoiding wide obstacles such as a gillnet through 'instantaneous' judgment.

Animals reared in small pools or net enclosures need not echolocate at maximum power and probably adjust their normal acoustic activities to suit the environment. The source level of clicks was low in the pool and high (when presumably paying much more attention to the environment) in the open sea.

A Dall's porpoise was caught by harpoon in the North Pacific Ocean in June 1986. Recordings were made for one hour. Ten or more emissions of clicks were found in the tape. The clicks were analysed with an FFT analyser (Ishii

et al., 1989) and the results are listed in Table 1 (No. 2). As the animal was seriously wounded, it is difficult to compare the data with those for free swimming animals. If the sounds were emitted intentionally for help or alarm, they may be of value in playback experiments.

On 27 January 1983, a 190cm male of the *truei*-type was caught by harpoon. Recordings were made for about 8 minutes at a distance of 3–4m, during which over 10 series of clicks were recorded. Four series of clearly recorded clicks were selected and three clicks of each series were analysed by Hatakeyama (1984a). The analysed results are listed in Table 1 (No. 5).

Harbour porpoise in captivity

Although it is difficult to catch Dall's porpoises and keep them in captivity for any length of time, the related harbour porpoise (*Phocoena phocoena*) has been successfully kept in several aquaria. We have therefore attempted to obtain information on the echolocatory ability of the Dall's porpoise by analogy through experiments using harbour porpoises. There has been considerable amount of published information on the clicks and echolocatory abilities of harbour porpoises (van Dudock, 1960; Busnel *et al.*, 1965; Busnel and Dziedzic, 1967; Zaslavskii *et al.*, 1969; Andersen, 1970a; b; Dubrovskii *et al.*, 1971; Møhl and Andersen, 1971; Pilleri *et al.*, 1980), although their reactions to gillnets have not been previously reported.

In January 1987, therefore, we studied the waveform characteristics of clicks emitted by three captive harbour porpoises kept in a pool (17x12x3.5m) at Kamogawa Sea World (Hatakeyama *et al.*, 1988). Horse mackerel, *Trachurus japonica* and sillaginoid, *Sillago sihama* (both species are 10–15cm in length) were thrown into the pool and clicks were recorded while the porpoises approached and echolocated the fish.

Four series of clicks with considerably high sound pressure were selected and 48 clicks were analysed in total. Our results and those of Møhl and Andersen (1971) are listed in Table 1 (No. 6 and 7). Our source level is about 20dB higher, probably because the pool was larger and because the three porpoises competed for the food.

Detailed analyses indicated the following characteristics: (1) the band width of clicks ranged from 9 to 33kHz with a mean value of 21kHz; (2) the clicks included about 9 cycles of narrow band sine waves which gradually increased and usually reached a maximum at the fourth cycle.

In comparison with the Dall's porpoise, the frequency of clicks emitted by the harbour porpoise is 12kHz lower, the pulse width is 11μs shorter and the click is a single pulse. The mean frequency of the peak spectrum is 130kHz and close to the upper hearing limit of the harbour porpoise (Andersen, 1970a). This suggests that the harbour porpoise lays more stress on reflectivity and distance/angle resolution than on auditory sensitivity.

ABILITY TO DETECT GILLNETS

Reaction of Dall's porpoises to gillnets

The following reactions were observed when chasing Dall's porpoises toward the gillnet in the capture experiment conducted in the coastal area off Hoddaido in August 1983 (Taketomi, 1984). In general, the porpoises changed their swimming direction in front of the net and then swam along the net or dived to avoid it. However, in one case two Dall's porpoises swam ahead of a third and dived about 4–5m in front of the net but the third rushed into the net, broke through it and escaped as shown in Fig. 1.

Dall's porpoises were observed swimming around gillnets from a salmon research vessel that was retrieving gear in July 1983 (Hatakeyama and Shimamura, 1984). Two out of three Dall's porpoises in a school dived under the net but the third one following became entangled in the intermediate portion of the net. On two occasions a Dall's porpoise was seen to pass through a hole (1.5m wide x 1.0m high) in the upper portion of the net without changing its swimming speed (3–4ms^{-1}).

In contrast to the above examples, on one occasion at sunset in June 1989, we observed the first of a group of three Dall's porpoises rush into and break through a net while the two following animals changed their swimming direction in front of the net.

These observations suggest that, during daytime at least, porpoises are able to detect the presence of the net. Although both visual and acoustic cues may aid in detection, the former are probably weak given the generally cloudy conditions and the nature of sea water. It seems that Dall's porpoises have sufficient echolocatory ability to recognise nets and even small holes in the netting, and thus that entanglements arise because they are not always echolocating and searching when swimming in open sea. In addition, animals which approach the net perpendicularly at high speed can break through it; entanglement probably occurs if the angle of approach is acute and/or they are swimming slowly. The problems may be exacerbated at night, particularly during 'sleep'. This should be studied further and, for example, it should be ascertained whether they swim slowly near the sea surface while sleeping.

Table 1

Waveform characteristics of clicks.

No.	Species	Environment	Peak frequency (kHz)	Source level (dB)	Pulse width (μs)	Interclick interval (ms)	Total no. of clicks in a series	Remarks	Reference
1	Dall's porpoise	Open sea	135-149	165-170	50-60	8-150	9-47	Free swimming	This paper
2	Dall's porpoise	Open sea	125-135		70	15-70	36	Caught by harpoon	This paper
3	Dall's porpoise	Pool	90-115	155	15-60	9-48	64-176	Caught by seine	This paper
4	Dall's porpoise	Open sea	120-160		50->1,000	13-143	9-40	Free swimming	Awbrey *et al.* (1979)
5	True's porpoise	Open sea	122-136	137-168	40-210	2-14	20-148	Caught by harpoon	This paper
6	Harbor porpoise	Pool	125-140	158-162	29-83	10-123	4-23	Entered the set net	This paper
7	Harbor porpoise	Pool	110-150	132-149	100	20	14		Møhl and Andersen (1971)

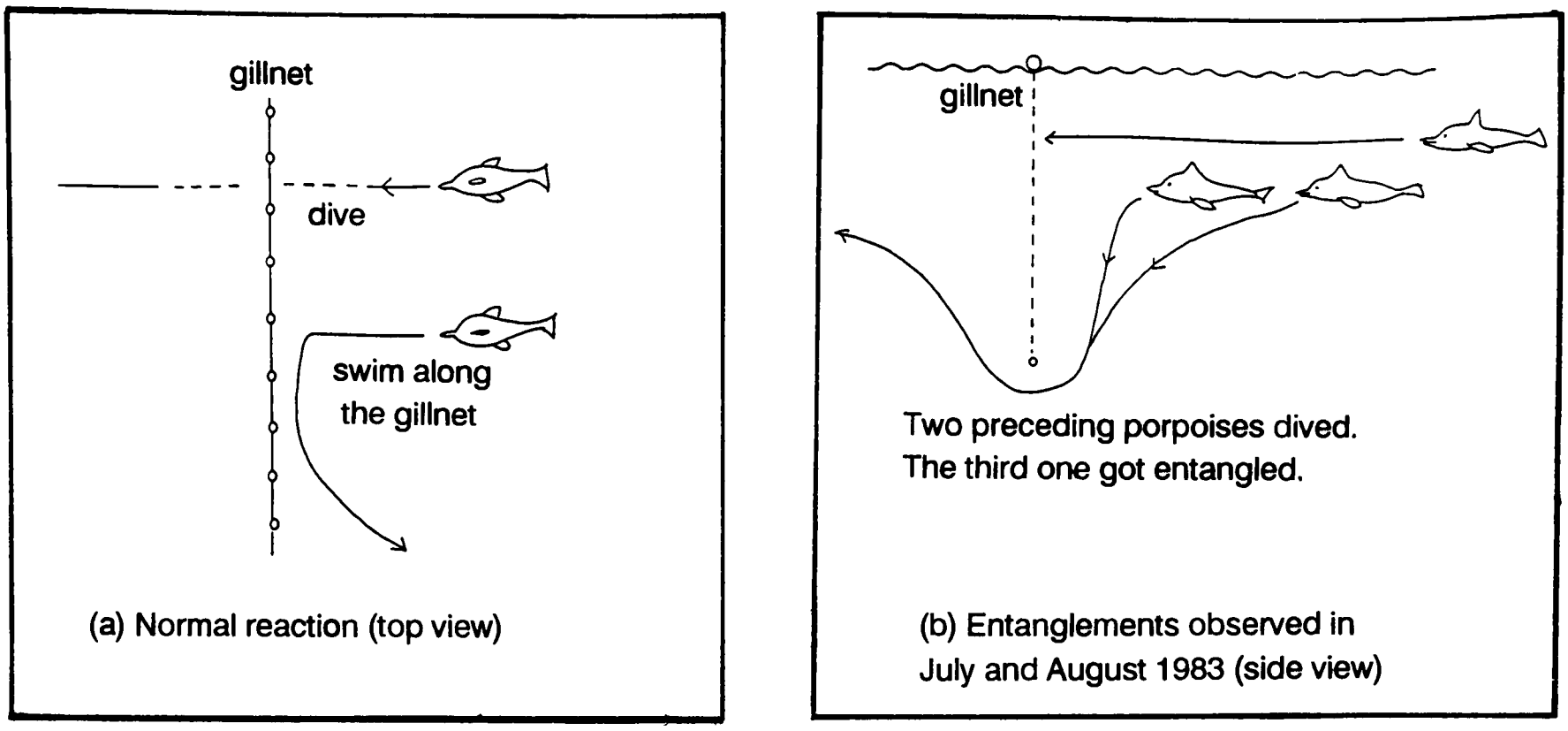

Fig. 1. Reaction of Dall's porpoises to gillnets in the open sea.

Target strength of the gillnet

Hatakeyama (1984b) measured the target strengths (TSs) of the net components (thread, netting, float, lead and line) using ultrasonic pulses (143kHz, pulse width of 100μs) similar to those of the clicks of Dall's porpoise. The results are given in Table 2.

The transmitting directivity was 16° at 6dB down point and the distance between the transmitter and reflector was 1m. The diameter of the ultrasonic beam at the position of the reflector was 28cm. The reflected wave was measured with a hydrophone (*B&K* 8103) whose receiving directivity was broad at 143kHz.

The results showed that the TSs of float, lead, leadline and netting were –25, –39, –33 and –55dB, respectively. The float and leadline reflect sound waves which are 10 to 30 times greater than those reflected by the netting. Pence (1986) reported that the TS of netting was –50dB at a frequency of 200kHz and a 3dB beam width of 20°.

To compare his result with ours, it is necessary to correct for the differences of the beam width (ϕ) and frequency (f) between the two measuring systems. On the condition that $\phi$is narrow and an amplitude of a reflected wave is proportional to the square root of an area of a reflecting portion of the netting, the TS is proportional to log ϕ. The TS is also proportional to $20\log f^{3/2}$ (Welsby and Goddard, 1973). The corrected TS is –56dB, almost equal to our result.

From the relationship between the TS and the length or area of the reflector in the beam, the TSs for a unit length of the leadline and for a unit area of the netting are –27 and –43dB, respectively.

The mesh size of the net is 114mm and the total area of the netting in the beam is 620cm^2. The total length (L) of the nylon monofilament in this area is about 2m. The TS of coiled nylon monofilament (total length 10m) is 54dB as shown in Table 2. Since the TS is proportional to log L, the TS of the netting without a knot is estimated to be –61dB. If the diameter of the knot is 2mm, its TS is –80dB following Rayleigh (1945). There are 20 knots within this area and the presence of knots will affect the TS, depending upon the phase of the reflected waves from the knots.

In 1984, directivities of ultrasonic reflection from the float and leadline whose TSs were large, were measured for 50 and 100kHz pulses. The maximum target strength (TS_{max}) and the angle width (α) at which the TS becomes 6dB smaller than the TS_{max} were obtained (Hatakeyama and Ishii, 1985). For example, TS_{max}'s and α's of the float, lead and leadline at 100kHz were –27dB and 5°, –35dB and 60°, and –32dB and 9° respectively. An example of the reflection directivity of the float at 100kHz is shown in Fig. 2.

Although the reflection from the float and leadline is strong perpendicular to their long axis (0°), when angles become

Table 2

Target strengths, materials, sizes and weights of measured samples.

Measured sample	Target strength(dB)	Material	Size and weight*
Commercial monofilament	-55	Nylon	d=0.5m, ms=114mm, a=148x185cm
Commercial monofilament	-54	Nylon	d=0.5mm, l=10m, ϕ=11cm, t=28
Lead	-39	Lead	d_1=21mm, d_2=10mm, l=31mm, w=75g
Float	-25	Vinyl chloride	Max d_1=46mm, d_2=9mm, l=154mm, w=50g
Leadline	-33	Poli propilene	d=7mm, l=69cm

* ms = mesh size; a = area; d = diameter; d_1 = outer diameter; d_2 = inner diameter; ϕ = diameter of coil; t = number of turns; l = length and w = weight.

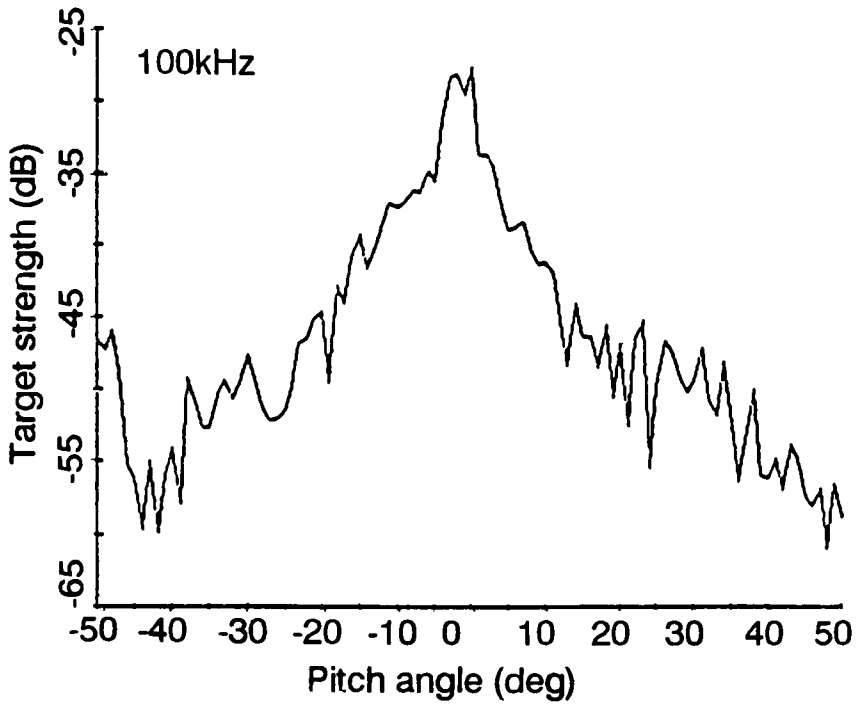

Fig. 2. Reflection directivity of a float.

larger than around 10°, the TSs decline suddenly and reflections become as weak as those from the netting. At these angles the detection range of the porpoise is short.

Maximum detection range of Dall's porpoise

A key parameter that must be determined is the distance at which Dall's porpoises can detect a salmon gillnet.

There are two ways of calculating the maximum detection range. In the first, the range (R_1) is estimated on the assumption that the auditory threshold, corrected for click duration, is equal to the received echo level (Hatakeyama, 1984b). In the second, the range (R_2) is calculated by the sonar equation in which the detection threshold (DT) is determined from data of detection experiments using bottlenose dolphins (Au, 1988a; b). As the distance between the porpoise and gillnet becomes greater, there is an increase in number of floats and lead, the length of the rope and the area of the netting, that are within the ultrasonic beam. This will result in an increase in the TS of the 'net'.

For the first method, as an approximation, the TSs of the leadline and netting were assumed to be constant at values of –25 and –50dB, respectively and a Dall's porpoise click was assumed to have a major frequency component of 145kHz, a pulse width of 50μs and a source level of 168dB. The absorption coefficient was 37dBkm^{-1}. The auditory threshold of Dall's porpoise at 145kHz was estimated to be 55dB by Awbrey *et al.* (1979) from morphological cochlea data. However, other available auditory data on Dall's porpoise were so few that those for bottlenose dolphins and humans were used to calculate the corrected auditory threshold. As a result, the R_1s for the leadline and netting were 30 and 8m, respectively.

In the second method, the TS is assumed to change with the distance between the porpoise and reflecting object. The noise-limited transient form of the sonar equation applicable to a dolphin was expressed in dBs (Au, 1988a):

$$DT_E = SE - 2TL + TS_E - (NL - DI)$$

where: DT_E = detection threshold; SE = source energy flux density; TL = transmission loss; TS_E = target strength; NL = background noise level; and DI = receiving directivity index.

Transmitting and receiving directivities are closely related to the porpoise's echolocation ability. However, in the absence of available Dall's porpoise data, the two directivities were assumed to be equal to those of the white whale, i.e. 6° (Au *et al.*, 1988). The DI was calculated to be 22dB following Au (1988a). The DT_E is equal to $\log(E_E/N_O)$, where E_E is the echo energy flux density and N_O is the noise spectral density. The average DT_E in the bottlenose dolphin experiments was 10dB.

The R_2s were calculated for three peak-to-peak source levels ($SL_{p\text{-}p}$ = 160, 170 and 180dB) and four noise levels (NL=30, 40, 50 and 60dB re 1μPa^2/Hz). As an example, the DT_E was calculated as a function of the distance for NL=30dB and $SL_{p\text{-}p}$=160dB as shown in Fig. 3. The R_2s for the netting and leadline were found to be 10 and 34m, respectively (Table 3). R_1 is nearly equal to the R_2s for three combinations of NL and $SL_{p\text{-}p}$, namely, 30 and 160dB, 40 and 170dB, and 50 and 180dB.

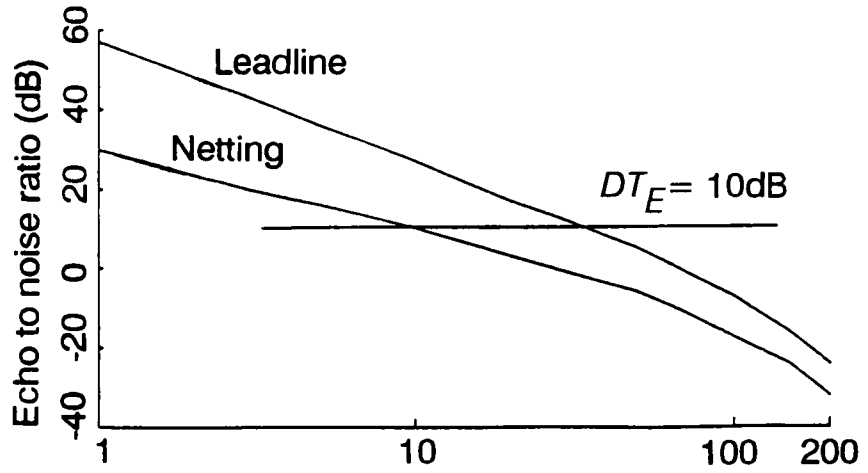

Fig. 3. Determination of maximum detection range, R_2(m), when NL=30dB and $SPL_{p\text{-}p}$=160dB.

Table 3

Maximum detection range $R_2(m)$.

SPLp-p (dB)	Net material	NL(dB) 30	40	50	60
160	Netting	10	3.2	1.0	0.21
160	Leadline	34	16	7.6	3.6
170	Netting	27	10	3.2	1.0
170	Leadline	66	34	16	7.6
180	Netting	67	27	10	3.2
180	Leadline	114	66	34	16

The assumptions inherent in the R_1 estimate have not yet been experimentally determined. However, the DT used in R_2 has been determined from many detection experiments, albeit using bottlenose dolphins. This suggests that the R_2 approach is more reliable but given the paucity of information on the auditory and detection abilities of the Dall's porpoise, both values should be considered as preliminary and be corrected in the future.

Despite this, it seems clear that echolocating Dall's porpoises can recognise objects such as a whole gillnet, at a long distance. On approach they become increasingly careful and can detect thin elements such as the netting itself. Thus echolocating animals should normally avoid getting entangled.

Discrimination between gillnets and fish

As discussed previously, the net TSm^{-2} and leadline TSm^{-1} are –43 and –27dB, respectively. These TSs change with distance, because of their spatial extent in the ultrasonic beam, whereas the TS of a fish does not. The average TS of the fish is assumed to be –30dB.

The TSs as a function of the distance between the porpoise and reflectors are shown in Fig. 4. Assuming that the discrimination threshold between two reflectors is 6dB, the porpoise can discriminate the fish from the netting at shorter ranges (<25m) and discriminate the leadline from the fish at longer ranges (>20m). Pence (1986) reported that at a range of about 30m, a porpoise approaching a net could no longer distinguish it from the floats bobbing on the surface and leadlines suspended 10m below the surface.

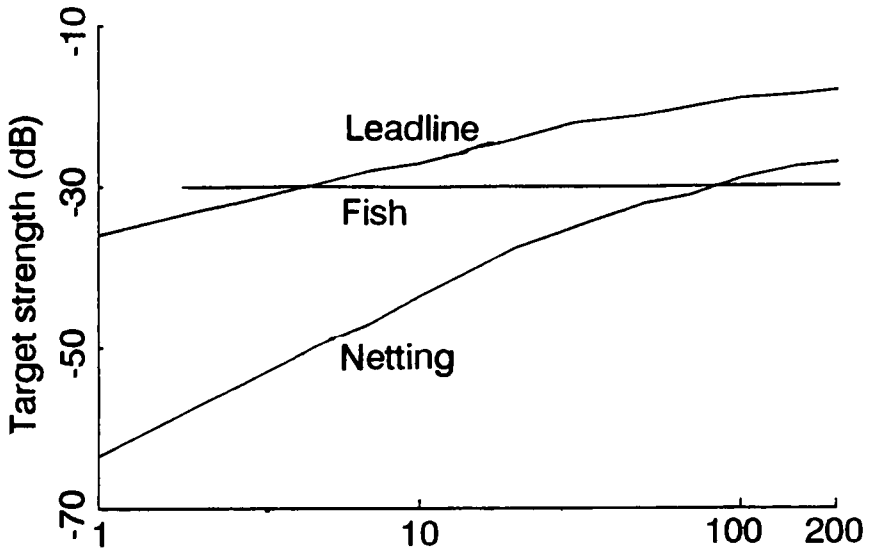

Fig. 4. Target strengths of leadline, fish and netting as a function of distance.

However, it is important to determine whether porpoises can detect two reflectors separately when they sweep echolocation beams from a small TS reflector to a large TS reflector. They appear to have a wide dynamic range of acoustic detection mechanisms, given that they can detect even a small hole in the netting near the surface and also the netting between the floatline and leadline.

Eyesight of Dall's porpoise

The eyesight of Dall's porpoises was examined under a research programme granted to the Ocean Research Institute, University of Tokyo, by the Fisheries Agency of Japan from 1989 to 1991. In 1989, the character of the retina and the distribution of photoreceptors and ganglion cells in the eye was investigated in order to provide basic data for the elucidation of the mechanism of incidental entanglement in gillnets (Murayama *et al.*, 1989).

The eyes were sampled within 24 hours of death. After fixation with Bouin solution or with 10% formalin, the retina including the choroid was excised from the eye cup. Segments of the retina were embedded in paraffin and sectioned at 4 or 12μm and these sections were stained with hematoxylin and eosin. The retina was prepared as a wholemount and stained with cresyviolet. The choroids were stained following the Van Gieson method. All specimens were examined under a light microscope. The results are summarised below.

(1) The retina consists of 10 layers as in other mammals. Much of the pigment in the pigment epithelium layer accumulates in the peripheral area of the retina. Cone and rod nuclei can be distinguished in the outer nuclear layer. The number of cells in the outer nuclei layer is much larger than in the inner, usually considered a characteristic of nocturnal animals.
(2) Density of photoreceptors is high near the optic disk. Few ganglion cells exist near the optic disk but they increase in number with increasing distance from the optic disk. The highest density of ganglion cells (G) is 10–12mm from the optic disk.
(3) The tapetum lucidum in the choroid seems to be composed of collagen. Most tapetum lucidum is found at the fundus and very little at the periphery.
(4) There is little qualitative or quantitative difference between the eyes of the Dall's porpoise and the bottlenose dolphin.

Experiments on the gillnet detection ability of other species

Pacific white-sided dolphin, bottlenose dolphin and false killer whale

In 1981, the ability of three species (1 Pacific white-sided dolphin, *Lagenorhynchus obliquidens*, 3 bottlenose dolphins, *Tursiops truncatus*, and 1 false killer whale, *Pseudorca crassidens*) to detect a gillnet was examined in an experimental pool (20x14x3.5m) at the Kamogawa Sea World (National Research Institute of Fisheries Engineering, 1982).

The results are summarised below. No species differences were determined.

(1) All dolphins detected the existence of the nylon monofilament (0.5mm in diameter) through echolocation.
(2) If one dolphin swam into the salmon gillnet at high speed, it broke through the net without getting entangled. After that, other dolphins approaching the net could precisely detect the hole and pass through the opening in the net.
(3) The individual components of the net such as the floatline, leadline and rope each represented a barrier for the dolphins.

White whale visual recognition of a gillnet

Since small cetaceans may also recognise both nets and their prey visually, at least during daylight at short distances, gillnet recognition experiments (using eyesight only) were carried out in 1982 and 1983 on a white whale, *Delphinapterus leucus*, at the Kamogawa Sea World, by shutting off the ultrasonic pulses of clicks (Soeda *et al.*, 1986).

The underwater irradiance in the pool ranged from 340 to 650lux. The experimental equipment (Fig. 5) was set at a distance of 7m from the start line of the white whale. The animal was conditioned to indicate when it recognised a thread or netting in the equipment. The recognition 'action' was made after stopping briefly in front of the equipment. The recognition time (RT) taken from its first stop to indicating its recognition represents the difficulty in recognition (Table 4).

Experiments with various thicknesses and colours were conducted 20 times or more. Using a chi^2 analysis, significant results were observed for thread itself of 0.6 or 1.2mm diameter and red, blue, black or white, and for net of 0.6 or 1.2mm diameter threads and red, black, white, colourless (air tube thread) and/or green i.e. the whale could recognise some combinations better than others. It could not recognise thread or net of 0.25mm diameter.

Table 4

Mean recognition time (sec) and standard deviation (SD) for each material, white whale visual experiment.

Diameter or colour	Recognition time (Mean±SD) (sec)	
	Thread	Netting
1.2(mm)	1.84±0.53	1.41±0.50
0.6(mm)	2.04±0.52	1.52±0.47
Red	1.61±0.50	0.95±0.18
Blue	1.63±0.41	1.21±0.29
Black	1.53±0.42	1.02±0.25
White	1.87±0.61	1.13±0.50
Colourless		1.24±0.48
Green		1.22±0.29
(Air-tube)		

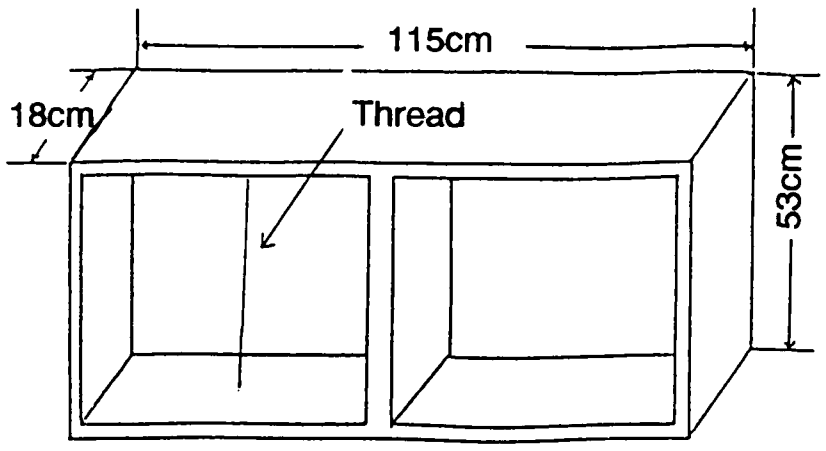

Fig. 5. Experimental equipment to show net materials to beluga.

The *RT* values were shorter for both thread and net of 1.2mm diameter than for 0.6mm, but the differences were not significant. Net was more easily recognised than thread of the same diameter (significant difference in *RT*). Although *RT* values for thread increased through the sequence black, red, blue and white, the only significant difference was observed between black and white. For the net, the *RT* values increased through the sequence red, black, white, blue, green and colourless. There were significant differences between red and blue, colourless or green, and between black and blue or green, i.e. recognition ability differs with net colour.

White whale echolocatory recognition of a gillnet

In 1985, experiments on the acoustic recognition of the netting were conducted using a white whale (blindfolded with eye cups) in the Kamogawa Sea World (Hatakeyama *et al.*, 1986). The netting was folded four times. First, the animal was trained to place its lower jaw on the rack and take a fixed position and direction. It was then trained to detect the object by echolocation only and take different actions according to its judgment as to whether the object was present or not. The object was shown to the animal directly by the trainer.

At a range of 4m, the rate of correct response was 75%. This is probably less than the likely range in the open sea, as disturbance by reflective waves from the concrete walls of the pool and from the hand of the diver increased as the distance became larger.

Bottlenose dolphin behaviour and a gillnet

The reaction of three bottlenose dolphins to a gillnet was observed in February 1986 (Hatakeyama and Ishii, 1987). As shown in Fig. 6, three dolphins were held in a net enclosure which was partitioned equally with a salmon gillnet (45m long, 3m deep, 115m mesh size). They could move freely to other areas either by passing through spaces at both ends of the gillnet or passing under the gillnet or the floating pier. To more easily observe dolphin behaviour at night, a small flashing buoy (15cm in length, 7.5cm in diameter) was attached to one animal. The flash interval was 3sec. The behaviour was recorded on video tape.

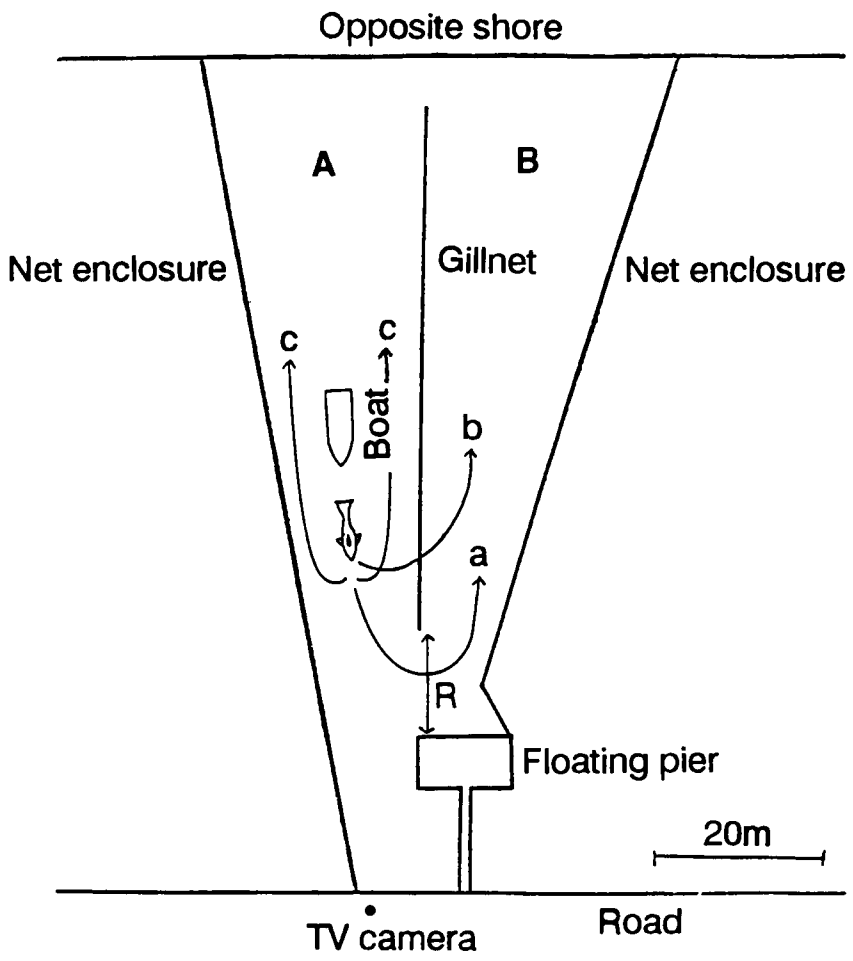

Fig. 6. Layout of the gillnet, pier, boat and dolphin to observe bottlenose dolphin's behaviour to the gillnet.

Three situations were considered: (1) when they were swimming freely under ordinary conditions (day and night); (2) when they were chased; and (3) when they were feeding on fish attached to the gillnet.

Fig. 7 shows the frequency distribution of distances between the gillnet and the dolphins. Dolphins seldom went closer than 1m to the gillnet. For the experiment with chased dolphins, the length (*R*) of the rope between the edges of the pier and gillnet was varied from 0 to 10m. With *R*=5 or 10m, the dolphins passed easily under the rope ('a' in Fig. 6). When *R*=0m, on most occasions the dolphins passed the boat many times ('c'); on one occasion they passed under the gillnet ('b').

For the 'feeding' experiment, weak cotton thread was bound around the tail of 25–28cm mackerels, *Pneumatophorus japonicus japonicus*, and they were hung from the floatline at the side of area B and kept at a depth of 0.5 to 1m. Even when the dolphins were hungry, they fed on the fish attached to the gillnet without getting entangled. They were conducting careful echolocation with a horizontal shake of their heads.

In all categories, the dolphins fully detected the existence of the gillnet and did not get entangled in the gillnet.

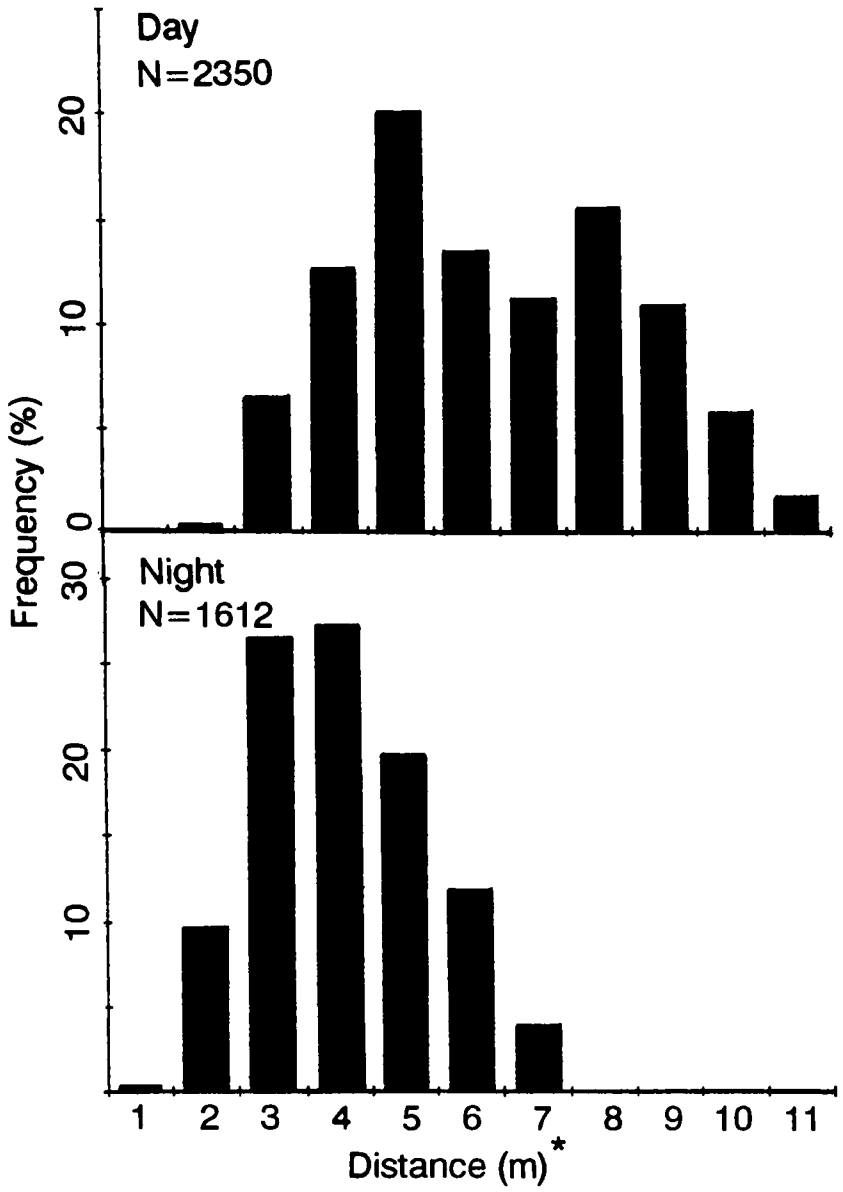

Fig. 7. Distribution of distances between the dolphin and gillnet. *Distance ranging from N-1 to N(m) is regarded as N(m).

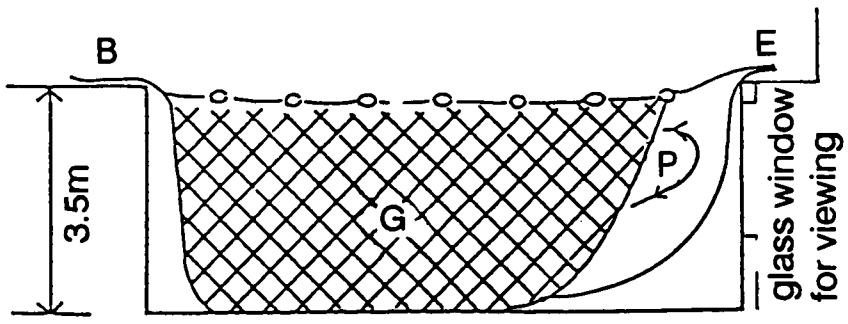

Fig. 8. Side view of the gillnet in the experimental pool.

Reaction of harbour porpoises to gillnets in a darkened pool
Since salmon gillnets are set from evening to the following morning, it is important to observe the reaction of animals to gillnets in a darkened pool; in 1987, this was done for two harbour porpoises using a nightscope in front of the glass window (Hatakeyama *et al.*, 1988).

Table 5

Harbour porpoise behaviour near the gillnet.

Time (h:m:s)	Pattern of behaviour	Swimming speed (cm/s)	Time (h:m:s)	Pattern of behaviour	Swimming speed (cm/s)
18:47:00 [1]			18:59:59	3' lower	
57:48	2' middle	121	19:00:16	3' middle	
58:03	2' middle	97	29	2' lower	106
10 [2]			41	2' lower	166
37	3' lower		53	2' lower	146,225
56	3' lower		1:07	1 upper	
59:09	2' upper	132	26	1 lower	
25	2' lower	94	40	2 middle	
35	2' lower	224	2:03	2' lower	
37	3' middle		22	1 middle	
49	3' upper		32 [3]	4 middle	85

[1] Start time. [2] The net was completely set in the pool. [3] One porpoise got entangled.

All mercury lamps over the experimental pool were turned off. The underwater irradiance was 1.4lux. vertically and 0.9lux. horizontally and conditions were such that nearby netting at a distance of about 2m could be seen dimly by the naked human eye accustomed to the darkness. The salmon gillnet was cut and remodelled to a small-sized gillnet (4m in height, 15m in length) as shown in Fig. 8; there was some space between the rope and net.

Reactions to the gillnet were categorised by pattern (Fig. 9, Table 5). The animals passed between the rope and net eight times and made nine U-turns immediately in front of the net. One porpoise approached the net at a right angle, 4mins 22secs after the net had been set. Whilst turning counter-clockwise immediately in front of the net, its caudal fin became entangled in the middle of the net.

The maximum detection ranges of harbour porpoise for the leadline and netting were estimated to be 9m and 2m, respectively, from an echo level and corrected auditory threshold. The echo level was calculated by taking account of distance-related variations in the areas of the reflecting portions. The auditory threshold of 68dB at 130kHz for a sound of 1.5sec (Andersen, 1970a) was corrected for the pulse width (43μs) of clicks emitted by harbour porpoises.

These estimated detection ranges are based on simplified models of the gillnet and reflection mechanism, and from the auditory characteristics of a dolphin from another family. Gillnets set in the sea will change their configurations in a complex three-dimensional manner. It is clear that further studies are required on the reflection of the ultrasonic pulse waves and the Dall's porpoise's ability to detect the gillnet. However, it should be noted that the echolocation ability of the Dall's porpoise will be better than that of the harbour porpoise because the source level, pulse width and frequency of its clicks are more suitable for echolocation.

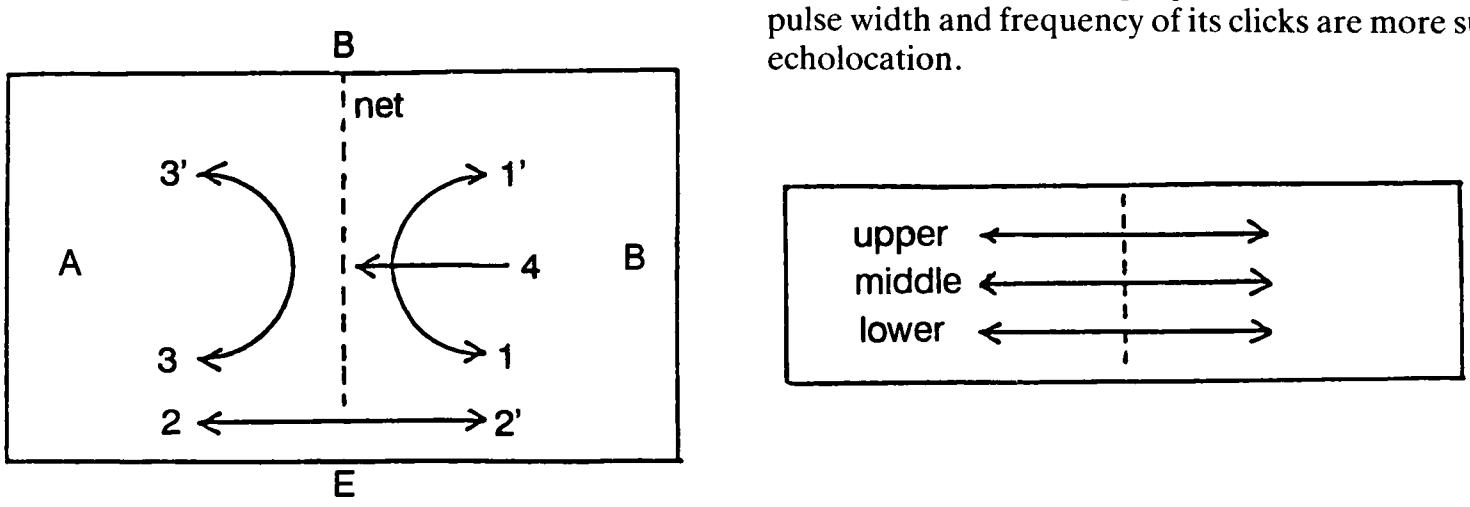

Fig. 9. Patterns of harbour porpoise's behaviours near the gillnet.

RESPONSES TO SOUND WAVES AND OBJECTS

It is important to observe the response of porpoises to a variety of sound waves and objects in order to examine the likely success of different active and passive methods to prevent their incidental catches.

Dall's porpoise on the high seas

Sound projection experiments in the Bering Sea

Although it is difficult to make detailed observations of the behaviour of Dall's porpoises around a vessel in open seas and thus to evaluate quantitatively their responses to ultrasonic pulses, we attempted to do this as little or no such information exists.

The following ultrasonic pulses were projected toward Dall's porpoises which approached the stationary salmon research vessel in the Bering Sea: pulses with frequencies of 75, 115 and 143kHz in July 1983 (Hatakeyama and Shimamura, 1984) and randomly generated 20–50kHz pulses in July 1984 (Taketomi *et al.*, 1985). The specifications of the pulse generators are listed in Table 6.

Swimming behaviour was observed in relation to the ultrasonic beam of the transmitter hung at the side of the vessel (Fig. 10). Results from the 1983 experiments suggested that the response to the 115kHz pulses was strongest. When the source level was 196dB or more, they made a quick U-turn as they became aware of the beam even at distances of 20 to 40m. It appeared that the porpoises regarded the beams as barriers.

At 143kHz, with a fixed sound source level of 210dB and varied pulse width of 100μs to 50ms, the animals showed avoidance responses more frequently to the greater pulse width. Responses to 75kHz pulses were the weakest but frequent avoidance occurred at a source level of 228dB.

In the experiments using randomly generated 20–50kHz pulses, reaction frequently entailed avoiding the ultrasonic beams or making a sudden dive when entering the beams.

Sound projection experiments in the Okhotsk coast off Hokkaido

A series of experiments were carried out in the Okhotsk Sea off east Hokkaido (Taketomi *et al.*, 1985; Ishii et al., 1986). The following types of sound wave were projected toward Dall's porpoise resting at the surface as the boat (about 2GRT) approached: ultrasonic pulses of 24 or 50 kHz and randomly generated 20–50kHz pulses in August 1984 and ultrasonic pulses of 24kHz and a vocalisation of killer whale in August 1985 (Table 6).

A total of 14 trials was conducted, two with 50kHz pulses, two with killer whale sounds, three with randomly generated 20–50kHz pulses and seven with 24kHz pulses. In addition 21 control trials were conducted in which no sounds were emitted while the boat approached. Transmission loss of sound pressure is calculated for each type of sound wave and shown in Fig. 11.

If Dall's porpoises were found 2–3km from the boat, they were slowly approached up to 500–600m. In general, they showed two types of reaction to the boat at this

Table 6

Specifications of sound generators used in the experiments of sound projection.

Frequency (kHz)	Source level (dB)	Directivity (°)	Pulse width (ms)	Interval (ms)	Experiment year (Field)
75	158-228	5x8 [1]	0.5	250	1983 (Bering)
115	177-222	3.5x9	0.5	250	1983 (Bering)
143	150-210	8	0.1-50	10-500	1983 (Bering)
20-50	186 at 35kHz	360x60 at 50kHz	PCM 1-109 (at random) FM continuous	PCM 10-226 (at random)	1984 (Bering, Okhotsk) 1985 (Okhotsk)
24	208	72x58	1-10	30-500	1985 (Okhotsk)
50	214	40	1-10	30-500	1985 (Okhotsk)
0.2-20 (Killer whale)	160	360			1985 (Okhotsk)

[1] Horizontal x vertical.

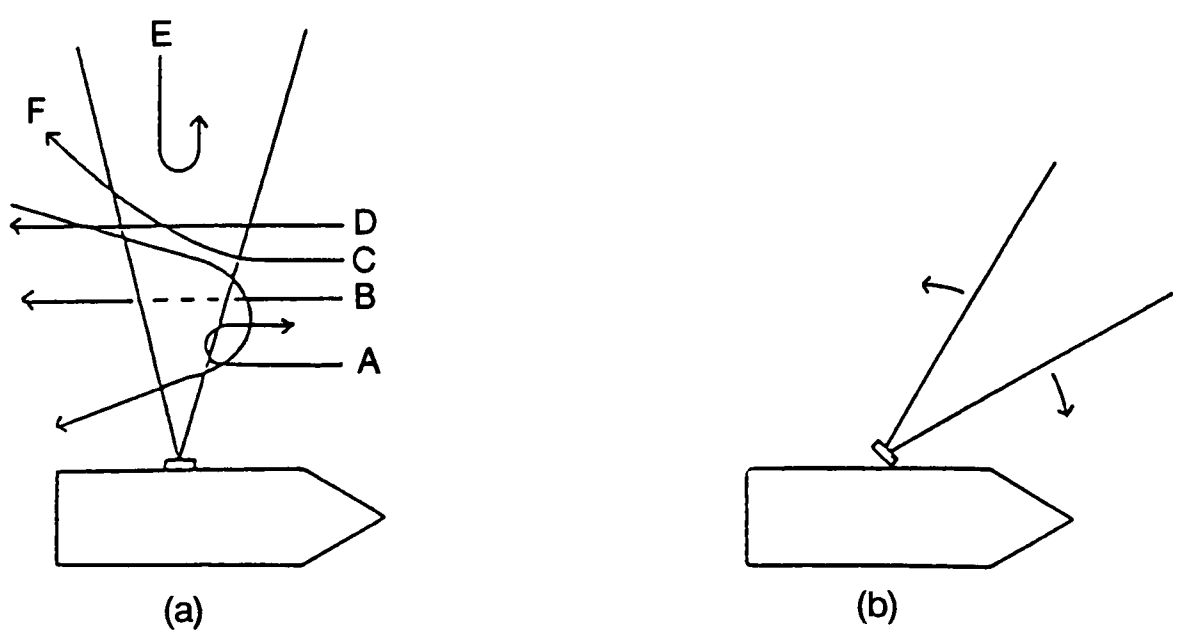

Fig. 10. Ultrasonic beam and swimming patterns of Dall's porpoises. (a) Beam was fixed perpendicularly to the ship. (b) Beam was swept to the porpoise. a-f: typical swimming patterns.

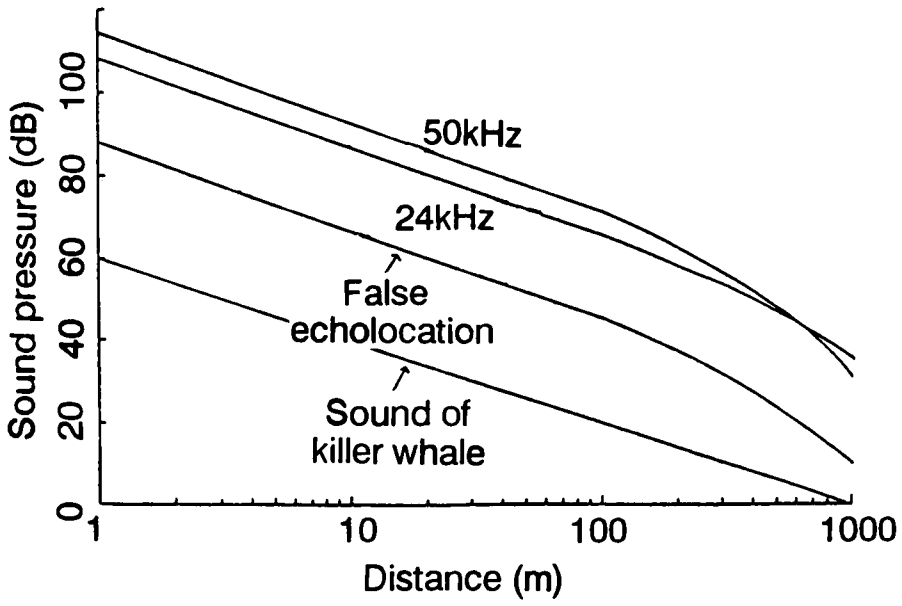

Fig. 11. Sound pressure of each sound projected to Dall's porpoise as a function of distance.

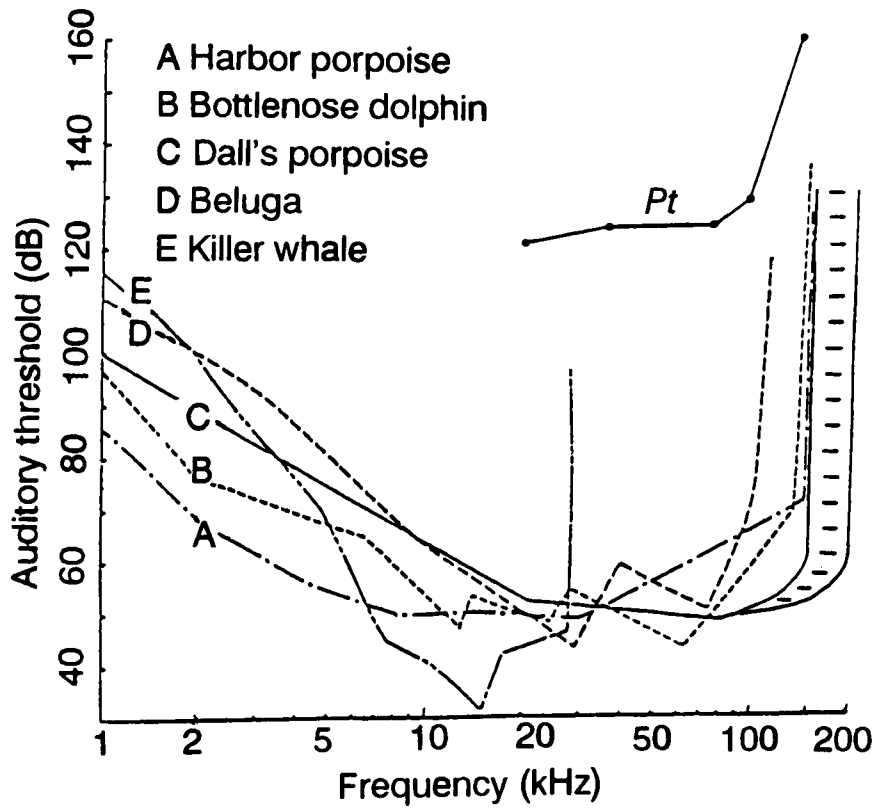

Fig. 12. Sound pressure (*Pt*) where Dall's porpoise began to respond to supersonic pulses. Auditory thresholds of Dall's porpoise and other species. From Awbrey *et al.* (1979).

distance when no sound was emitted: either to remain at the sea surface or to suddenly dive and disappear. When ultrasonic pulses were emitted from distances of 100–700m, the animals immediately became disturbed and swam rapidly away, splashing at each surfacing. No escape response was apparent during the killer whale sound experiments; after 2–3 minutes the animals swam away.

A captured live Dall's porpoise in a pool

Response to sound waves

Hatakeyama and Shimizu (1985) reported the observed responses of a Dall's porpoise captured in May 1984 to sound waves. The animal did not respond to potential food items thrown into the pool (anchovies, *Engraulis japonica* (about 7cm in length) or sardines, *Sardinops melanosticta* (about 20cm in length)) either as prey or merely as a source of underwater sound as the fish hit the water (when anchovies were thrown in the source level ranged from 140 to 150dB and the spectrum peak was between 1 and 3kHz).

Low frequency sounds (the source level was 171dB at the depth of 50cm and the spectrum peak was between 2 and 2.5kHz) were produced by striking the inner wall of the concrete pool (7x5x3m) six times but the porpoise did not seem to be frightened and did not change its swimming behaviour.

These experiments suggest that the Dall's porpoise is not sensitive to low frequency sound waves at pressure levels of up to about 170dB.

Randomly generated ultrasonic pulses 20 to 50kHz were projected twice toward the Dall's porpoise, with the sound pressure adjusted to 178dB at the position of the porpoise. The animal was clearly disturbed and this was indicated by: (1) an increase of four times its 'normal' respiration rate; (2) changing from its 'normal' circular swimming pattern; (3) constantly swimming at the surface to avoid the pulses.

Experiments were also conducted on the animal live-captured in 1986 and kept in the pool (5.1x5.7x2.0m) of the National Fish Farming Centres. Ultrasonic pulses ranging from 20 to 143kHz were projected towards the animal from a distance of 2m. The sound pressure (*Pt*) at which responses began was examined in 10dB increments (Hatakeyama *et al.*, 1987). The animal had floats on either sides of his body and in the absence of sounds swam slowly around the pool in a clockwise direction. When the pulses were emitted, two types of response were noted: movement to avoid the sound and irregular breathing or the emission of sounds in the air.

The *Pt*s at a pulse width of 1ms and the estimated auditory threshold (Awbrey *et al.*, 1979) of Dall's porpoise are shown in Fig. 12. The Pts between 20 and 100kHz range from 122 to 130dB and this sound pressure is approximately 70dB higher than the auditory threshold. The *Pt* increases drastically to 158dB at 143kHz and the auditory threshold deteriorates in a similar way. As the pulse width is reduced by a factor of about 10 (e.g. 10–1ms or 1–0.1ms at 143kHz) the *Pt* increases by 10dB, similar to the case of bottlenose dolphin (Johnson, 1967). The audible frequency range of the Dall's porpoise is similar to that for the bottlenose dolphin and harbour porpoise.

Responses to objects

When a white nylon rope (10mm in diameter) was stretched on the water surface of the pool (7x5x3m), the porpoise swam in a circle with its head up furiously blowing up in the air with splashing sounds on one side of the rope. It did not attempt to dive under the rope. The animal appeared to be both aware and cautious of the rope. No reaction was observed when the rope was stretched 10cm above the water surface.

In experiments where nylon monofilaments (0.6 or 1.2mm in diameter) were hung at intervals of 35 or 70cm, as the diameter of the threads became larger and the interval became smaller, the porpoise was more aware of the existence of the threads and the time it took to swim between the threads became longer. Since the porpoise emitted few clicks while passing through the interval, recognition of the existence of the threads seemed largely to have been visual (Hatakeyama and Shimizu, 1985).

SOUND GENERATORS

Specifications of sound generators

Specifications of all sound generators are listed in Table 7. The four types of sound generators (SG-1 to 4) were constructed on the basis of the frequency components of clicks and responses to ultrasonic pulses (National Research Institute of Fisheries Engineering, 1982; Hatakeyama, 1983; 1986).

Table 7

Specifications of sound generators tested in the actual fishing ground.

Type	Frequency (kHz)	Source level (dB)	Directivity (°)	Waveform τ	Waveform t	Waveform t'	Waveform T	Size (mm) D*	Size (mm) L*	Weight (kg)	Power supply	Life time (days)	Test year
SG-1	9	140	360	100ms [1]	4s		4 min.	83	406	0.786	Dry cell 1.5Vx4	60	1981-1984
SG-2	145	185	360x40 [2]	50ms	3s			380	797	20	Dry cell 12Vx2	30	1983-1986
SG-3	135-150	185	360x40 [2]	100μs	7-28ms [3]		3s	380	797	20	Dry cell 12Vx2	30	1983-1986
SG-4	20-50	186	360-60	1-109ms	10-226ms	9-110ms [4]	6s	380	797	20	Battery 12Vx2 [5]	1	1985-1989

[1] 4 pulses in 16 sec. in every 4 min. [2] Horizontal x vertical. [3] 47 pulses in 0.6 sec. in every 3 sec. [4] Pulses and FM sounds in 1 sec. in every 6 sec. [5] 300-400 times rechargeable battery. Discharge and charge once a day. D = Maximum diameter; L = length.

Given the lack of available data in 1981, SG-1 was developed by the marine mammal project team on the basis of the whistle of bottlenose dolphin.

SG-2 and 3 took into account information obtained in 1983 concerning the frequency components of clicks emitted by the Dall's porpoise. SG-2 emitted 145kHz ultrasonic pulses repeatedly with a constant period. Its pulse width (50ms) was 1,000 times greater than that of clicks made by Dall's porpoises to stimulate their auditory sense with the duration time (energy quantity) and to attract their attention by disturbing their echolocation. SG-3 emitted 135–150kHz pulses similar to those used in echolocation by Dall's porpoises, by changing the pulse interval. SG-4 (manufactured in 1985) emitted random ultrasonic pulses and FM continuous waves of 20 to 50kHz which had been found to affect Dall's porpoises in a series of three experiments in 1984.

The electronic circuit of SG-1 was installed in a plastic case whilst those of the other sound generators were installed in buoys (Fig. 13).

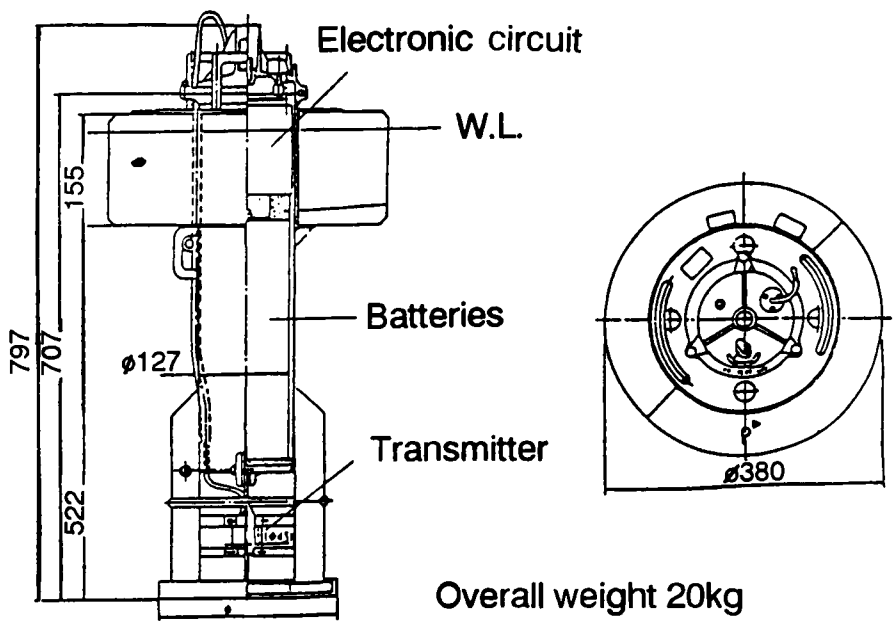

Fig. 13. Sound generator (SG-2, 3 and 4).

Results of tests in the mothership fishery

The four types of sound generators were tested in the mothership salmon fishery and the results from 1983 to 1986 are shown in Table 9 (Kumagai *et al.*, 1984; Ogiwara *et al.*, 1985; 1986; 1987; Snow, 1987).

Decrease rates (DR) of the entanglement for SG-1 to 3 were 3–16%, smaller than expected. The DR for SG-4 was 19% in 1985. SG-1 was not used after 1985 given its low DR and difficulty of use.

In the experiments using SG-4 (Hatakeyama, 1986; 1987; 1988), there was a concentration of the entanglement in that portion of the gillnet where no sound generator was attached and the sound wave was weak. A total of 3–4 SG-4s per net were attached to positions either near both ends of the gillnet or on one half of it. The horizontal distribution of the entanglement is given in Table 8.

Porpoises incidentally taken were concentrated in sections 7–9. The CPUEs for the horizontal sections 1 to 6 which appeared to be within sound range and for the

Table 8

Horizontal distribution (%) of Dall's porpoises entangled in the test nets equipped with SG-4.

Test year	Horizontal section 1	2	3	4	5	6	7	8	9	Total number Porpoise	Operation
	▲		▲				▲		▲		
1985	0	9.1	0	36.4	36.4	9.1	0	0	9.1	11	34
		▲		▲	▲						
1986	12.5	0	0	0	0	12.5	25.0	12.5	37.5	8	32
		▲		▲	▲						
1987	8.3	8.3	8.3	0	16.7	8.3	8.3	16.7	25.0	12	60
		▲		▲	▲						
1989	0	11.1	11.1	0	0	0	11.1	33.3	33.3	9	30
Average of ordinary nets (1984-6)	12	12	11	9	9	9	10	13	15		

▲ = Positions of sound generators.

Table 9

Number of marine mammals incidentally taken by modified gears, decrease rate (DR) and statistical tests.

Year	Classification	Set	Incidental take			U test[1]		chi[2] test[2]		t test[3]	
			No.	CPUE	DR(%)	Whole[4]	Adjacent[5]	Whole	Adjacent	Whole	Adjacent
1983	Standard boats	5,051	2,033	0.347	0						
	AT-1	627	195	0.311	10.4	0.378	0.390	3.985			
	AT-2	627	197	0.314	9.5	0.378	0.057	1.450			
	SG-1	209	65	0.311	10.4	0.435		6.466*			
	SG-2	209	63	0.301	13.3			3.846			
	SG-3	209	61	0.292	15.9	0.128		8.887*			
1984	Standard boats	4,462	1,479	0.331	0						
	AT-1	2,134	647	0.303	8.5	1.498	2.205*	3.448	6.187*	1.913	2.322*
	SG-1	194	62	0.320	3.3	0.509		2.186			
	SG-2	194	61	0.314	5.1	0.023		2.222			
	SG-3	194	60	0.300	6.6	0.669		8.223			
1985	Standard boats	2,000	926	0.445	0						
	AT-1	3,200	1,173	0.358	19.6	4.763**	5.294**	23.446**	29.525**	5.268**	5.232**
	AT-3	320	116	0.354	20.4	1.782		4.090			
	SG-2	164	69	0.421	5.4	0.234		1.539			
	SG-3	164	66	0.402	9.7	0.387		0.278			
	SG-4	13	13	0.317	28.8	1.138		1.839			
1986	Standard boats	1,000	422	0.388	0						
	AT-1	3,366	1,041	0.309	20.4	4.112**	5.282**	19.198**	31.427**	6.812**	3.922**
	MT-1	272	76	0.279	28.1	2.282*		7.149			
	AT-1 + SG-2	136	43	0.316	18.6	0.510		3.290			
	AT-1 + SG-3	136	39	0.287	26.0	1.384		3.213			
	AT-1 + SG-4	34	8	0.235	39.4	1.220		2.045			

[1] U Test: Number of times of entanglement. [2] chi Test: Frequency. [3] t Test: CPUE. [4] On the whole. [5] Adjacent boats. Classifications - AT-1: 3 air-tube threads in the central portion; AT-2: 5 air-tube threads in the central portion; AT-3: 3 air-tube threads in the upper portion; MT-1: Multi threads in the central portion; SG-1: 9kHz sound generator; SG-2: 145kHz sound generator; SG-3: 135-150kHz sound generator; and SG-4: 20-50kHz sound generator. * Within the level of 5%. ** Within the level of 1%.

Table 10

Comparison of CPUE between near and far horizontal section groups from sound generators.

Test year	Horizontal section	
	Near group (1-6)	Far group (7-9)
1986	0.09	0.56
1987	0.15	0.30
1989	0.10	0.70
1986 (ordinary net)	0.32	0.35

horizontal sections 7–9 at which the sound pressure was weak were calculated (Table 10). The former were much smaller than the latter. Given the relatively small sample sizes involved, it is not appropriate to statistically analyse the data. The purpose of the experiment was to determine whether the approach was considered worthy of further attention, and this is clearly the case.

Effective range of SG-4

The effective sound pressure of SG-4 was examined under conditions where Dall's porpoise was facing the sound generator (Hatakeyama *et al.*, 1987). The sound pressure (*Pt*) at which Dall's porpoise began showing a response was 126dB. Since the increase step of sound pressure in the experiment was 10dB, the true value of the *Pt* was in the range of 116 to 126dB. The frequency characteristics of the projector rendered the sound pressure to be a maximum at 35kHz. The auditory threshold (TH) at 35kHz was estimated to be 51dB by Awbrey *et al.* (1979). The TH represents the sound pressure at which Dall's porpoise would barely hear the sound wave whereas the *Pt* represents the sound pressure at which Dall's porpoise would show an external response. There presumeably is an intermediate sound pressure (*Pc*) that would draw the Dall's porpoise's attention to the sound.

The effective range was obtained on the points of intersection between an attenuation curve of the sound and above parameters as shown in Fig. 14 and Table 11 (Hatakeyama, 1987). Dall's porpoises were observed to jump and flee when the sounds were projected from distances up to 700m. The effective range based on the value of *Pt* is 440–740m and this upper limit is close to the experimental value (700m).

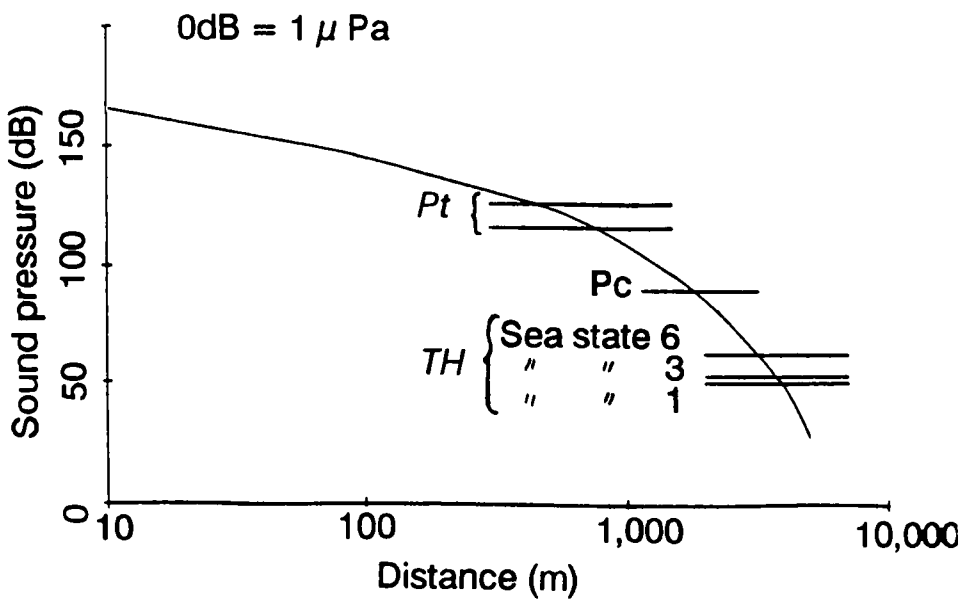

Fig. 14. Sound pressure of SG-4 as a function of distance and various detection threshold. TH: Auditory thresholds masked by ambient sea noise.

Table 11

Effective range(m) of SG-4.

Detection threshold		Effective range(m)
TH	Sea state 1	4,000
	Sea state 3	3,800
	Sea state 6	3,300
	Pc	1,900
	Pt	440-740

GEAR MODIFICATION

Gillnets with air-tube nylon threads

Awbrey *et al.* (1979) recommended that attempts be made to weave air-filled line into the net in order to increase the net target strength and thereby decrease mortality. Accordingly, the marine mammal project team conducted an experiment using air-tube nylon threads (outer diameter about 0.6mm; ratio of inner to outer diameter about 0.5). The TS of the gillnet with three air-tube threads was larger by 3 to 4dB than that of the ordinary net.

The project team monitored the incidental take and calculated its decrease rate (DR), comparing CPUE (number of incidental take/net) of the modified net with that of the standard unmodified net (Kumagai *et al.*, 1984; Ogiwara *et al.*, 1985; 1986; 1987; Snow, 1987). Four types of modified nets were used: 3 air-tube threads in the central portion (AT-1); 5 air-tube threads in the central portion (AT-2); 3 air-tube threads in the upper third of the net (AT-3); and 3 multi-filament threads in the central portion (MT-1). The results from 1983 to 1986 are listed in Table 9. The DRs of AT-1 to 3 were in the range of 8 to 20%.

Multi-filament thread has a higher (about 10dB) target strength than nylon monofilament and the obtained DR was 28%. Two statistical tests were used to examine the results: a test using entanglement frequency rate (U Test) was used for those cases where the sample size was small, e.g. for AT-1; a test using frequency distribution of the entanglement (chi^2 test) was also used. A significant difference (1% level) was found for 1985 and 1986 (Table 9). In addition, since 1984, the sample size has become sufficient to compare CPUEs for the two types of gillnets using the t-test; significant differences were found for 1985 and 1986 at the 1% level (Snow, 1987).

Gillnets equipped with reflectors

A total of 13 operations were conducted by a research vessel from 2–28 June 1986 with a set of 135 tans (1 tan=45m) of gillnet (Hasegawa *et al.*, 1987). Gillnets of five types were used. Types A to D were equipped with reflectors such as vinyl string, rope and sheets of blister plastic packaging material (Fig. 15). Type E, the control, comprised ordinary nets.

The target strengths of these objects are larger than that of the netting by 20 to 40dB, if the porpoises approach the net at a right angle. However, when they approach it at a diagonal angle, the reflected waves have a tendency to decrease abruptly. The mean values of the numbers of salmon caught per tan were 3.4 in type A (total length (TL) = 195 tans), 3.5 in type B (TL = 260 tans), 3.3 in type C (TL = 260 tans), 3.4 in type D (TL = 195 tans) and 3.7 in type E (TL = 845 tans). Although the values for the modified nets were smaller than for the control net, they were not significantly different.

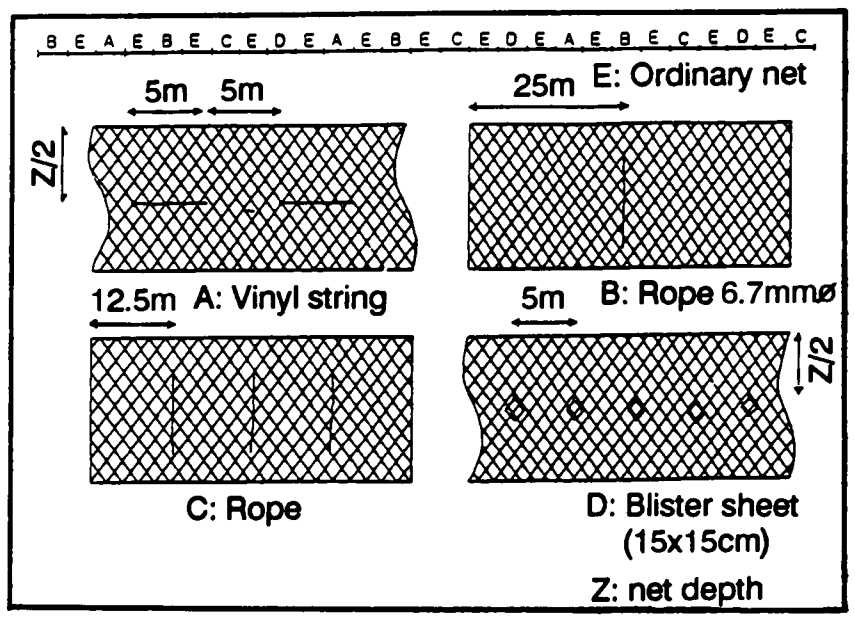

Fig. 15. Schema of experimental gillnet with reflectors.

A total of five Dall's porpoises became entangled during the 13 operations, 1 in type B net, 2 in type C net and 2 in type E net. It was assumed that the vertical ropes had no alerting effect on Dall's porpoise. Given the small sample sizes it is not surprising that no significant differences were apparent between the modified and unmodified nets. If this approach is to be pursued, the experimental procedures must be greatly enlarged.

CONCLUSION

It is very difficult to successfully live-capture a Dall's porpoise. In addition, although we eventually succeeded in live-capturing two Dall's porpoises with purse-seines, we did not succeed in feeding them.

Dall's porpoises in the Bering Sea emit short high frequency (135–149kHz) pulses with pulse widths of 50–60μs and source levels of 165–175dB re 1μPa. When chased toward gillnets in open sea, they changed their swimming direction in front of the net, either swimming along it or diving and passing under it. This fact shows that they have a highly resolutive echolocation ability and normally can avoid getting entangled in gillnets during the daytime.

Measured target strengths of a float, leadline, lead and netting were –25, –33, –39 and –55dB, respectively. The rough estimates of their detection ranges for the leadline and netting were found to be 30 and 8m, respectively.

Responses to sounds showed that Dall's porpoises are insensitive to low frequency (<3kHz) sounds with a sound pressure of up to 170dB, but are noticeably sensitive to ultrasonic pulses of 20 to 143kHz. Responses to objects suggested that they are aware and cautious of a rope on the water surface.

Four types of sound generator (SG-1 to 4), air-tube threads and reflectors such as rope were tested aiming to reduce the incidental catch. The decrease rates (DR) of the entanglement for the sound generators except SG-4 were 3 to 16% and the DR of the gillnet with three air-tube threads in its centre portion was 8 to 20%. As for SG-4, there was a concentration of entanglements in the portion of the net where it was not attached.

Although the numbers of salmon caught per unit length (tan) for nets with reflectors were smaller than that for the ordinary net, there was no significant difference between them. A total of 3 Dall's porpoises became entangled in the nets with vertical ropes. The vertical ropes probably have no alerting effect.

Although the harbour porpoise can detect netting at a short distance, one porpoise became entangled in a gillnet in a darkened pool. Judging from the waveform characteristics of clicks, the echolocatory ability of the harbour porpoise is worse than that of the Dall's porpoise. Bottlenose dolphins fully detected the existence of the gillnet and did not get entangled either at night or during the day.

From visual experiments with white whales, it was found that the netting is more easily recognised than the thread and that there are colour differences in recognition ability. The eyes of Dall's porpoises were examined and compared with those of bottlenose dolphins. The histological characteristics were similar. Neither the distribution of cells nor the mean ratio of the density of photoreceptors to that of ganglion cells were significantly different.

A number of questions concerning Dall's porpoises must be clarified in the future, including the following.

(1) How frequently and 'seriously' do they conduct echolocation during the day and night in the open seas?
(2) Which members conduct echolocation when swimming in a group?
(3) Do they respond to sounds such as alarm or distress calls emitted by other porpoises?
(4) At what distance can they recognise the net by eyesight at various light levels?
(5) When do they 'sleep'? At what depth and speed do they swim while sleeping? What are their sensory contacts with the environment at night?

Items (1) and (5) can be examined with a radio telemetry system. If the sensitivities of their auditory and visual organs are weak during sleep, a passive method will not be effective in reducing their entanglement rates and strong stimuli will be required to awaken them. If they swim near the water surface at night, especially during sleep, nets set a few meters below the water surface should be effective.

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Sonar Detection of Gillnets by Dolphins: Theoretical Predictions

Whitlow W.L. Au

Hawaii Institute of Marine Biology, Marine Mammal Research Program, PO Box 1106, Kailua, Hawaii 96734, USA

ABSTRACT

The detection and avoidance of gillnets by echolocating dolphins is examined by using the generalized sonar equation along with target strength values of nets and dolphin sonar detection data. Acoustic reflection data were obtained for several types of nets and associated gear by ensonifying them with simulated bottlenose dolphin sonar signals. Threshold detection ranges corresponding to a 90% probability of detection were calculated as a function of a dolphin's peak-to-peak source levels for: (a) monofilament gillnet used in the salmon mothership fishery, (b) Macah tribal cord setnet, (c) a twisted polyester rope 'poly rope' and (d) household light switch chain.

From calculations based on the measured ability of Atlantic bottlenose dolphins (*Tursiops truncatus*) to detect targets in noise, detection ranges for a monofilament drift gillnet should vary from 1.2m for a source level of 140dB re 1μPa to 25m for a source level of 190dB. The Macah tribal cord setnet should be detected at least twice as far as the monofilament gillnet. The results indicated that most dolphins should be able to detect a monofilament gillnet at sufficiently long ranges to avoid entanglement. The sonar detectability of nets can be enhanced considerably by attaching poly rope or light switch chain on the nets. Some reasons as to why dolphins get entangled in nets which they should be able to detect with their sonar are discussed.

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; BEHAVIOUR; ATLANTIC BOTTLENOSE DOLPHINS; DALL'S PORPOISE; HARBOUR PORPOISE; SPINNER DOLPHINS; FALSE KILLER WHALE; ACOUSTICS

INTRODUCTION

Coastal and high seas gillnet fisheries result in the incidental take of large numbers of small cetaceans and the global extent of such takes is described in IWC (1994). Dall's porpoise (*Phocoenoides dalli*) are incidentally taken in high seas salmon and squid driftnet fisheries (Jones, 1984; 1988). Dall's porpoises and harbor porpoises (*Phocoena phocoena*) are also caught in coastal salmon gillnet fisheries in Alaska (Matkin and Fay, 1980) and Washington (Gearin *et al.*, 1990). Harbor porpoises are incidentally taken in gillnets off California (DeMaster *et al.*, 1985; Peltier *et al.*, 1993) and in waters off Maine (Read and Gaskin, 1988). Bottlenose dolphins (*Tursiops* sp.) and spinner dolphins (*Stenella longirostris*) were caught by gillnets in the northern Australian seas (Harwood *et al.*, 1984). Thousands of small cetaceans die annually in coastal driftnets off Sri Lanka (Leatherwood, 1994). These references are but a few examples of the pervasive problem of incidental take of small cetaceans by gillnets throughout the world. Nearly every species of small cetacean is affected. If gillnet fisheries are to continue to be used in cetacean habitats, methods to reduce or eliminate entanglement are urgently needed.

Dolphins possess a sophisticated sonar system that should assist them in detecting and avoiding nets. Yet the continual problem with entanglement has led some to assume that gillnets, especially those constructed of nylon monofilament lines are 'acoustically invisible'. However, Au and Jones (1991) clearly showed that monofilament gillnets will reflect acoustic energy and that an echolocating dolphin should be able to detect a monofilament gillnet at a sufficient range to avoid entanglement. In this study, the biosonar net detection problem will be examined in a different manner to that of Au and Jones (1991) and the maximum detection ranges of nets and associated gear will be calculated as a function of the dolphin sonar source level. The Atlantic bottlenose dolphin (*Tursiops truncatus*) will again be used as the model. Reliable target detection and related acoustic data exist for only a few cetacean species such as the bottlenose dolphin (Au, 1988b) and the false killer whale (*Pseudorca crassidens*; Thomas and Turl, 1990). Unfortunately, few echolocation data exist for some of the phocoenids such as the Dall's and harbor porpoises, two species that are commonly caught in gillnets.

TARGET STRENGTH MEASUREMENTS

Target strength measurements were performed at the Naval Ocean Systems Center Hawaii Laboratory test pool using a monostatic echo measurement system that transmitted a broadband dolphin-like echolocation signal. Details of the measurements are given by Au and Jones (1991). The simulated dolphin echolocation signal resembled the sonar signal of the bottlenose dolphin, having a peak frequency (frequency of maximum energy) of 122kHz and a 3dB bandwidth of 37kHz. The transducer had a 3dB beam width of approximately 8° in the horizontal plane and 13° in the vertical plane. At the measurement distance of 2.4m, the effective area covered by the transducer's beam was rectangular, 0.34m by 0.55m. The nets were laid out with a minimum of tension applied so that their shapes were not rigid but resembled wavy curtains.

Target strength can be defined in several ways when dealing with short broadband signals such as dolphin echolocation signals. Target strength is often determined by using the peak-to-peak values of the incident and reflected sound pressure levels, and is denoted as TS_{pp} here. However, if an energy detection scheme is used to process echoes then target strength needs to be defined as the ratio of the incident and reflected energy flux density, and is denoted as TS_e. Au *et al.* (1988) have shown that the bottlenose dolphin processes sonar echoes like an energy detector with an integration time of approximately 264μs. Therefore, the received energy flux density should be integrated up to 264μs, resulting in a third target strength definition, TS_{tt}, applicable to *T. truncatus*. All three target strengths will be given since it is not clear which is most applicable to other species of dolphins. Although the animal's bandwidth for the detection of click signals is not

known, the critical ratio measured with narrow band signals may be used as an estimate. The critical ratio measurements of Johnson (1968) and Au and Moore (1984) indicate that bottlenose dolphins process narrowband sounds with a filter having a Q (ratio of center frequency to bandwidth) of about 12.

Fishing equipment investigated

Three nets/fishing gear will be considered in this study, along with a household light switch chain.

(1) *Commercial monofilament gillnet* used in the salmon mothership fishery, constructed of 0.49mm diameter nylon monofilament lines with a 10cm mesh size (distance between parallel lines of the webbing).
(2) *Macah tribal setnet* used for salmon fishing in the state of Washington, constructed of 0.97mm diameter twisted (3 strands of 0.25mm diameter) cord with a 20.3cm mesh size.
(3) *Poly rope*, 0.635cm diameter twisted polyester rope.
(4) *Household light switch chain* consisting of chrome plated nickel beads, 0.3cm diameter spaced 0.4cm apart, center to center.

Target strength results

Waveforms and frequency spectra of echoes from the commercial monofilament gillnet are shown in Fig. 1, for different angles of incidence. The echo waveforms are relatively complex with many highlights, at all angles of incidence. With such complex echo structures, TS_e and TS_{tt} will generally be higher than TS_{pp} because the echo is considerably longer than the projected signal. Target strength varied little with angle of incidence. This probably was a result of the net being suspended like a wavy curtain which produced relatively similar echoes for different angles of incidence. The Macah tribal setnet also had similarly complex echo structures with little variation in target strength with incidence angles between 15 and 45°.

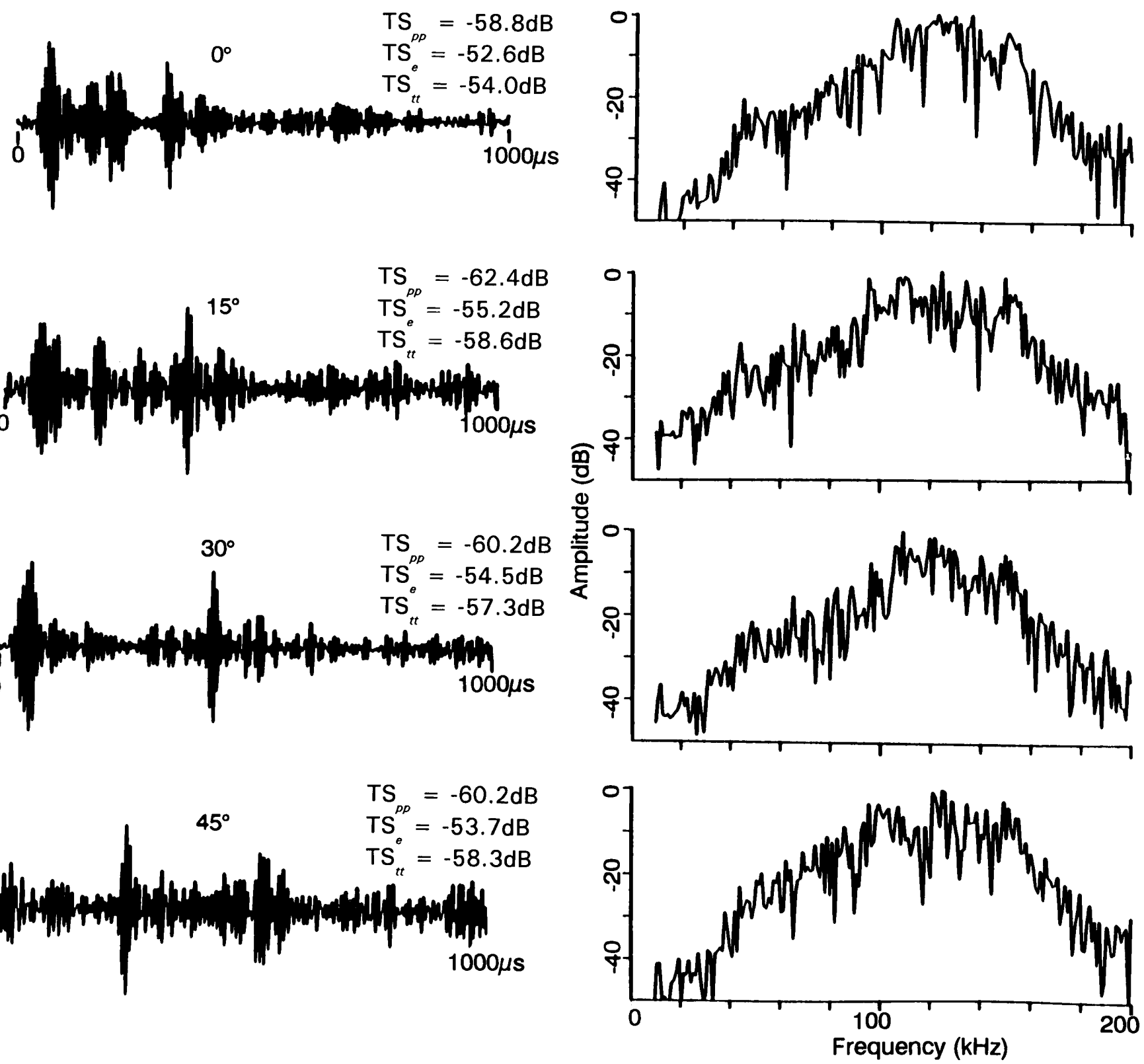

Fig. 1 Echo waveform and frequency spectra of acoustic reflections from the nylon monofilament gillnet for angles of incident of 0, 15, 30 and 45°. The target strength based on peak-to-peak amplitude (TS_{pp}), energy in a 1ms window (TS_e) and energy in the 264μs integration window of *Tursiops truncatus* (TS_{tt}) are also included.

Target strength values for the nets and gear are presented in Table 1. The monofilament gillnet had the lowest target strength making it the most difficult object to detect. The Macah tribal setnet had the higher target strength of the two nets. The echo waveform for the poly rope and the light switch chain, which were dangled vertically in front of the transducer, consisted of a single click resembling the incident signal. Therefore, the three types of target strength were the same for the associated gear. The unsoaked poly rope had the highest target strength. When the rope was left in the water for 24hrs, air bubbles trapped between the fibers dissipated and the target strength decreased by about 6dB. The target strengths of the rope and light switch chain were at least 20dB greater than the monofilament gillnet. This means that the acoustic reflectivity of a monofilament gillnet can be increased substantially by attaching objects such as the poly rope or light switch chain to it.

Table 1

Target strength (dB) of the gillnets and associated gear.

Net type	Incident angle	TS_{pp}	TE_{e}	TS_{tt}
Commercial gillnet	0°	-58.8	-52.6	-54.0
	15°	-62.4	-55.2	-58.6
	30°	-60.2	-54.5	-57.3
	45°	-60.2	-53.7	-58.3
Macah tribal setnet	0°	-36.7	-36.2	-36.2
	15°	-49.3	-43.6	-43.7
	30°	-55.8	-47.7	-49.4
	45°	-56.1	-46.8	-49.8
Poly rope (unsoaked)	0°	-25.8		
Poly rope (soaked)	0°	-33.0		
Light switch chain	0°	-36.5		

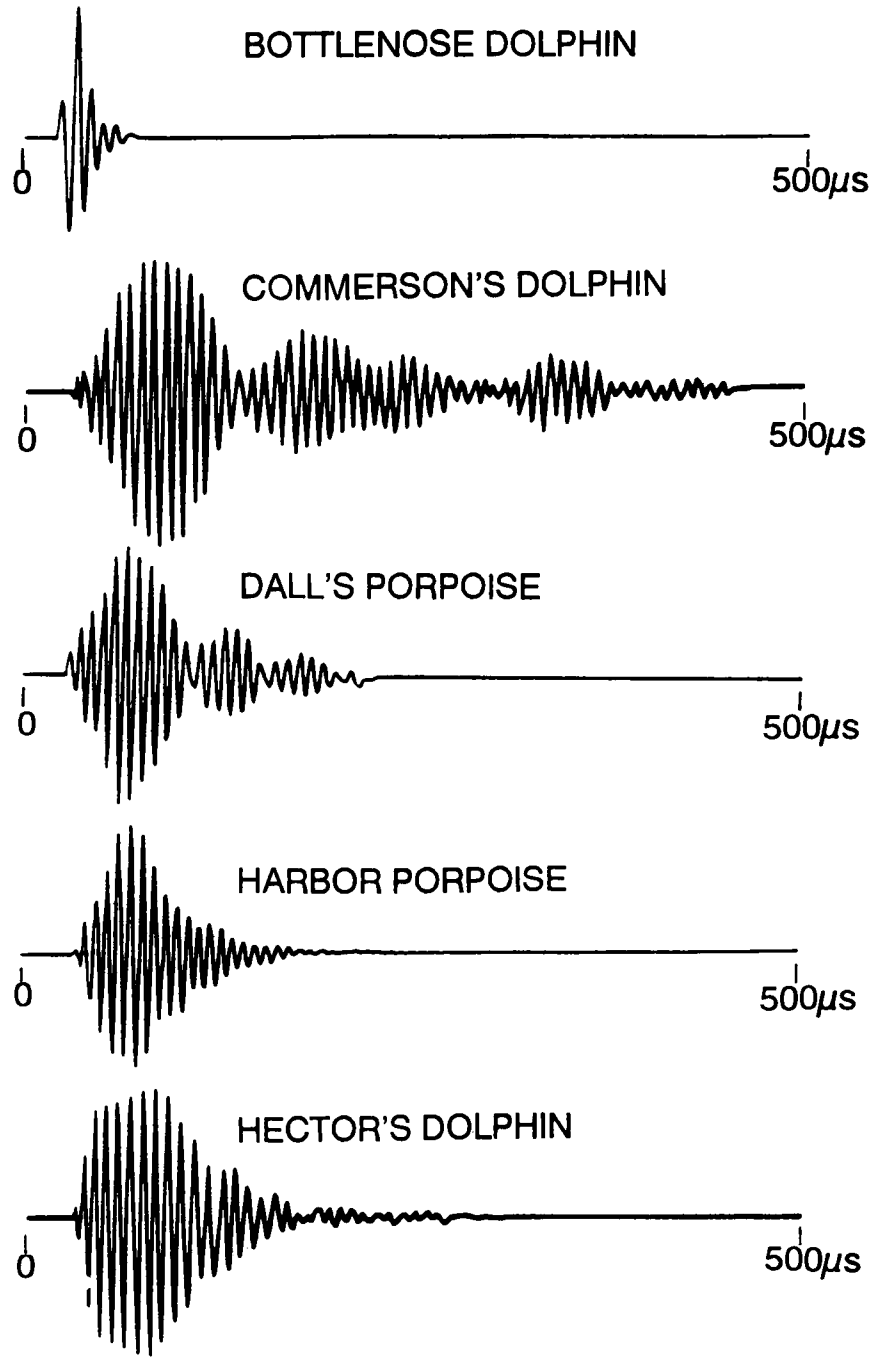

Fig. 2. Examples of sonar signals of (a) bottlenose dolphin (Au, 1980), (b) Commerson's dolphin (Evans *et al.*, 1988), (c) Dall's porpoise (Hatakeyama and Soeda, 1990), (d) harbor porpoise (Kamminga and Wiersma, 1981), (e) Hector's dolphin (Dawson, 1988).

Target strength for harbor porpoise signals

The sonar signals of small cetaceans from the phocoenid family (Kamminga and Wiersma, 1981; Evans *et al.*, 1988; Hatakeyama and Soeda, 1990) and the genus *Cephalorhynchus* (Dawson, 1988; Evans *et al.*, 1988; Dawson and Thorpe, 1990) are considerably different to those used by bottlenose dolphins (Au, 1980), white whales, *Delphinapterus leucas* (Au *et al.*, 1987) and the false killer whale (Thomas and Turl, 1990). The sonar signals of these small cetaceans tend to have narrower bandwidths, longer durations, higher peak frequencies and lower amplitudes. Examples of echolocation signals for the bottlenose dolphin and some of the smaller odontocetes are shown in Fig. 2. Note how much shorter the bottlenose dolphin signal is compared with the other signals. The reflection of a harbor porpoise sonar signal from the gillnet can be estimated mathematically by calculating the transfer function of the gillnet and convolving it with the signal of interest. Au and Jones (1991) performed this calculation for a Dall's porpoise signal. The monofilament gillnet echo for the *Phocoena* signal shown in Fig. 2 is presented in Fig. 3 for a 0° incident angle. There is little difference in the target strength based on energy between the results shown in Figs 1 and 3. The structure of both echoes is equally complex with many highlights. The frequency spectrum of the echo obtained with the *Phocoena* signal is narrower because of the narrower bandwidth of the *Phocoena* signal.

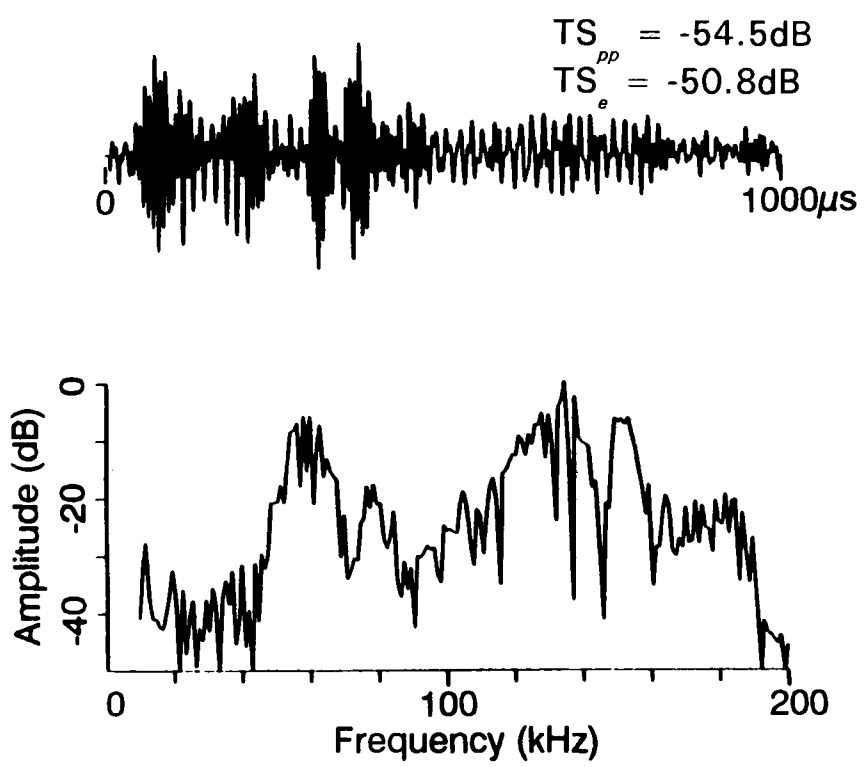

Fig. 3. Calculated reflection from the monofilament gillnet for the harbor porpoise signal shown in Fig. 2d.

PREDICTION OF BIOSONAR DETECTION RANGES OF GILLNETS

The simplest and most accurate way of predicting the ranges at which echolocating dolphins can detect gillnets is to use target detection data obtained under controlled conditions and extrapolating the data for different conditions. Unfortunately, there are few data on biosonar detection in noise except for *Tursiops truncatus* (Au, 1990). The target sensitivity of *Tursiops* has been measured by three equivalent methods: (1) the range of a 7.62cm diameter water-filled sphere was increased until the dolphin could no longer detect it (Au and Snyder, 1980; Murchison, 1980); (2) a 7.62cm sphere was used at different target ranges and the amount of masking noise was increased until the dolphin could not detect the target (Au and Penner, 1981; Turl *et al.*, 1987); and (3) an electronic simulated target was fixed at a range of 20m and its target strength progressively decreased until the dolphin could not detect it (Au *et al.*, 1988). The results of all of these studies are summarized in Fig. 4 with the percent correct response plotted against the received echo energy-to-noise (*E/N*) ratio. The echo energy used in Fig. 4 was calculated with the click signal having the maximum energy for each experimental trial. The solid curve is the best-fit 3rd order polynomial curve and the dashed lines indicate the signal-to-noise ratio needed for the dolphin to achieve a 90% correct response performance (approximately 14dB).

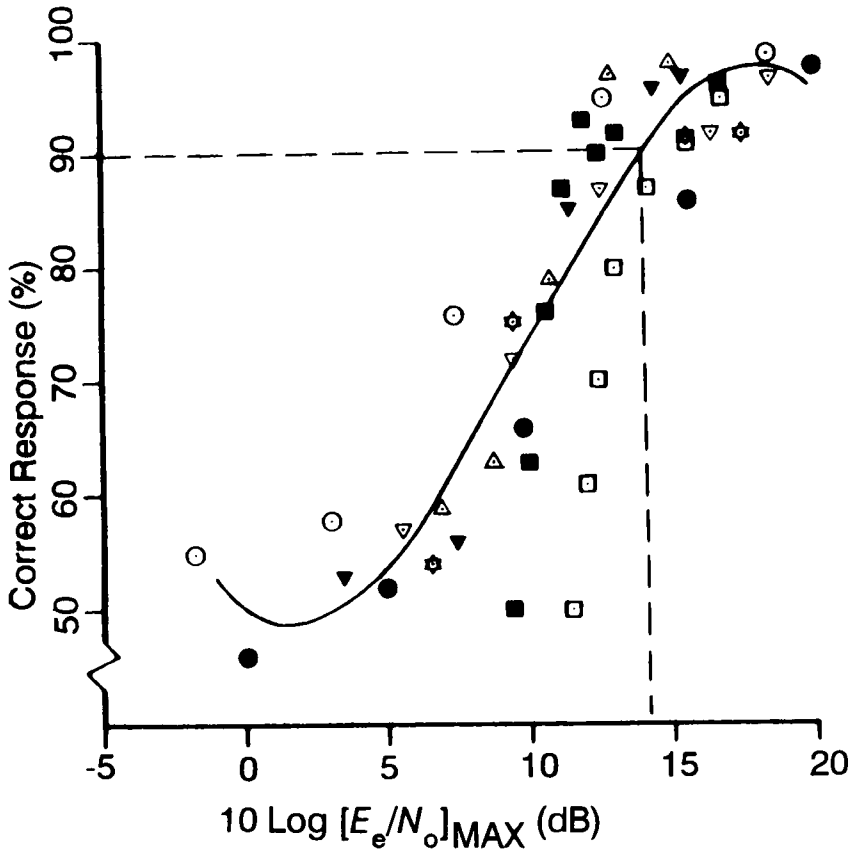

Fig. 4. Target detection capability of *Tursiops truncatus* from five studies (Au and Snyder, 1980; Murchison, 1980; Au and Penner, 1981; Turl *et al.*, 1987; Au *et al.*, 1988). The solid curve is a 3rd order polynomial fit to the data.

The dolphin target detection performance shown in Fig. 4 can be used to estimate the detection range for a gillnet by using the sonar equation. The noise-limited form of the sonar equation modified for dolphin sonar signals can be expressed in dB as (Au, 1988a):

$$DT_E = SE - 2TL + TS_{tt} - (NL - DI_R) \qquad (1)$$

(echo energy; noise energy)

here: DT_E = detection threshold; SE = source energy flux density; TL = one way transmission loss; TS_{tt} = target strength based on energy with *Tursiops*' integration time window; NL = noise level; and DI_R = receiving directivity index.

Although SE is used in the sonar equation, peak-to-peak sound pressure level (SL) is more commonly used in describing the levels of dolphin signals. Au (1988a) derived a simple relationship between SE and SL by expressing the signal as $A \cdot s(t)$ where A is the peak amplitude and $s(t)$ is the waveform function ($|s(t)| \leq 1$), so that

$$SE = SL - 6 + 10 \text{ Log} \left(\int_0^T s^2(t)\, dt \right) \qquad (2)$$

The log integral term for a typical *Tursiops* signal in Kaneohe Bay is approximately –52dB. Therefore, $SE = SL - 58$dB for *Tursiops*.

The one way transmission loss can be expressed simply as the spherical spreading loss plus an absorption term,

$$TL = 20 \log R + \alpha(f_p)R \qquad (3)$$

where: R = target range in metres and $\alpha(f_p)$ = the absorption coefficient evaluated at the peak frequency of the dolphin sonar signal.

For short ranges (<25m), absorption losses will be small and can be ignored.

The received directivity index in the sonar equation was determined by Au and Moore (1984) and their results are shown in Fig. 5 with the received directivity index plotted as a function of frequency. The directivity index was found to vary with frequency according to the equation:

$$DI_R = 16.9 \text{ Log } f(\text{kHz}) - 14.5 \text{ dB} \qquad (4)$$

The sonar equation may be used to calculate the ranges at which an echolocating *Tursiops* should be able to detect a monofilament gillnet 90% of the time. I will assume that the typical deep water noise spectral density shown in Fig. 6 is applicable. For sea state conditions between 0 and 3, the noise at 120kHz is at the thermal limit and is equal to 27dB re 1μPa²/Hz (Albers, 1965). The noise then increases linearly to 33dB for sea state 6. Substituting $SE = SL - 58$ (from Equation 2) into Equation 1, DT_E = 14dB (from Fig. 5), and DI_R = 21dB (from Equation 4), we obtain the following equation:

$$40\text{Log}R = \begin{cases} SL + TS_{tt} - 79 & SS\ 0\text{–}3 \\ SL + TS_{tt} - 84 & SS\ 6 \end{cases} \qquad (5)$$

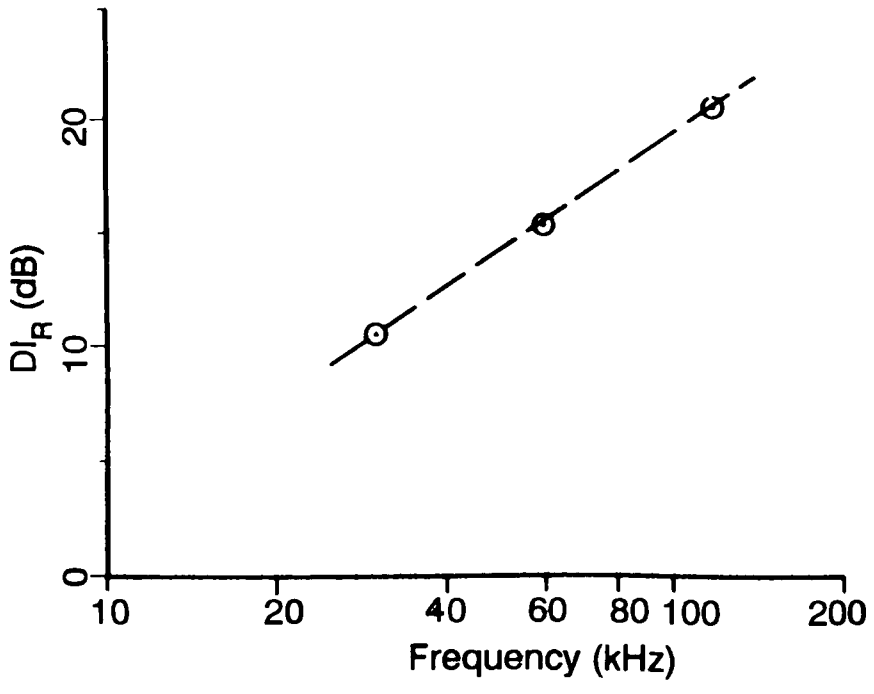

Fig. 5. Receiving directivity index as a function of frequency for *Tursiops truncatus* (Au and Moore, 1984).

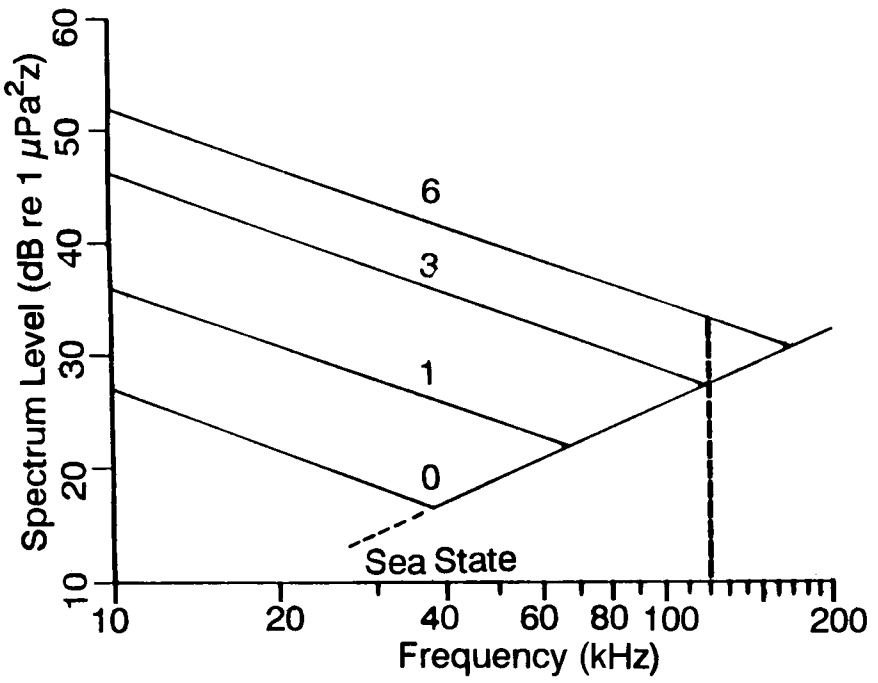

Fig. 6. Deep-water ambient-noise levels for sea states 0 to 6 (Albers, 1965).

The 90% probability of detection range for *Tursiops truncatus* emitting signals with different peak-to-peak source levels are shown in Fig. 7 for sea states between 0 and 3. Equation 5 was used to generate the curves shown in Fig. 7. The calculated results indicate that if *Tursiops* emitted signals with a source level of 140dB re 1μPa, it should be able to detect a monofilament gillnet at a range of at least 1.2m, and for a source level of 190dB the detection range should increase to at least 25m. The detection ranges for the Macah tribal setnet are also shown in Fig. 7. Since the Macah tribal setnet had a higher target strength than the monofilament gillnet, its detection ranges were correspondingly greater. These detection ranges are sufficiently long for a swimming echolocating dolphin emitting signals with source levels of 155–160dB to detect a gillnet in time to avoid the net.

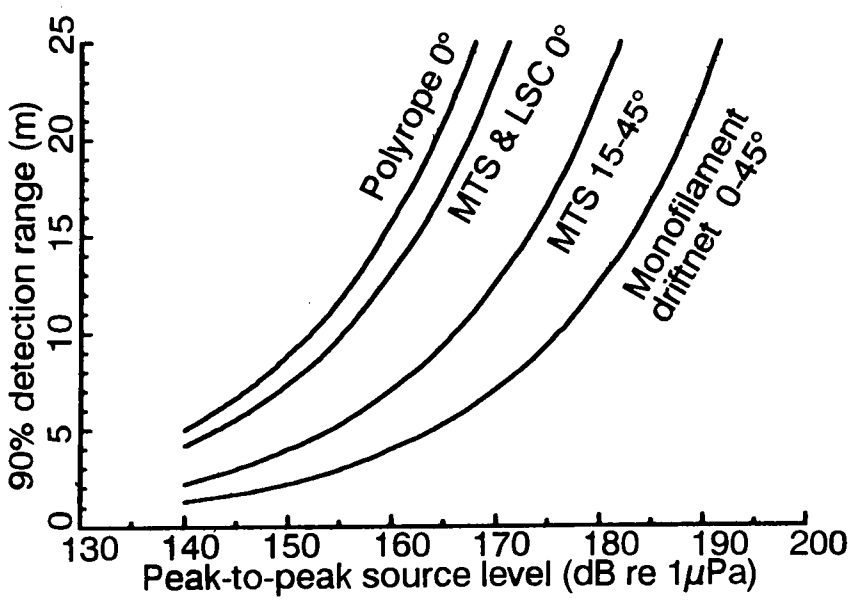

Fig. 7. Predicted biosonar detection of gillnets and associated gear by a *Tursiops truncatus* as a function of the peak-to-peak source levels. The detection range for the light switch chain (LSC) and the Macah tribal setnet (MTS) at 0° incident angle is identical.

The detection ranges for the poly rope and the light switch chain are also shown in Fig. 7. The target strengths used for both objects were obtained at normal incident where the reflection is highest. The amount of reflection will drop off substantially as the angle of incident deviates from the normal incident. However, the use of the normal incident value for poly rope and light switch chain interwoven vertically, horizontally and diagonally, into a gillnet seems appropriate. Both of these items will not be taut but will follow the geometry of the net, and will take on an undescriptive, irregular and slack geometry. An echolocating dolphin will most likely scan a net from various aspects as it swims and will probably experience many occasions in which the rope or chain within the sonar beam will be nearly perpendicular to the beam resulting in relatively high-amplitude echoes. Therefore, the detection range of a gillnet can be increased substantially by attaching poly rope or light switch chains to the net.

Tursiops typically emit signals with source levels in the vicinity of 220dB in detection experiments performed in Kaneohe Bay (Au, 1980) and so the low source levels used in Fig. 7 are extremely conservative for *Tursiops* but may be more in line with phocoenids. Hatakeyama and Soeda (1990) recorded source levels of 165–170dB re 1μPa for Dall's porpoises in the open ocean, and 152–157dB in a tank. They also reported source levels close to 160dB for three *Phocoena phocoena* in a tank. With a source level of 160dB, a dolphin should be able to detect a monofilament gillnet at a range of 4m and a Micah tribal cord setnet at 7 to 13m. For a given peak-to-peak source level, some of the smaller cetaceans (signals shown in Fig. 2) may be able to detect a gillnet at roughly 20 to 30% longer ranges than *Tursiops* because they typically emit longer signals containing on the order of 5dB more energy.

DISCUSSION AND CONCLUSIONS

The target strength measurements and sonar detection range calculations indicate that echolocating *Tursiops* and other odontocetes should be able to detect gillnets at long enough ranges to avoid entanglement. This conclusion is supported by observations and experiments performed by Hatakeyama and his colleagues in Japan (see review by Hatakeyama *et al.*, 1994). Hatakeyama *et al.* (1986) found that a white whale had a 50% detection range of 5.5m with a salmon gillnet used as the target. The animal used relatively low amplitude clicks of approximately 182–189dB re 1μPa, in this tank experiment, which is considerably lower than 210–225dB for a white whale measured in Kaneohe Bay (Au *et al.*, 1987). Hatakeyama and Ishii (1987) constructed a net enclosure in a cove that was partitioned with a salmon gillnet to house three bottlenose dolphins. Night observation of one of the dolphins with a flashing marker light attached to it indicated that it did not approach closer than 3–5m from the gillnet. Hatakeyama and Soeda (1990) observed Dall's porpoises around a salmon research vessel in the Bering Sea as gillnets were being retrieved. They saw two Dall's porpoises out of three in a group dive and pass under the gillnet and reappear on the other side. However, the third one became entangled in the net. They also twice observed a Dall's porpoise passing through a 1.5m wide, 1.0m high hole of a damaged gillnet without changing its swimming speed of 3–4ms^{-1}. On another occasion they found a school of Dall's porpoises along the coastal area of east Hokkaido and set a gillnet (1,300m long, 6m deep). The porpoises were chased toward the gillnet with four boats. Upon approaching the net the porpoises changed direction and swam along the net or dived and passed under the net. In one case, two porpoises out of a group of three dived suddenly when they were about 4 to 5m from the net and surfaced about 10m on the other side. The third animal swam into the net and broke through it. Hatakeyama and

Soeda (1990) concluded that Dall's porpoises can detect gillnets by echolocation and can also distinguish holes within nets. Hatakeyama and Soeda (1990) also observed the behavior of harbor porpoises in a tank that was partitioned with a salmon gillnet. Nightscope observation of the harbor porpoises suggested that they could detect the presence of the net and initially avoided it. However, when they became accustomed to the net, they became careless and some became entangled. Although many of the observations are anecdotal and each observation means little by itself, taken together they tend to support the notion that gillnets are detectable by echolocating dolphins.

Since this analysis and field observations indicate that echolocating dolphins should be able to detect gillnets at sufficient ranges to avoid them, why then do they still become entangled? This question is a puzzling one and has been addressed by other investigators (Awbrey *et al.*, 1979; Dawson, 1994; Goodson *et al.*, 1994). I would like to suggest a number of possibilities.

(1) Pelagic dolphins may not echolocate while transiting a body of water. In the open ocean, there seems to be little need for dolphins to echolocate except to detect prey and possibly to avoid predators. However, little is known about how odontocetes utilize their sonar in the wild.

(2) The problem may be in the difference between detecting and perceiving an obstacle. Although the nets are detectable, the echoes will be relatively weak, and a dolphin may not perceive the net as an obstacle but as a penetrable entity. Dolphins probably encounter sources of volume reverberation that are penetrable, such as the deep scattering layer, and may not perceive gillnets as harmful obstacles. In the open ocean, the concept of a barrier is probably foreign to a dolphin. Attaching more acoustically reflective items such as poly rope or light switch chains on a net may help to make a net seem more impenetrable. However, Hembree and Harwood (1987) have experimented with the use of metallic bead chain on gillnets and found them ineffective in reducing the incidental take of *Tursiops truncatus* and *Stenella longirostris* in Australian waters. The results in Fig. 7 (the light switch chain was similar but not identical to those used by Hembree and Harwood, 1987) indicated that *Tursiops* should be able to detect the metallic bead chains at tens of metres.

(3) In some circumstances dolphins may be feeding on prey that inhabit the same general location where fishermen typically set driftnets (Ellis, 1989) and may be too distracted by prey to notice the presence of gillnets or may not be able to distinguish between the sonar reflections from prey and gillnets (Awbrey *et al.*, 1979; Evans *et al.*, 1988). Cockcroft (1990) indicated that *Tursiops* that are caught in shark gillnets used to protect swimmers in South Africa, seem to be aware of the presence of these nets, judging from their normal swimming patterns around them. Nevertheless, when they forage for food, they seem to become oblivious to the nets and are sometimes caught. An analysis of stomach contents indicated that most of the captured dolphins had almost full stomachs, implying that capture occurred either during or subsequent to feeding.

(4) The presence of entangled fish and aggregations of free swimming fish in the immediate vicinity of a gillnet may prevent dolphins from acoustically sensing the presence of the net. The sonar returns from free swimming and entangled fish may mask the presence of gillnets, since the echoes from the nets will be much smaller than echoes from the fishes. For example, from the expression of fish target strength given by Love (1971), a 40cm long salmon will have a target strength (frequency of 120kHz) between –26 and –33dB, considerably greater than the target strength of a gillnet.

(5) The disturbances caused by entangled, struggling fish may actually attract dolphins to a net. As dolphins approach a net to investigate the cause of the commotion, the entangled fish may also distract them from sensing the presence of the gillnet.

In searching for viable solutions to the incidental gillnet capture problem, we should perhaps concentrate in areas other than the animal's sonar detection capabilities. Although only thoughtful speculations on why dolphins seem not to detect gillnets are presented here, some of these speculations should be seriously considered in future research. There is a need to obtain better understanding of the dynamics involved with the incidental catch problem. Why do dolphins swim close to gillnets? How do they typically get entangled? What percentage of dolphins swimming toward a gillnet actually become entangled? What is the role of fish and other marine life already entangled or entrapped by gillnets in attracting porpoises to the nets? Part of the entanglement problem may involve the presence of large quantities of entangled marine life which may attract dolphins to gillnets. Therefore, it may be difficult to discourage dolphins and porpoises from approaching these nets.

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SC/O90/G13

The Potential for Reducing Entanglement of Dolphins and Porpoises with Acoustic Modifications to Gillnets

Stephen M. Dawson

Department of Marine Science, University of Otago, P.O. Box 56, Dunedin, New Zealand

ABSTRACT

To reduce incidental catch of cetaceans in gillnets, two forms of acoustic modifications are reviewed here; one to make gillnets more reflective to cetacean sonar, and another using active sound emitters in nets to alert cetaceans to the presence of nets. A review of the literature shows that neither strategy has proven indisputably effective. Air-tube nets and multifilament nets used in the North Pacific Japanese driftnet fishery for salmon have caught fewer Dall's porpoises than equivalent standard gillnets. However, results were not consistently significant over several years, and have not been confirmed by a thorough study of modified gillnets in another driftnet fishery. Studies examining effects of adding sound emitters to gillnets have also proven inconclusive. Further, there appear to be serious problems with the logical basis for acoustic net modification strategies. I argue that such strategies are not likely to achieve the reductions in cetacean bycatch that are required to conserve several dolphin and porpoise species and propose alternative methods which are likely to be more effective.

KEYWORDS: INCIDENTAL CAPTURE; NORTH PACIFIC; FISHERIES; DALL'S PORPOISE; HARBOUR PORPOISE; BOTTLENOSE DOLPHINS; HECTOR'S DOLPHIN; ACOUSTICS; BEHAVIOUR

INTRODUCTION

'In marked contrast to the improving prospects for the great whales, the status of many smaller cetaceans has continued to deteriorate over the last two decades' (Brownell *et al.*, 1989, p.5; and see Perrin, 1988). In part this is due to their incidental capture in gillnet fisheries (for a recent compilation of estimated catches, see IWC, 1994). Incidental catch of cetaceans in gillnets appears to be a generic problem inherent in all forms of gillnetting. Oceanic driftnet fisheries kill many thousands of cetaceans annually (e.g. Jones, 1984; Harwood *et al.*, 1984; Harwood and Hembree, 1987). Large incidental catches also occur in coastal gillnet fisheries for groundfish (e.g. Pilleri, 1971; Harrison *et al.*, 1981; Gaskin, 1984; Peltier *et al.*, 1993; Read and Gaskin, 1988; Dawson, 1991a; Brownell *et al.*, 1989). Such coastal fisheries may have a greater impact than oceanic fisheries because they kill coastal cetaceans which often have more restricted distributions than their oceanic relatives (Dawson, 1991b). The Gulf of California harbour porpoise, *Phocoena sinus*, ostensibly the rarest marine cetacean, appears threatened with imminent extinction by entanglement in gillnets (Barlow, 1986; Silber, 1988; Brownell *et al.*, 1989; Vidal, 1995).

There have been many proposals to reduce incidental catch of cetaceans by modifying gillnets. Several of these are based on the concept of modifying gillnets acoustically, so that dolphins and porpoises can detect them and hence avoid entanglement. In this paper I will briefly review the results of experiments testing these modifications, discuss some of the difficulties with the concepts and make some specific recommendations for the management of cetacean bycatch problems. Statistical tests used here are tests of proportion (Neter *et al.*, 1988) or G tests with Williams' correction (Sokal and Rohlf, 1981).

CONSTRAINTS ON POTENTIAL MODIFICATIONS

Modifications must be practical to be adopted in commercial gillnet fisheries. The conditions described below must be met.

(1) *The modifications must have reasonable longevity under commercial fishing conditions.* For acoustic reasons, air-containing structures (as long as they are of reasonable size; Pence, 1986) are ideal to increase the reflectivity of nets to sonar. As they have a very different density to the surrounding water, they reflect sonar pulses better than any solid object of similar size. However, because they lack internal support, air-containing structures are usually less robust than solid ones and hence are more easily damaged. Also, unless rigid they are likely to crush at depth, becoming less effective as reflectors. Air-filled plastic tubing (8mm) in gillnets did not function as intended because it filled with water after compression by the net hauler (Hembree and Harwood, 1987). Similarly, panels of plasticised aluminium foil incorporated into the net matrix were found unsuitable as sound reflectors because seawater dissolved the aluminium layer when the plastic layer was damaged (Peddemors *et al.*, 1991).

(2) *The modified gillnets must be safe to handle.* Peddemors *et al.* (1991) found that netting braid incorporating a double strand of 0.16mm diameter stainless steel braid became too brittle to handle safely. This is likely to occur in any method involving the addition into nets of wire filaments which are large enough to be detectable by cetaceans (Busnel and Dziedzic, 1966).

(3) *To avoid compromising the economic efficiency of gillnetting, the net modifications must be reasonably lightweight and inexpensive.*

(4) *Net modifications must not decrease catch rates of target species below an economic level.* For example, Hembree and Harwood (1987) found that nets set 4.5m below the surface caught significantly fewer cetaceans than standard nets, but that the modified nets also caught about 25% fewer fish. The gillnetting industry is unlikely to accept these costs willingly.

EXPERIMENTS TESTING ACOUSTIC MODIFICATIONS TO GILLNETS

Modifying gillnets by increasing their target strength

Most gillnets are made from nylon monofilament. This material is almost the same density as seawater and gives a poor sonar echo (i.e. has low target strength; Pence, 1986). Prompted by this observation, many authors have assumed or suggested that entanglement occurs because the animals' sonar *cannot* detect the net (Ohsumi, 1975; Awbrey *et al.*, 1979; Hatakeyama, 1986a; Hembree and Harwood, 1987).

On the assumption that increasing the target strength of gillnets will decrease incidental catches, Japanese workers have experimented with two types of passive modifications to gillnets. In the first (AT-1), three air-tube threads were intertwined into the central band in an otherwise standard gillnet (Snow *et al.*, 1988). These hollow threads were 0.5mm in diameter with a 0.25mm internal air space. Between 1981–6, mean incidental catch rates in these air-tube nets were about 21% lower (range = 6 to 48%; Ogiwara, 1986) than catches in standard nets. This reduction seems surprising, considering that the air-tube nets have a target strength only 3–4dB higher than standard monofilament (Hatakeyama, 1986a). The AT-1 nets showed significantly lower catch rates in four of the six seasons tested. This inconsistency is possibly explicable by the marginal nature of the increase in target strength. Neither increasing the number of air-tubes to five (AT-2) nor concentrating the air-tubes in the top third of the upper portion of the net (AT-3) resulted in lower catch rates than in AT-1 nets (Ogiwara, 1986).

A second type of modification has been tested since 1986. In these nets (MT-1), three multifilament threads were intertwined into a central band of an otherwise standard gillnet. Although Snow *et al.* (1988) do not give the plane in which target strength was measured, they state that multifilament thread had a target strength about 10dB higher than standard monofilament. In both the 1986 and 1987 trials, multifilament nets had marginally lower catch rates than air-tube nets, but the difference was not significant in either season (z[1986] = 0.6; p = 0.27: z[1987] = 1.06; p = 0.14: test of proportions; data from Ogiwara, 1986; Snow *et al.*, 1988). Data from adjacent sets provide a stronger test, but were available only from the two month study of 1987. A paired-sample t test comparing 88 pairs of adjacent air-tube and multifilament nets showed that multifilament nets caught significantly fewer (28%) porpoises ($p < 0.01$; Snow *et al.*, 1988). Catch rates of the two net types were significantly different in June ($z = 3.7$; $p < 0.001$), but not in July ($z = 0.96$; $p = 0.17$).

If multifilament threads are easier for porpoises to detect than air-tube threads, one would predict fewer entanglements in the modified portions of multifilament nets than in corresponding portions of air-tube nets. Only the 1987 data were available to test this idea. The vertical distribution of entanglements was significantly different between the two net types ($G = 16.3$; $p < 0.001$; 2*3 G test); paradoxically, the multifilament nets caught more porpoises in their central portions than did the air-tube nets (Hatakeyama, 1988; Snow *et al.*, 1988).

In summary, the Japanese AT-1 air-tube nets appeared to reduce entanglement by about 21% over standard nets. However, the reduction was variable among years and not consistently significant. Multifilament nets also produced inconsistent results, but appeared to have lower catch rates than air-tube nets. However, more porpoises were caught in the modified portions of MT-1 nets than in corresponding sections of air-tube net, suggesting that the benefit of multifilament is yet to be established clearly.

After finding that captive, blindfolded, bottlenose dolphins (*Tursiops truncatus*) reacted strongly to 4mm chrome-plated nickel bead chain, Hembree and Harwood (1987) used this material to modify nets used in the Taiwanese drift gillnet fishery in northern Australian waters. In their 1984 trials, alternating half and full-length pieces of bead chain were woven vertically into the net every 8m. During the next season bead chain was woven into the mesh as nine 3m diagonals per 15 x 15m net panel. In neither season did the net modifications significantly reduce the number of dolphins caught. The 1985 trials produced the unexpected result that the modified nets caught more dolphins than the control nets (Hembree and Harwood, 1987).

The Japanese results, and those of Hembree and Harwood (1987) are somewhat in conflict. Bead chain has a much higher target strength than air-tube thread or multifilament thread (Au and Jones, 1991), and yet the bead chain did not reduce entanglement while the air-tube threads did (at least in four of six seasons). There are three reasonable interpretations of this result. (1) Increasing the target strength of gillnets is less effective in reducing entanglement than the Japanese studies suggest. (2) Target strength increases quoted above may represent the best case, measured with a sound source perpendicular to the modification material. An echolocating animal approaching from other angles is likely to perceive a lesser target strength. Hence, the modifications above, from an acoustic point of view, have not been ideal (Goodson *et al.*, 1994) and this may have contributed to the inconsistency of effectiveness. (3) There is something radically different between the sonar capabilities of bottlenose and spinner dolphins, *Stenella longirostris* (the major catch off Northern Australia) and Dall's porpoise, *Phocoenoides dalli*.

There are some valuable lessons to be learned from the approach of Hembree and Harwood (1987). Their 1985 trials are the only passive net modification trials which have used a balanced design with equal numbers of control and experimental net panels. This balance was achieved by using nets with alternating 1km long modified and unmodified sections. Balanced design helps strengthen the power of statistical comparison. Also, Hembree and Harwood's (1987) study was conducted on a scale which was large enough to be useful. Several smaller-scale studies have involved too few entanglements to allow statistical comparison of modified and unmodified nets (Hasegawa *et al.*, 1987; Peddemors *et al.*, 1991). This is unavoidable where the entanglement problem is localised and the total number of animals involved small (Peddemors *et al.*, 1991). However, in the North Pacific driftnet fishery for salmon the total number of porpoises caught is large and despite the extra expense, studies of adequate design and scale could have been conducted. For example, the goal of Hasegawa *et al.* (1987) was to assess the catch rate of four types of modified net against a control, unmodified net. However, they studied only 13 setting operations in which the amount set of each net type was unbalanced (195–260 tans for experimental nets; 845 tans for standard net (1 tan = 50m)). It is not surprising that the total number of porpoises caught was small (5) and that there was no significant difference between between catches in modified nets (3) and those in unmodified nets (2). Studies like this can do little to clarify the value of gillnet modifications.

Unfortunately, this is not an isolated case in tests of the effectiveness of net modifications (Silber *et al.*, 1994) or sound emitters (Hatakeyama, 1986b; Hatakeyama, 1987) in reducing incidental catch.

The influence of active sound emitters in gillnets

Sound emitters appear to be of marginal benefit, if any. When sound emitters were added to AT-1 nets, there was no significant decrease in catch rates in any of the years tested (Ogiwara, 1986; Hatakeyama, 1988; Snow *et al.*, 1988).

If sound emitters reduce incidental catch, one would expect fewer entanglements in regions of the net near emitters than in regions further away. As indicated above, attempts to make such comparisons have been frustrated by small sample sizes and unbalanced designs. Data are available for only 13 entanglements from 1985 (Hatakeyama, 1986b) 8 from 1986 (Hatakeyama, 1987) and 12 from 1987 (Hatakeyama, 1988; Snow *et al.*, 1988). The 1985 and 1986 data suggested that the emitters may have an effect, but in 1987 the entanglement rate in sections of the net near emitters (<55 tan) was not significantly different from that in sections further away.

Even if sound emitters reduced catches of dolphins and porpoises it is extremely unlikely that it would be practical in the foreseeable future to place them in all gillnets. Devices currently available are large, heavy (Hatakeyama, 1986a), relatively expensive (Ogiwara, 1986) and require regular recharging (Hatakeyama, 1988). As Peddemors *et al.* (1991) point out, metal devices, whether electronic or not, are vulnerable to corrosion. Further, as high-frequency sounds attenuate quickly in water, there would need to be many emitters spaced along the net (Awbrey *et al.*, 1979). Their comment that 'The cost and complications of active devices would preclude their proper use and maintenance.' (1979, p. 36) is still accurate today. This applies not only to set-up and operating costs, but also to costs of enforcement, as an observer scheme would be necessary to ensure that fishers use the devices as intended (Gaskin, 1984).

LOGICAL PROBLEMS WITH ACOUSTIC MODIFICATIONS TO GILLNETS

Increasing the target strength of gillnets

I. The assumption that nets are difficult to detect

The strategy of increasing target strength to reduce entanglement is largely based on the assumption that the sonar systems of dolphins and porpoises are incapable of detecting unmodified nets, or at least have difficulty in doing so (Ohsumi, 1975; Awbrey *et al.*, 1979; Gaskin, 1984; Hatakeyama, 1986a; Hembree and Harwood, 1987). At face value this assumption seems fair, but data on the sonar capability of dolphins and porpoises and observations of their behaviour near nets suggest that entanglement does *not* result from an inability of the sonar system to detect nets (Au and Jones, 1991; Dawson, 1991b; Au, 1994). Similar phenomena are observed in insectivorous bats, which despite their remarkable sonar ability are routinely caught in mist nets for study and marking by researchers.

Dubrovskiy reported that the harbour porpoise, *Phocoena phocoena*, can detect nylon filaments of 0.1mm diameter (Dubrovskiy, pers. comm. in Evans *et al.*, 1988). Even so, harbour porpoises are routinely entangled in gillnets made of nylon several times that diameter (0.8mm; Gaskin, pers. comm.). Au (1994) has shown that bottlenose dolphins should be able to detect gillnet webbing made of 0.49mm diameter monofilament at long enough ranges to avoid entanglement. However, that species is occasionally entangled in shark nets of coarse 3mm multifilament braid (Peddemors *et al.*, 1991), which would be much easier to detect. A net's detectability is enhanced by the knots between the meshes (Pence, 1986). Furthermore, the floats along the top of a groundfish gillnet should be easily detected by even a crude sonar system (Awbrey *et al.*, 1979; Pence, 1986; Ogiwara, 1986). If cetaceans can detect the nets which entangle them, entanglements are most likely to result from one or more of three factors: (a) the animal is not making sonar pulses at the time of entanglement and hence is not aware of the net's presence; (b) the animal is aware of the net but fails to perceive it as something to avoid; or (c) the animal is aware of the net and the danger it poses, but simply makes a (fatal) mistake.

II. How much of the time do cetaceans use their sonar?

Increasing the target strength of a gillnet is irrelevant if the animals are not making sonar pulses when they encounter nets. If cetaceans only echolocate when they need to, i.e. when feeding or trying to localise objects, they are likely to be silent most of the time. Species which remain in relatively small areas for extended periods (such as Hector's dolphin, *Cephalorhynchus hectori*; Slooten and Dawson, 1988) would seem to have no need to constantly interrogate their environment with sonar as they would be thoroughly familiar with it. Neither would oceanic species cruising in open areas where they do not expect an obstacle. No study has yet quantified what proportion of time free-ranging dolphins and porpoises spend echolocating. This would be a difficult task because of the narrow emission field of these animals (Au *et al.*, 1978; 1986; 1987) and the inherent directionality of high-frequency sounds[1]. During my recordings of free-ranging Hector's dolphins (Dawson, 1988; Dawson and Thorpe, 1990; Thorpe and Dawson, 1991) sounds were not recorded every time a nearby dolphin was oriented at the hydrophone, suggesting that they were not always vocalising.

III. Perceptual problems

When using sonar, cetaceans probably have a 'search image' of what they expect to encounter. It is possible that sonar reflections from airfilled net modifications might mimic a fish's swimbladder, and attract cetaceans to nets. In other cases, foraging dolphins may disregard echoes from a net as being from non-prey, and hence become entangled (Awbrey *et al.*, 1979; Evans *et al.*, 1988). Observations of insectivorous bats confirm that echolocating animals are not always able to detect obstacles when chasing prey. Evans *et al.* (1988) described these bats as having a detection system which is open for prey detection but closed for obstacle avoidance.

[1] Quantification of the time dolphins spend silent could be possible using small event recorders which store the time of occurrence of each of a free-ranging dolphin's high frequency sonar pulses. In a study such as the long-term study of bottlenose dolphins in Sarasota Bay (e.g. Wells *et al.*, 1987) in which dolphins are routinely caught, examined and released, an event recorder could be attached to a dolphin's melon with a suction cup and recovered when it detaches for downloading of its data.

The rate at which clicks are repeated is probably a significant factor in gillnet detection by dolphins. Dolphins normally space their clicks apart so that the previous pulse's echo returns before the next pulse is emitted (Au *et al.*, 1982; for review see Turl and Penner, 1989). When searching for a target they 'range-gate' using a click repetition rate suited to detecting a target within an expected range (Au *et al.*, 1974; Turl *et al.*, 1987; Goodson *et al.*, 1994). Once a target is detected, echolocating animals typically increase their click rate as they approach the target (Watkins, 1980: i.e. range and click rate are matched). In both the searching and target-locked phases, objects outside the (expected) range of the target are unlikely to be easily perceived. This suggests that dolphins, like bats, may not perceive obstacles (gillnets) while chasing prey.

Echolocating dolphins and porpoises may not interpret echoes from gillnets (modified or not) as representing an impassible obstacle. Cetaceans, especially oceanic species, live in an environment in which barriers are rare. Also, they routinely encounter sources of volume reverberation which are passable (e.g. the deep scattering layer), and may interpret the reflections from gillnets similarly (Au, 1994). Further, even if they perceive gillnets as dangerous obstacles, some entanglements will occur because cetaceans make mistakes. Human car accidents are analogous in that although drivers know the dangers, accidents still happen at a high rate.

Active sound emitters

To be effective in reducing entanglement rates, sound emitters could work if (a), (b), or (c) (below) were true.

(a) *The sound is sufficiently aversive to scare cetaceans away from nets.* It seems likely that any low frequency sound sufficiently aversive to scare cetaceans away from nets would also decrease fish catches. That 'tuna bombs' are used to herd dolphins shows that high-level explosive sounds are aversive to dolphins. However, such sounds are rich in low frequencies which are readily perceived by fish. Sounds of sufficiently high frequency to be inaudible to fish are unlikely to be perceived by dolphins as inherently aversive.

(b) *The sound is effective at both attracting the attention of nearby cetaceans and encouraging them to use their sonar to carefully examine their environment.* Implicit in this idea is the assumption that cetaceans might investigate the source of sound and discover the gillnet in the process. It would seem paradoxical to attempt to reduce entanglement by encouraging cetaceans to investigate the source of the danger.

(c) *The sound is effective as a warning which cetaceans associate with the danger of gillnets.* However, 'warnings' involve learned behaviours which, in the absence of sophisticated communication between individuals, will only be apparent to those who experience both the danger and the warning sound, and survive to associate the two. According to Awbrey *et al.* (1979, p.2) the 'low incidence of net damage unrelated to porpoise deaths would be evidence that encounters are usually fatal'. In addition, if the danger is not clearly perceived and associated with the sounds, cetaceans might be expected to quickly habituate to the emitters' sounds (Gaskin, 1984). Randomising the sounds used (Hatakeyama, 1986b) might prevent habituation, but it may also prevent association of any particular sound with the danger of gillnets.

Habituation to the sounds is a general problem in each of these hypotheses, and even if the emitters are successful in making cetaceans aware of the presence of gillnets, cetaceans may not perceive gillnets as an impassable barrier (see III above).

Additionally, there are cases in which marine mammals appear to feed directly on fish caught in gillnets, or on the scavengers of gillnetted fish. In Canadian waters, harbour porpoises appear to be attracted to gillnets to feed on hagfish, which are scavengers of gillnet-caught fish (Gaskin, pers. comm.). In this situation, attaching sound emitters to nets could have the effect of 'ringing the dinner bell'.

CONCLUSIONS

To maintain current dolphin and porpoise populations, acoustic modifications to gillnets need to be shown to result in unequivocal and large reductions in cetacean bycatch. It must be stressed that even statistically significant reductions in catch rates may be insufficient to stem population declines. Most dolphins and porpoises have relatively low reproductive rates (Gaskin *et al.*, 1984; Perrin and Reilly, 1984; Reilly and Barlow, 1986; Slooten and Lad, 1991) and some stocks or species appear to have suffered population declines as a result of gillnet entanglement (Gaskin, 1984; Read and Gaskin, 1988; Dawson and Slooten, 1993). Potential gillnet modifications have now been tested for over ten years. No study has demonstrated that they achieve unequivocal, large reductions in catch rate of cetaceans. This fact must surely argue against the continuation of gillnetting in areas where entanglement rates remain high.

Obvious differences exist among the sonar signals of different odontocete species (Au, 1994), yet no species common in intensively gillnetted areas appears able to avoid entanglement completely. The generality of the problem across many different gillnet fisheries suggests that the answer does not lie in detailed investigations of the interactions present in each. I suggest that the problems discussed above and elsewhere (Awbrey *et al.*, 1979; Au, 1994; Au and Jones, 1991; Dawson, 1991b) are likely to apply in most, if not all, situations in which odontocetes are incidentally caught in gillnets.

Management action required

As a top priority it is essential that the status and reproductive rates of incidentally caught species be assessed as soon as possible. Such data could be used to determine acceptable catch levels for gillnet fisheries. Decisions about whether to continue the fishery should be based on the need to prevent further declines of cetacean stocks or species rather than on the economic needs of gillnet fisheries.

From these arguments, I believe there are two reasonable courses of action.

(1) Abandon acoustic gillnet modification experiments because of their poor prospects for success and in their place initiate time/area and/or gear restrictions to achieve the necessary reductions in incidental catch.
(2) If, despite the arguments above, it is believed that acoustic gillnet modifications still hold promise (Goodson *et al.*, 1994), conduct one more set of experiments for a limited time, perhaps over three seasons. These experiments should test only the modification which is most promising (by acoustical and practical criteria; Goodson *et al.*, 1994). The experiments should be of balanced design, preferably

using alternate modified and unmodified panels (Hembree and Harwood, 1987). Power analysis, based on the reduction in catch necessary to avoid population decline, should be used to determine an appropriate scale for the experiments (Fairweather, 1991). If the experiments fail to demonstrate an unequivocal reduction in catch rate to, or beyond, the required level, acoustic gillnet modifications should be either abandoned or used only in conjunction with time/area and/or gear restrictions.

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Response of Free-Ranging Harbour Porpoises to Potential Gillnet Modifications

Gregory K. Silber

Institute of Marine Science, University of California, Santa Cruz, CA 95060, USA[1]

Kelly A. Waples

255 Via San Andreas, San Clemente, CA 92672, USA[2]

and

Peter A. Nelson

Institute of Marine Science, University of California, Santa Cruz, CA 95060, USA[3]

ABSTRACT

Thousands of porpoises die annually in monofilament gillnets. Simple net modifications may alleviate the problem. In June through August 1988, we quantified harbour porpoise (*Phocoena phocoena*) reactions to weighted vertical lines suspended from corklines. If effective in deterring porpoises, vertical lines might be threaded into gillnets to reduce entanglement rates. No structure deflected all porpoise groups, but strands consisting of small metallic spheres and surgical tubing turned a greater proportion of porpoises than did polypropylene line verticals. Although the structures may not be useful in reducing cetacean mortality in gillnets, the experiment may have merit in identifying areas for continued research in attempts to reduce cetacean entanglement in gillnets.

KEYWORDS: INCIDENTAL CAPTURE; HARBOUR PORPOISE; BEHAVIOUR; ACOUSTICS; VISION; FISHERIES

INTRODUCTION

Porpoises (family Phocoenidae) are vulnerable to entanglement in monofilament gillnets because their distributions overlap those of commercial fisheries. Thousands of porpoises die annually due to entanglement in set and drift gillnet fisheries. For example, throughout the 1980s, an average of 2,300 Dall's porpoises (*Phocoenoides dalli*) died each year in drift gillnets (Jones *et al.*, 1986), although incidental catches of this species have declined in recent years (Hobbs and Jones, 1993). Harbour porpoise (*Phocoena phocoena*) annual mortality on the California coast was estimated to be between 200–400 individuals from 1983–1986 (Hanan *et al.*, 1987), and Read and Gaskin (1988) concluded that incidental mortality in gillnets may seriously threaten the harbour porpoise population on the Atlantic coast of North America. Gillnet entanglement most affects coastal species and populations that are small or have limited distribution. For example, the vaquita (*Phocoena sinus*), one of the rarest cetaceans, continues to die in gillnets in unknown numbers (Silber, 1988; Vidal, 1995).

There have been few published accounts of experiments aimed at reducing cetacean entanglement through net modifications. Air-filled nylon tubing has been incorporated into gillnets in an attempt to reduce the incidental catch of Dall's porpoises in North Pacific salmon fisheries (Snow *et al.*, 1988), but these efforts were ineffective in reducing incidental entanglement (Jones, 1984). Hembree and Harwood (1987) performed open ocean trials of modified nets and examined changes in dolphin mortality rates and fish catch rates. The two materials used, air-filled tubing and metallic bead chain, both yielded inconclusive results with respect to cetacean entanglement rates. The bead chain, although promising in one trial, yielded no significant difference in dolphin mortality in a second trial.

Our objective was to study porpoise reactions to vertical lines in the water column and to identify economical and readily accessible materials that, when incorporated into gillnets, might deter porpoises. The study was based on the findings of Norris and Dohl (1980) who determined that spinner dolphins (*Stenella longirostris*) did not swim between vertical 30m lengths of 6.35mm diameter polypropylene line suspended from the surface. This apparatus was called a 'hukilau'. When the distance between verticals was increased incrementally from 1 to 6m, spinner dolphins continued to avoid swimming through the hukilau.

We theorised that harbour porpoises, like spinner dolphins, might avoid swimming through hukilaus. If effective in deterring porpoises, vertical lines could be threaded into gillnets without a concomitant reduction in target species catch levels. This paper reports on our initial testing of porpoise responses to hukilaus of various materials and configurations; it quantifies porpoise reaction to hukilaus in Monterey Bay, California in the summer months of 1988.

METHODS

Two corklines 120m in length were constructed with 9.53mm diameter yellow polypropylene line, strung with either 7.0 x 7.5cm styrofoam floats or 5.5 x 9.5cm plastic floats at roughly 10–15cm intervals. Suspended verticals, 10m in length, were attached to the corkline. The lines were held vertical in the water column with 3–4 links of

[1] Present address: *Marine Mammal Commission, 1825 Connecticut Ave NW, Room 512, Washington, D.C. 20009, USA.*

[2] Present address: *Marine Mammal Research Program, Bioenergetics Laboratory, Texas A&M University, 4700 Avenue U, Bldg. 303, Galveston, TX 77551, USA.*

[3] Present address: *Department of Biological Sciences, Northern Arizona University, Flagstaff, AZ 86011, USA.*

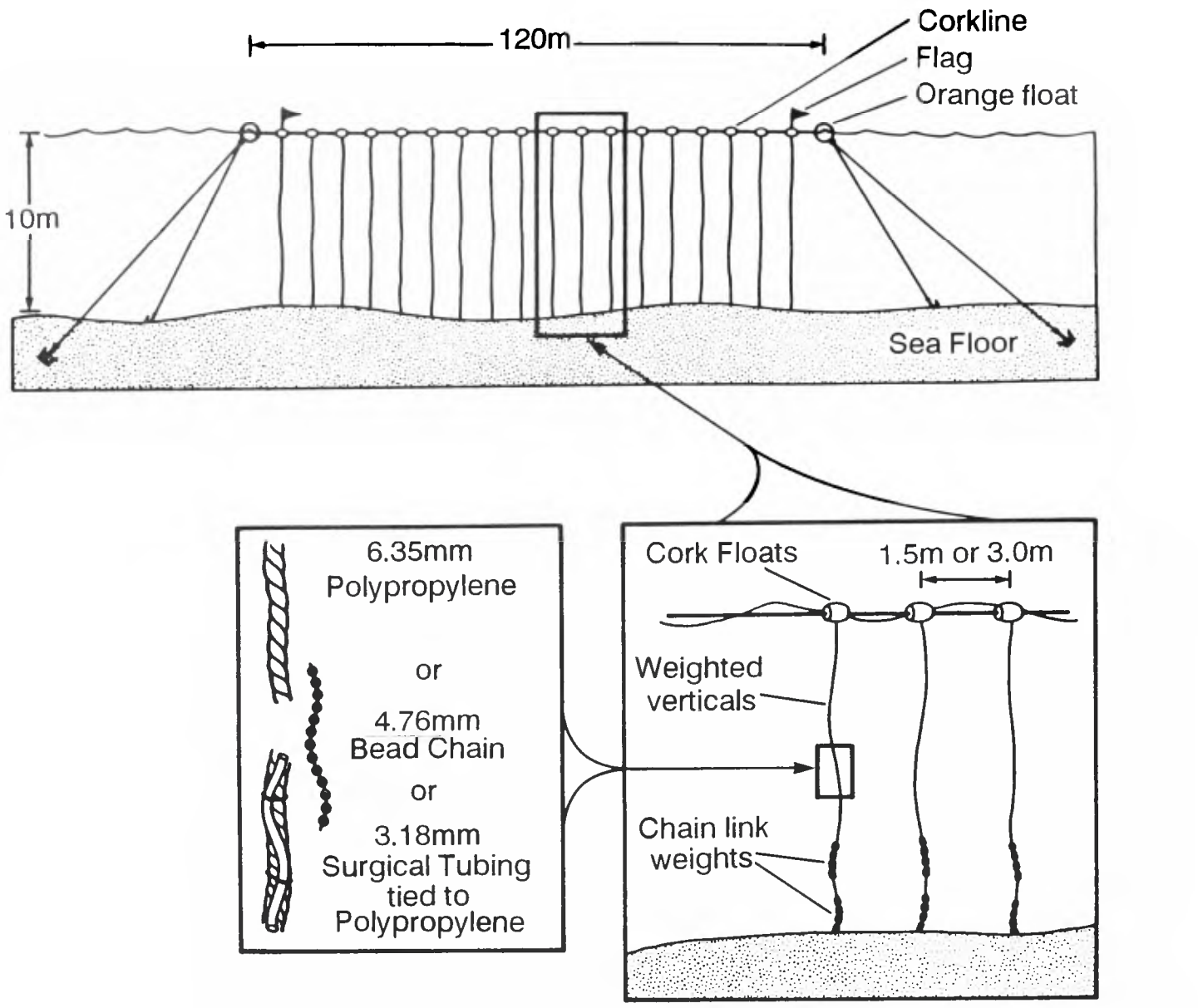

Fig. 1. Schematic representation of experimental apparatus. Weighted vertical lines that consisted of three types of material were suspended from corklines to the sea floor.

6.35mm chain at the bottom and roughly 1.5m from the bottom (Fig. 1).

Five variations on this structure were used: (1) a corkline with nothing attached; (2) a corkline with 6.35mm polypropylene line verticals spaced 1.5m apart; (3) a corkline with 6.35mm polypropylene line verticals 3.0m apart; (4) a corkline with 10m verticals of surgical tubing tied to rope 3.0m apart; and (5) a corkline with 10m verticals of 4.76mm diameter bead chain (strands of metallic spheres) 3.0m apart.

Surgical tubing (interior diameter of 3.18mm and 0.79mm walls) was used in an attempt to utilise air trapped in water, to reflect underwater sound. The tubing was knotted at the ends and at roughly 1–2m intervals to hold air when submerged. However, parts of the tubing collapsed and fused following extended exposure to salt water, sunlight and water pressure, and it probably did not hold air for the duration of the study period. Bead chain was selected based on the gillnet trials by Hembree and Harwood (1987). It was suspended without polypropylene line and without weights because it was sufficiently dense to hang straight in the water column.

Corklines and hukilaus were placed roughly perpendicular to the shoreline at two observation sites in water 8–10m deep. They were held in place by 5–22lb Danforth anchors; two anchors at each end on 12.7mm diameter nylon or polypropylene line (Fig. 1). To render the structures more visible to boat traffic, 45.72cm diameter orange polyvinyl floats were secured at each end of the corkline. A red flag extending 0.75m above the water's surface was also attached to the corkline.

Observations of porpoises were conducted from bluffs overlooking Monterey Bay (Fig. 2). The sites, located at Sunset and Manresa State Beaches were 67.5 and 22.4m above mean sea level respectively. They were operated (simultaneously on 24 days) from 25 June to 26 August 1988. Each configuration remained in the water from 13–37 days and a minimum of 25 hours of observations was conducted per variable (Table 1). Porpoise movements were plotted with two theodolites: a *Leitz* DT20E and *Pentax* TH-10WA.

Wind speed and direction, sea state (Beaufort scale), cloud cover and visibility were estimated at the outset of observations, and when changes occurred in conditions. All observations were conducted when sea state was ≤ 3, 96.6% were conducted when the sea state was ≤ 2 and the mode was sea state 1.

Porpoises were usually abundant within the study area which allowed us to concentrate on those in the vicinity of experimental apparatus. From computer-generated plots of theodolite data, we assessed porpoise behavioural response to the experimental gear. In 52 cases, porpoises clearly responded by swimming through (Fig. 3a) or by avoiding (Fig. 3b) hukilaus. However, in some cases ($n=30$) it was not possible to definitively ascertain porpoise reaction to the structures. In analysis, we used only those cases for which we were certain about the porpoise's reaction to the gear. The 'closest observed approach' to the gear was measured as the closest surfacing to the gear, even though we were unable to quantify the possibility that they may have proceeded closer to the gear by travelling underwater.

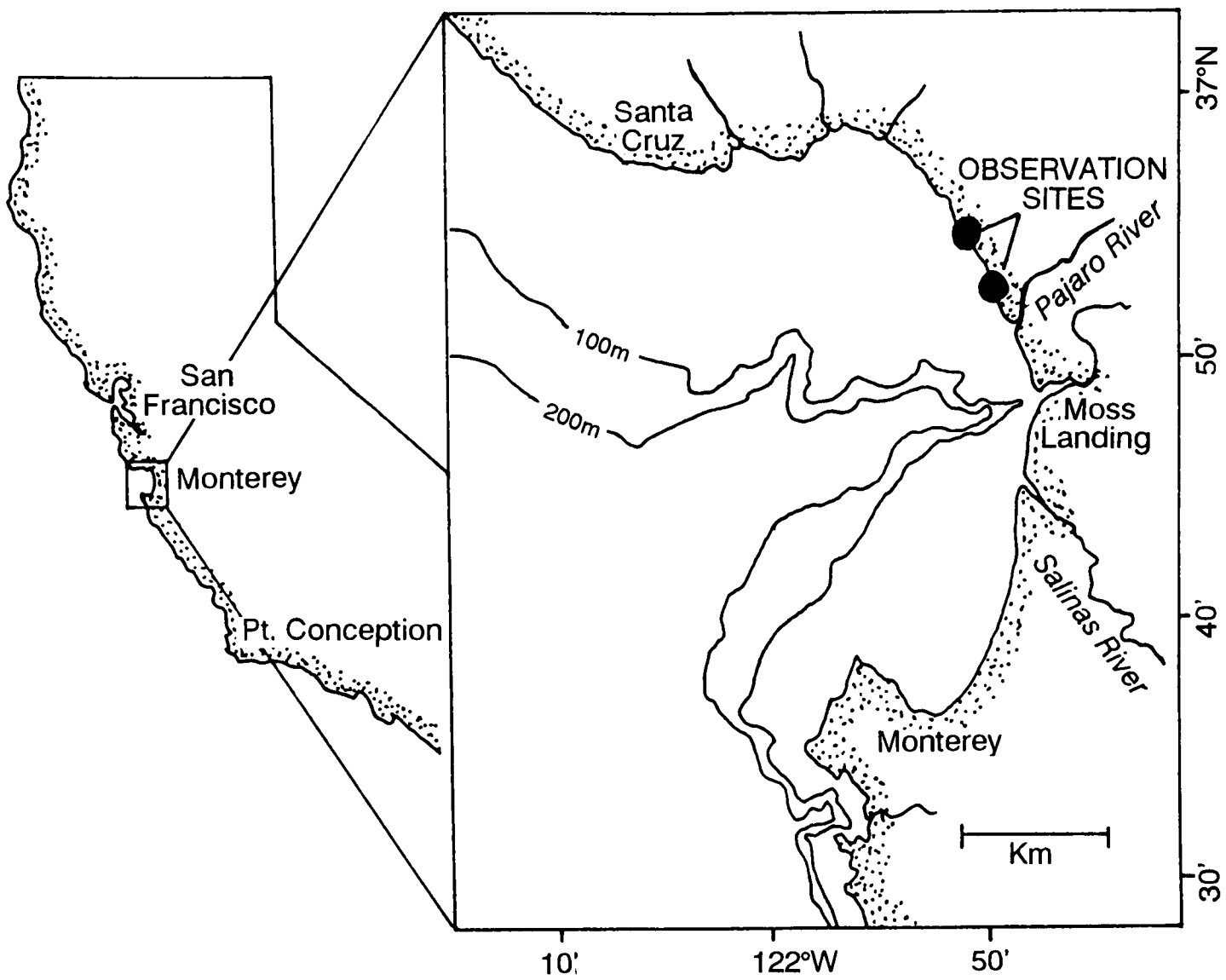

Fig. 2. Study area where harbour porpoise observations were conducted in Monterey Bay, California.

Table 1

Deployment schedule of experimental structures and hours of observation.

Variable	Period	Obs. days	Total obs. hrs.
Cork line	25 Jun - 11 Jul	11	37.5
Polypropylene 3.0m	11 Jul - 23 Jul	9	28.8
Surgical tubing 3.0m	06 Jul - 11 Aug	27	83.7
Polypropylene 1.5m	23 Jul - 11 Aug	10	31.5
Bead chain	11 Aug - 25 Aug	11	25.0
Total:		68	206.5
Mean:		13.6	41.30
SD:		7.54	24.14

A log likelihood ratio test (and Yates continuity correction statistic where appropriate) was used to determine if the number of porpoise groups that altered course differed between configurations. An analysis of variance (ANOVA) was used to determine if differences existed in the distances that porpoises turned from each experimental configuration. A Student's t-test was used to determine if differences existed in the size of groups swimming through versus those swimming around the gear, and the size of groups that swam within 50m of the gear relative to those whose closest approach exceeded 50m.

RESULTS

Although the number of porpoise groups that encountered the experimental gear was relatively small, the proportion that responded by turning differed with each configuration. All of the structures turned some porpoise

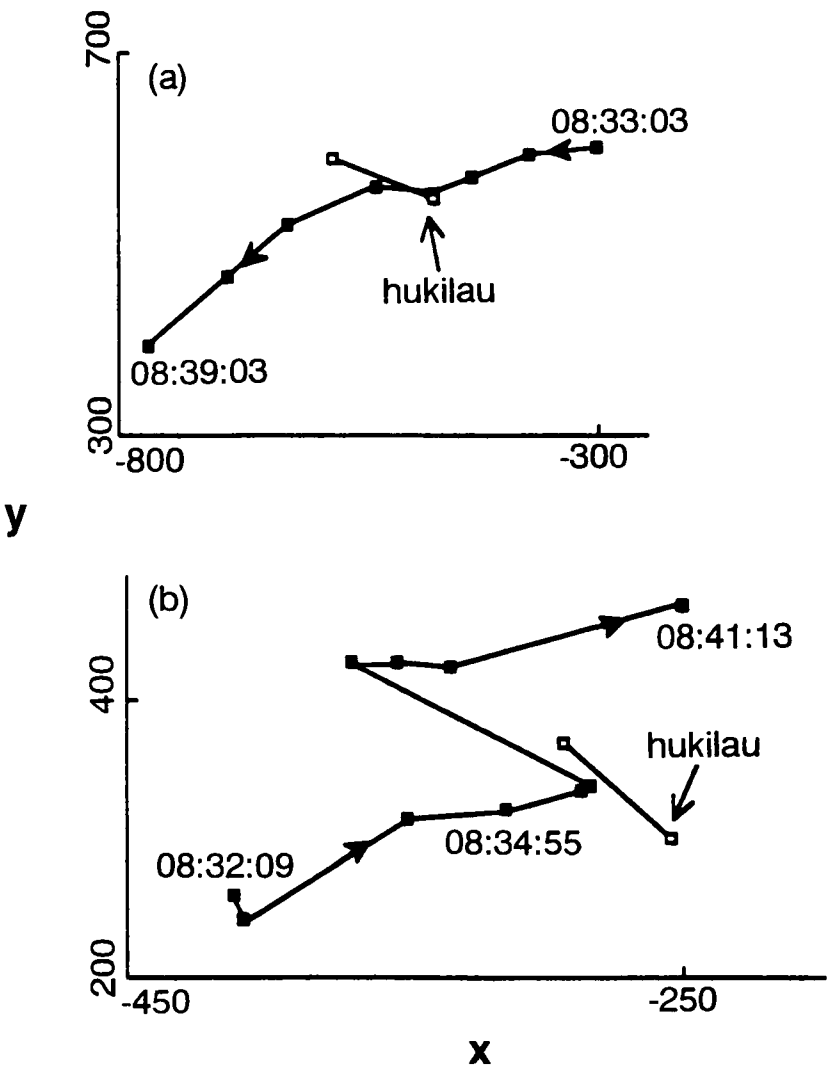

Fig. 3. Plots of porpoise response to experimental structures in Monterey Bay. Example of a porpoise group that swam through bead chain verticals on 14 August 1988 (a), and a porpoise group that altered course relative to surgical tubing verticals on 13 July 1988 (b).

groups, but no structure deflected all groups (Fig. 4, Table 2). There was a significant difference (G=33.86, 4 df, $p < 0.001$) in the proportion of porpoise groups that swam through the five structures. Although some groups were turned by polypropylene hukilaus (vertical lines at 1.5 and 3.0m intervals), porpoises swam through them 68.2% (n=22) of the time (Table 2). The number of groups that altered course in response to polypropylene line did not differ significantly (G=0.0217, 1 df, $0.75 < p < 0.90$) from the number of groups that responded in a similar manner to the corkline alone. There was no significant difference (G=0.113, 1 df, $0.50 < p < 0.75$) between the proportion of groups that turned from bead chain versus surgical tubing hukilaus. Only 25.0% (n=3) of the groups that encountered bead chain and surgical tubing hukilaus swam through them, and there was a significant difference (G = 6.102, 1 df, $0.005 < p < 0.01$) between the number of groups that turned away from these hukilaus relative to all other hukilaus. On two occasions (both were polypropylene hukilaus) porpoises initially turned from the hukilau and subsequently swam through it. Several groups milled near the corkline and two groups swam under it repeatedly.

Although dive times and respiration intervals were not quantified, groups which swam close to the experimental gear (<30m) appeared to dive for longer periods or interrupted patterned surfacing sequences relative to those which did not encounter the structures. This may have been a period in which they explored the apparatus. The mean closest observed approach was greatest for bead chain, least for surgical tubing, and intermediate for corkline and polypropylene hukilaus (Fig. 5), however these data were not significantly different (F=1.178, 4 df, p=0.3576).

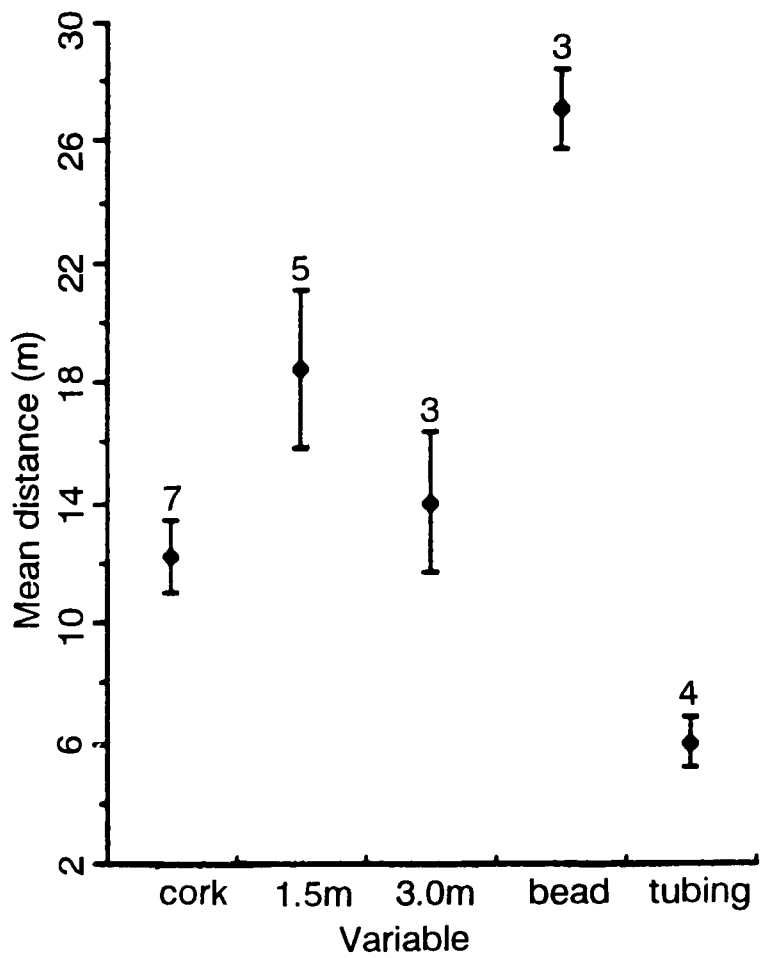

Fig. 5. Mean closest observed approach of porpoise groups relative to each experimental variable. One standard error is represented.

Table 2

Harbour porpoise reaction to experimental structures in Monterey Bay, June through August 1988.

Variable	*n*	Swam through	Altered course	Response uncertain
Cork line	26	11	7	8
Hukilaus				
Polypropylene				
1.5m	22	10	4	8
3.0m	13	5	3	5
Bead chain	6	1	4	1
Surgical tubing	15	2	5	8

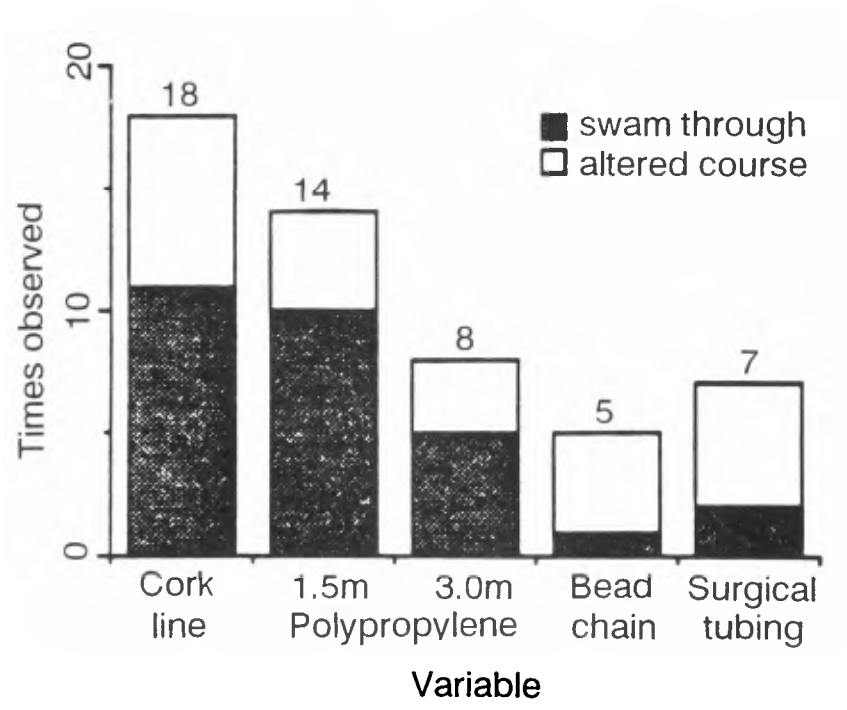

Fig. 4. Number of porpoise groups that swam through or altered course relative to each experimental variable.

Water clarity measurements, using a secchi disc within 20m of the experimental gear, ranged from 2.8 – 7.0m (mean = 4.4 ±1.53 (SD)m, n = 7). The degree of water clarity that we observed near the hukilaus was likely adequate for porpoises to see the structures. Therefore, the porpoises' reaction to the gear (their tendency to avoid or swim through it) probably was not dependent upon their capacity to visually detect the gear.

The mean size of groups that swam through the experimental gear (4.6 ±5.80(SD) individuals, n = 29) did not differ significantly (t = –0.206, 42 df, p = 0.838) from those that altered course or swam around the gear (4.3 ±2.23(SD) individuals, n = 23). However, there was a significant difference (t= –2.382, 77 df, p = 0.020) in mean group size between groups that approached within 50m (4.6 ±4.52, n=44) of hukilaus as compared to those whose closest approach exceeded 50m (6.9 ±3.77(SD), n = 35). It is possible that large porpoise groups possessed greater 'sensory awareness' and the ability to locate the gear was enhanced by cumulative abilities of large groups. Larger groups were more readily seen at greater distances than smaller groups, which may reflect a bias toward large groups being seen more often than smaller groups farther from the experimental structures.

DISCUSSION

Incidental mortality in gillnets poses an actual or potential threat to many cetacean populations worldwide and, in many settings, few alternatives are available to reduce

cetacean mortality in gillnets (IWC, 1994). Our work was undertaken to assess porpoise reaction to a particular type of net add-on or modification that might reduce incidental mortality by deterring porpoises from nets. We showed that some porpoises avoided vertical lines in the water column, although the variables that we tested were not completely effective in deterring porpoises.

Polypropylene vertical lines were no more effective in turning porpoises than was the corkline alone. Polypropylene line is a common material in coastal marine environments where humans are present (e.g. anchor lines). Familiarity with polypropylene line may increase the likelihood of porpoises approaching the material and may account for the lack of response to the corkline alone and to the polypropylene verticals. In contrast, those porpoises that avoided polypropylene hukilaus may have been responding merely to the corkline component of the hukilau. Bead chain hukilaus may have turned a higher proportion of porpoises than did other hukilaus because it was a less familiar material than the other hukilaus. In addition, bead chain hukilaus may have possessed acoustic properties which not only caused a greater proportion of porpoises to avoid this material, but also to change direction at slightly greater distances relative to other hukilaus. Because the surgical tubing did not hold air as intended, it probably reflected very little sound, such as porpoise echolocation signals. However, the tubing turned a relatively high proportion of porpoises. The tubing was used in conjunction with polypropylene and it may have represented a more obvious and unfamiliar material than did polypropylene alone.

Unlike harbour porpoises, spinner dolphins would not swim through hukilaus (Norris and Dohl, 1980). However, spinner dolphins are a pelagic species and are likely to respond to obstructions that are uncommon in their habitat. In contrast, harbour porpoises frequent coastal waters where they are likely to encounter structures in the water column such as pier pilings, kelp and anchor lines. In addition, groups of harbour porpoises typically average less than ten individuals, whereas spinner dolphin groups may contain tens or hundreds of individuals; greater distances between vertical lines may be needed to allow spinner dolphin schools to pass than is required for harbour porpoise schools.

The issue of gillnet mortality is biologically and sociologically a complex problem and a debate exists regarding solutions to high cetacean mortality in gillnets (IWC, 1994). Some researchers advocate a total elimination of gillnets (Dawson, 1991), others recommend fishery closures by location or time, while some believe that it is possible to render the nets less destructive through modifications (for example Goodson *et al.*, 1994).

Clearly more work is needed to address this problem and attempts to reduce cetacean entanglement almost certainly lie in a multi-faceted approach in which several avenues are pursued simultaneously. Restricting the use of gillnets by degree (e.g. time and area closures), the use of alternative fishing techniques, net modifications and total bans should all be considered depending upon the region, the fishery and the marine mammal species involved. Reasons for cetacean entanglement may vary with fishery, net type, means and timing of net deployment, mesh size and target species, and the social structure and behaviour of incidentally captured species.

We believe that in many cases, the abolition of gillnets may be the only solution. However, moratoria on gillnets will encounter resistance due to the detrimental economic impact on fishermen. In addition, in many remote locations enforcing bans on gillnet use will be extremely difficult. It is not reasonable to assume that gillnets will be eliminated in all regions in the foreseeable future, and because cetaceans continue to die, alternatives should be explored in the interim.

Further experimentation on gillnet modifications that reduce cetacean mortality should be considered, particularly if moratoria are not possible. However, gear modifications should not be necessarily regarded as solutions, but as potential short-term means of lowering cetacean mortality rates while more far-reaching and effective solutions are sought. Reductions of even small percentages in entanglement rates could benefit affected populations until permanent solutions are found. For example, in the Gulf of California, where vaquita incidental mortality is high relative to the population size, laws banning the use of gillnets have existed since 1975, but the practice continues unchecked due to a lack of resources to adequately enforce the laws (Vidal, 1994). Attempts to implement additional or more stringent laws are not likely to reduce the amount of gillnetting activity. However, by instituting a programme involving simple modifications that lower entanglement levels, it may be possible to mitigate the impact of incidental mortality, while other people work simultaneously toward the elimination of this fishing practice. Net modifications that reduce but do not eliminate porpoise entanglement rates should not be pursued *in lieu* of the possibility of substituting the use of gillnets with safer fishing methods, but they might provide relief to porpoise populations while more permanent solutions are sought.

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Enhancing the Acoustic Detectability of Gillnets

A. David Goodson

Signal Processing Research Group-Bioacoustics & Sonar, Electronic & Electrical Engineering Department, Loughborough University of Technology, Leicestershire, LE11 3TU, UK

Margaret Klinowska

Research Group in Mammalian Ecology and Reproduction, Physiological Laboratory, University of Cambridge, Downing Street, Cambridge, CB2 3EG, UK

Peter R.S. Bloom

The Dolphinarium, Flamingoland, Kirby Misperton, Malton, North Yorkshire, YO17 OUX, UK

ABSTRACT

The entanglement and drowning of large numbers of the smaller cetaceans in gillnets is a matter of international concern and necessitates research to identify techniques which will minimise such incidental catch. In attempting to explain the behaviour of animals immediately prior to net entanglement in modern driftnets we need to understand the ability of the animal to detect and assess the threat. A non-intrusive study of the behaviour of a solitary wild *Tursiops truncatus* (using sonobuoys) has examined several natural behaviour patterns classified respectively as: foraging, travelling and resting. This paper examines some specific acoustic behaviours which were observed to be employed by this free ranging animal. The interpreted behaviour of this dolphin is seen to further complicate the problems of gillnet perception. No simple solution appears to exist, but for those animals which are actively echolocating the authors believe the best chance of net avoidance requires that the net be detectable near the animal's maximum searched range. The target tracking behaviour employed during fish interception suggests that diffuse obstructions, i.e. gillnets, that can only be detected at lesser ranges, are likely to be ignored. Design parameters for passive enhanced echo reflectors which are orientation independent and optimised for dolphin sonar signal characteristics are discussed in detail.

KEYWORDS: INCIDENTAL CAPTURE; BOTTLENOSE DOLPHIN; ACOUSTICS; BEHAVIOUR

INTRODUCTION

The incidental capture of cetaceans in fishing gear is recognised as the major threat to their populations in many parts of the world (IWC, 1994). Attempts to reduce incidental catches have been hindered by a lack of knowledge as to why cetaceans become entangled. This can be oversimplified as a question of 'detection' (they do not know the net is there) or 'classification' (they know it is there but do not recognise it as a threat). Many of the early attempts to modify fishing gear were based on an assumption that the problem was one of detection. Given that dolphins used echolation it was concluded that the solution was to make nets 'louder'. These attempts rarely considered the detection capabilities of dolphins, their behaviour, the acoustic properties of water or the acoustic properties of the gear.

In this paper we examine these factors and use the information to consider ways of enhancing the detectability of gillnets in a manner that takes into account the physiology and behaviour of dolphins.

PHYSIOLOGICAL AND BEHAVIOURAL CONSIDERATIONS

Most studies of the acoustic capabilities of cetaceans have been of captive animals, for obvious reasons. However, while this is of value in providing baseline data, it is important to study the acoustic behaviour of animals in the wild in order to better address problems, such as gillnet entanglement, that face them in their natural environment.

A common difficulty encountered when carrying out acoustic studies of animals in the wild is that of isolating and identifying the individual sound sources within a group. Studies of a single wild animal, which exhibits repeatable patterns of behaviour, greatly simplifies the problems of classifying activity and correlating the associated sound emissions (Goodson *et al.*, 1988; Goodson and Datta, 1992).

The study animal

The solitary bottlenose dolphin (*Tursiops truncatus*) resident close to Warkworth harbour entrance at Amble by the Sea (Northumberland, UK) has been extensively studied since 1989 (Bloom, 1990; 1991). The animal is a mature male of approximately 20 years (this estimate is based on the dolphin's size, condition, visible tooth wear and apparent lack of tongue papillae – Kastelein and Dubbeldam, 1990). Conveniently, the animal normally remains within sight of shore inside a relatively small, well defined home range which is less than 1km square. Brief excursions outside this favoured area do occur, usually while providing an escort to local fishing boats as they approach or depart from Warkworth harbour. Increasing social interaction between the dolphin and humans, especially with divers, occurred after the first year of study but this modified behaviour is ignored here. Night-time foraging patterns of behaviour seem to be consistent, especially when interference due to human activity is absent.

Equipment

Sonobuoys (modified type *SSQ*41a) were employed to monitor the dolphin's acoustic emissions continuously during 24 hour intensive study periods. The available sonobuoy signal bandwidth was extended upwards to 40kHz and the low frequency response below 50Hz restricted for this application. The signal bandwidth in practice was restricted by the use of the original 'bender' hydrophones. Although sensitive, these hydrophones

possess a rippled frequency response above a nominal 2kHz resonance and are therefore unsuitable for determining signal power spectra or examining precise pulse wave shape. Precision hydrophones (*B&K* 8104s and *Universal Sonar* D/70s) were occasionally used but their deployment for directly wired wideband recording is limited by the weather and turbulent water conditions close to the pierheads. As a result sonobuoy radio telemetry provided the bulk of the data.

AOR Ltd AR-2002 and *Yaesu* FT9600 communication receivers were used to receive the sonobuoy signals. Simultaneous recordings from each deployed sonobuoy were made on separate channels of a wideband *Racal Store* 4D instrumentation recorder at 19cms^{-1} (37kHz bandwidth). A VHS Camcorder was deployed at the pier and operated by the observers. An additional sonobuoy communication receiver assisted the pierhead observers and supplied underwater sounds to the video camera sound track. Handheld VHF radio transceivers were used to coordinate observers, mobile activity, boat handling and the recording/control vehicle (Base) throughout the 24 hour watch periods. The sonobuoy (with a long-life battery pack) deployed at sea was moored between two small surface floats and kept on station by a double anchor system (to avoid entangling the hydrophone). The inshore sonobuoy was deployed 40m clear of the south pierhead and moored using a rope loop with a pulley at the seaward end attached to an anchored surface float. The inshore end was attached to the pierhead and could be controlled by the observers. This technique provided for sonobuoy recovery and replacement if required and allowed the hydrophone position to be optimised without needing a support boat. Subsequent analysis of the instrumentation recordings was aided by a Loughborough Sound Images (LSI) speech work station.

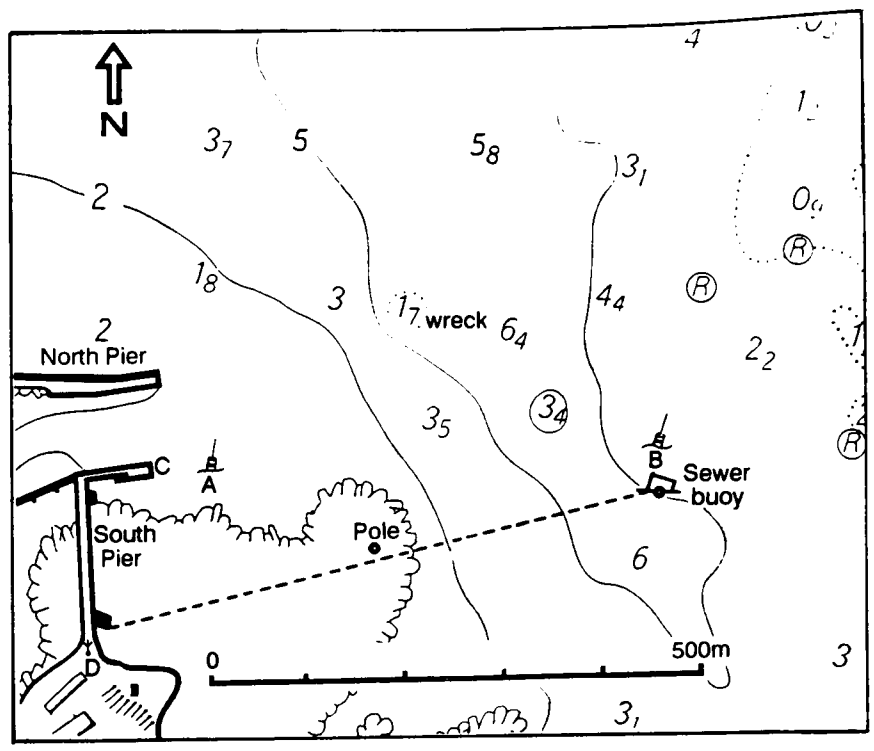

Fig. 1. The Amble dolphin's home range close to Warkworth harbour. A & B – sonobuoy positions; C – south Pierhead observers; D – base station for telemetry reception.

Summary of the animal's behaviour

During 1989 and 1990, the positions of the animal within its home range were logged, during daylight hours, by local observers. In addition, four intensive 24hr studies were carried out in order to acquire data under both winter and summer conditions. Bloom (1991) reported that typically during these 24hr study periods, the animal exhibited behaviour patterns loosely classified as foraging (53%); resting (22%); play or other behaviour (12%). The animal was out of observation range for 13% of the total period. This summary is based on 96 hours of observation, sampled at 15 minute intervals.

Acoustic behaviour – resting

A navigation buoy marking the outfall of a sewer pipeline some 500m offshore (Fig. 1) appeared to be used by the animal as a reference point during resting. The animal spent significant periods circling near it, exhibiting a regular breathing pattern. Sonobuoys deployed nearby registered no echolocation 'click trains' or 'whistle' sounds while the animal was near. A very occasional 'loud click' was the only sound noted which might possibly be classed as a bio-sonar emission from the dolphin (Goodson *et al.*, 1988).

Echolocation behaviour – travelling

The sonobuoy sensitivity is such that good detection of click train emissions could be obtained at ranges in excess of 500m when the animal was orientated towards the hydrophone. At ranges of <100m, the low directivity of the low frequency spectrum sampled ensured that clicks were detectable even when the animal was swimming away from the hydrophone. The relative amplitude of the clicks and their reverberation components also provided clues to changing orientation.

Sonobuoys were deployed at the sewer outfall and close to the end of the south pier. On a number of occasions the animal was timed travelling underwater quickly (8–10ms^{-1}) and directly between these two sonobuoy locations, which were about 500m apart. Echolocation signals were rarely evident in this fast travel mode. This 'quiet' travel behaviour was typical and noted in a variety of sea states, in both winter and summer, and in conditions of poor water visibility and fading evening or dawn light. No evidence was found to support the view that the dolphin employs its active sonar as a navigational aid within this home range.

The preferred foraging zone

The river at Amble passes into the sea between two parallel (concrete and stone) breakwater piers, some 68m apart, which define the harbour entrance. The area immediately outside and between the breakwater arms appears to be a prime foraging area. Sonobuoy deployment 40m seaward of the end of the south pier permitted continuous monitoring of the dolphin's sonar emissions. Observers based on the south pier head were well placed to monitor the dolphin's fishing activity, much of which occurred within 100m of their position. Even in total darkness, the animal's blow could usually be heard at this range while the radio receiver relayed underwater sounds from much greater ranges.

Fish entering or leaving the river must pass between the two piers of the harbour breakwater. Severe tidal scouring effects exist close to the north pier which has been undermined. A sand 'bar' causing a small step discontinuity in the seabed exists between the seaward ends of the piers. The average tidal range is 4.5m and the minimum water depth, measured at the bar, is less than 1m at spring low tides.

Echolocation – search patterns

The animal's search pattern was dominated by a slow, relatively loud click emission typically transmitted at a rate varying between 12 and 16Hz. In rough sea conditions or when the animal chose to fish between the pier heads, the click rate was noticeably faster, up to 25Hz. In contrast, in

calm quiet conditions when the animal was swimming clear of both piers, the slowest repetitive emission rate recorded was 8Hz. These slow repetition clicks were employed over long periods (hours) at a time. They were initiated at the start of a dive and were the emission pattern to which the animal returned after interruptions by other acoustic activity. These pulse trains exhibit a characteristic slightly irregular interval with each sequence settling to, and varying about, the nominal rate (Fig. 3a). The presence of this type of sonar emission has been used to classify 'foraging' behaviour. Foraging activity could occur during any tidal state, although the ebb tide appeared to be favoured. It was rare for the dolphin to fish close to the harbour mouth at low water. Extended periods of fishing activity frequently occurred at night.

There was a short pause after taking breath before these slow sonar transmissions resumed, suggesting that the animal dived to a preferred depth and levelled out parallel to the bottom before initiating a long range search transmission. During this activity, the animal frequently resurfaced in the same position and on the same heading as the preceding dive. The underwater search strategy would seem to be the repetition of a particular underwater manoeuvre.

Changes in the peak received signal intensity were minimised by the sonobuoy's reverberation gain control (RCG) circuitry, but cyclic variations in the relative strength of the inter-click reverberation components suggest that the animal may have been circling slowly on or near the bottom, presumably sweep-searching a large sector. Alternatives to this normal circling pattern included patrolling a path across the harbour mouth some 10 to 20m outside the pier heads and a 'figure of eight' pattern executed between the harbour pier walls. These patterns have been reported independently by divers near these locations.

Interaction with fish

The sudden cessation of the slow 'foraging' clicks and the initiation of a rising pitch 'mewing' sound (Goodson *et al.*, 1988) appears to characterise detection of a target fish and initiation of a chase sequence. After such sounds the animal was occasionally observed to surface holding a relatively large fish in its mouth. On several occasions the dolphin has also been seen to play with a fish, either 'herding' it along the surface or by throwing it into the air (Fig. 2). Salmon, sea-trout, herring, mackerel, cod, coalfish, flatfish (dabs or plaice) and dogfish are among species that have been tentatively identified as prey by both pierhead observers and divers.

Although the transition from the 'foraging' clicks to 'mewing' sounds may occur as a progressive increase in click frequency, it is more common for the foraging click sequence to terminate abruptly and after a brief silent period (some 200 millisecs) for 'mewing' to commence. The perceived pitch of this signal rises and may vary before terminating, either in silence or in an immediate resumption of the slow loud clicks.

Echolocation signals – interpretation

The inter-click period is presumed to define the maximum range being actively searched, as the next transmitted pulse must tend to desensitise the receiver and thus effectively terminate detection of weak echoes returning from greater ranges. If strong long range echoes originating from an earlier transmission are detected then the target range perceived will be ambiguous. The maximum range searched by this animal in ideal conditions is therefore believed to be less than 94m (from the occasional 8Hz repetition rate noted in calm conditions). The slow click repetition rates normally employed suggest that this dolphin was rarely interested in searching for prey much beyond about 60 to 70m, coincidentally the width of the Warkworth harbour entrance. This is also close to the maximum range achieved by trained animals searching for a –35dB target close to the seabed (Murcheson, 1980).

'Mewing' comprises a rapid sequence of discrete clicks emitted in a regular and precisely timed sequence (e.g. Fig. 3b). These rapid clicks appear to be repeated at intervals closely related to the two way sound propagation time between the animal and the target of interest and can be seen to represent the maximum rate at which echo data from the target can be acquired. By concentrating directly on the target range, this technique will effectively mask multipath secondary echoes of the target and also reject much of the echo clutter returned from greater ranges than that of the fish. The consistent range/time interval relationship appears to break down at very short ranges (<1m) but this may well be due to physiological factors controlling the maximum rate of click generation. *T. truncatus* is rarely observed to click at rates much above 1kHz.

Published studies of range locked behaviour (Au *et al.*, 1974; 1982; Turl *et al.*, 1987) are confined to constrained or stationary animals. It is worth considering whether the unrestrained forward motion of a wild animal during target interception should be considered as a parameter affecting the acoustic behaviour and, in particular, the reported variations in latency.

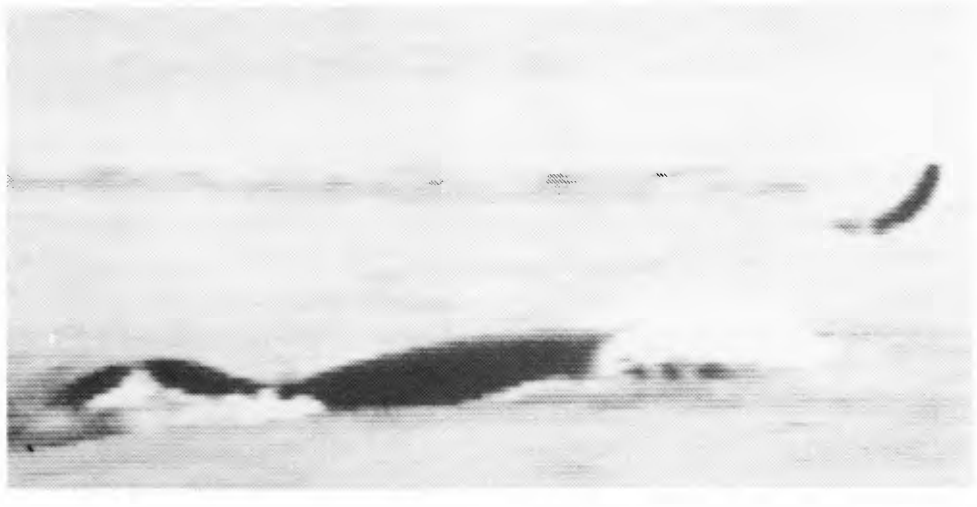

Fig. 2. Throwing a fish (salmonid) into the air.

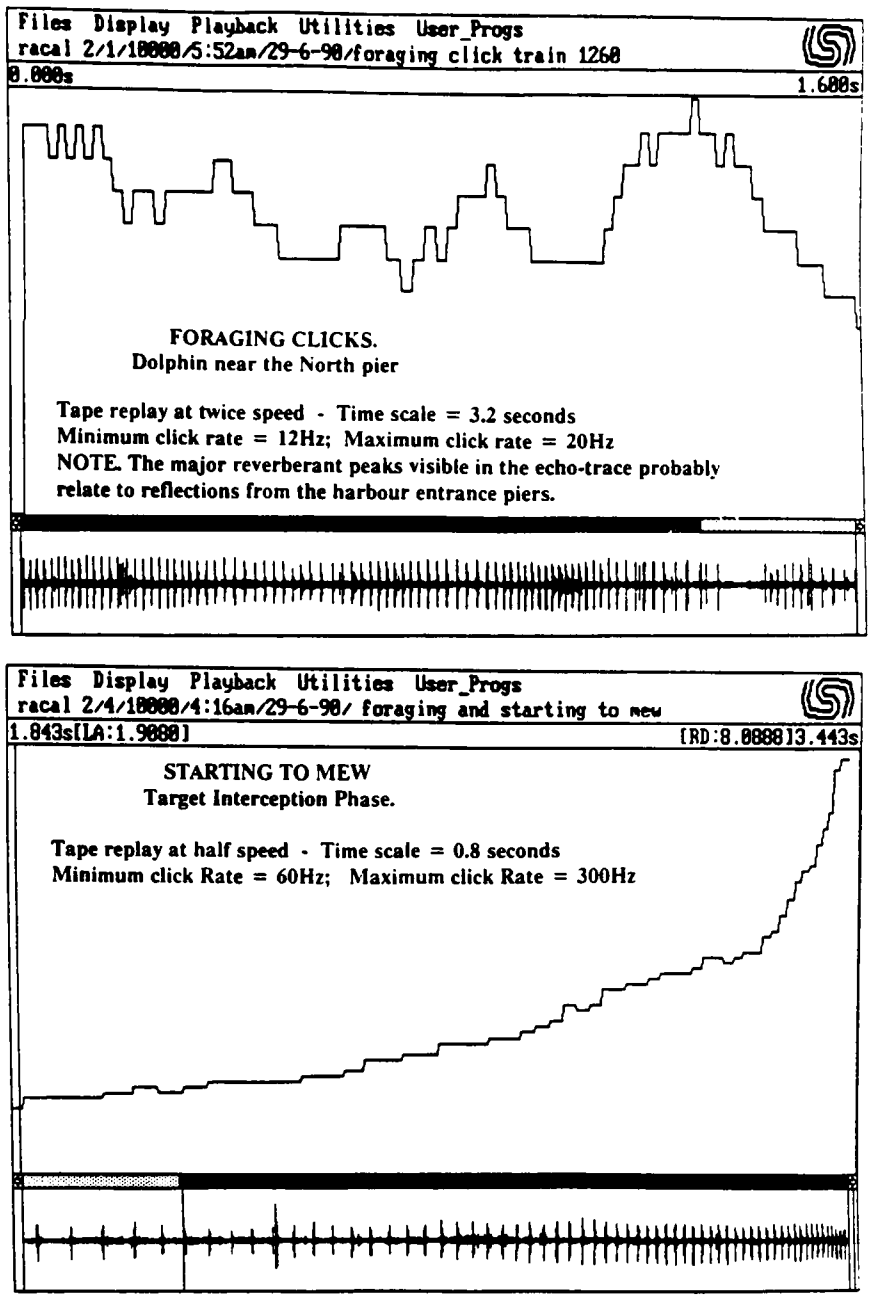

Fig. 3. Inter-click period (instantaneous frequency) plotted against time. (a) Foraging clicks 'unlocked' variable 12 to 20Hz. (b) Target interception phase, starting to 'mew'.

During a typical fish chase sequence, the pitch of the 'mew' increases as the dolphin rapidly shortens the range during interception. Short periods of almost constant pitch are occasionally observed which could suggest that, having achieved a close range, the animal may be content to tire its prey (fish muscle exhaustion tends to occur suddenly, leaving the fish helpless in the path of the dolphin). Alternatively, it seems probable that when intercepting a large target fish with a swimbladder, the increasing click rate employed as the range shortens will match and stimulate a resonant response in the swimbladder. The peak click rate then employed may thus reflect target size rather than range parameters. The subsequent reaction of the targeted fish is unknown but repetitive stimulation of the Mouthner escape reflex through swimbladder transduction is unlikely to aid the fish's ability to escape (Canfield and Eaton, 1990).

Unsuccessful chase sequences or target rejection are assumed to have occurred if 'mewing' stops and foraging clicks are abruptly resumed. The frequency of the 'mew' occasionally fell slightly before terminating. There is of course no reason why the ingestion of very small fish should necessarily interrupt the sonar transmissions. In chase sequences known to be successful, i.e. where a fish was brought to the surface within sight of observers, the sonar transmissions appeared to terminate at capture, the abrupt cessation of the 'mew' occurring at the highest frequency.

Long range 'foraging' clicks exhibit relatively loose timings and the instantaneous rate often seems varied cyclically about a nominal range (Fig. 3a). In contrast, 'mewing' comprises click sequences with precisely timed click intervals. Plots of inter-click period/time profiles (Fig. 3b) can be used to identify segments of acceleration, deceleration or constant swimming velocity relative to a target.

Selecting segments of constant gradient as indicative of a constant velocity allows the relative dolphin/fish velocity to be estimated; the Amble dolphin's swimming speeds during target interception were typically 5ms^{-1} terminating in a brief burst at higher speed (up to 8ms^{-1}).

In some of the data analysed, the dolphin appeared to employ an intercept behaviour built up from segments of nominally constant swimming velocity. If this 'stepped velocity' behaviour is non-accidental, it may be a technique employed to simplify the moving target interception problem.

Echolocation behaviour – implications

The detection and active tracking of a target by a dolphin is characterised by a range locked transmission, i.e. as the echo from the target is detected, the next click transmission occurs. The interclick period normally reflects accurately the range to the target at any instant and the increasing frequency as the dolphin closes with a target gives the observer a reliable indication of distance until the target is very close to the animal. At ranges less than 2.5m the range/frequency relationship ceases to be linear and it is unusual to observe click rates which peak at much above 1kHz, so the effort or usefulness of this information rate is assumed to be rarely needed.

One important benefit of a range locked transmission rate is the effective suppression of over-range target information and multipath 'echo clutter'. The transmission of the succeeding click immediately on receipt of an echo ensures that the echo-receptor is desensitised. A latency period will follow in which the receptor recovers. The perception of any over-range target during an active fish chase would appear to necessitate a very strong echo from the secondary target.

Dolphin sensory perception during fishing activity

The two senses which are usually assumed to predominate during fish hunting activity are hearing (sonar) and vision, with the former clearly the more important. Other senses such as chemoreception, may play a part in long range detection but are not believed to offer more than 'present/absent' clues, although it is not inconceivable that fish or shoals of fish might be tracked by taste. As noted above, at ranges greater than about 100m, the presence of gillnets will provide no warning clues to an animal swimming on a collision course. Underwater vision, even in ideal conditions, will not be able to detect netting until significantly closer than 20m. At night or in 'normal' sea conditions, animals will probably not see a net until collision is imminent. Sound detected in the passive sense may provide coarse hydrographic orientation and position clues to a travelling animal, especially in shallow coastal waters. However, gillnet 'self noise' (i.e. noise generated by the drifting netting due to sea state disturbance) will be at low levels and will probably be masked in most conditions by the background ambient seastate noise; it would be interesting to compare statistics of incidental catch in relation to sea state. The assumption must be then that few clues to a drifting gillnet position will be given to a

passively listening animal. The sense most likely to detect the presence of a net as an obstruction is therefore the active sonar 'echolocation' mode employed by the animals, especially when foraging.

Dolphin sonar – resolution

Bottlenose dolphins project their broadband transient clicks from the melon (Wood, 1964; Norris and Harvey, 1974; Romanenko, 1974). This anatomical feature functions as an acoustic lens of limited aperture and as a result the projected signal is spectrally dispersed in both azimuth and elevation. The energy distribution within a *T. truncatus* high source level transmitted pulse has been shown by Au (1980) to peak spectrally near 120kHz within a tight (10°) conical beam. The dispersive effect of the melon's limited acoustic aperture means that lower frequency components progressively dominate as the observation point is moved off axis (Au, 1980; Watkins, 1980). The projected acoustic 'directivity' pattern can be pictured spatially as a graded series of concentric conical beams of increasing included angle but dominated by progressively lower frequency and lower amplitude spectral components. If the dolphin's angular perception is based solely on the transmitted signal beamwidth, then the animal should have difficulty resolving target position in azimuth or elevation to better than 10° (unless the dolphin ignores the human convention of half-power beamwidth and successfully discriminates echo intensity variations significantly smaller than –3dB). However, trained animals have consistently displayed an ability to discriminate angular position in both azimuth and elevation to better than 1° (Renaud and Popper, 1975; Floyd, 1988). The receptor mechanism by which this angular resolution is achieved is unclear and not explained by the traditional hypothesis based solely on the cochlea response to a fatty tissue sound conduction pathway along the lower jaw. An alternative echo receptor hypothesis, optimised for high frequency echo-reception within the near field, is modelled in Goodson and Klinowska (1990).

It is evident from physical acoustic principles that, regardless of the receptor mechanism employed, the animals angular discrimination of very small objects must utilise the high frequency spectral components contained within its transmission. This perception can therefore only function within the very narrow 'spotlight' beam projected forward along the swim axis. Searching behaviour in dolphinarium experiments supports this, as head swinging actions are employed while swimming towards and discriminating between spatially separated target positions. Once the required decision has been made, the animal points its beak accurately towards the selected target for the final approach phase. For an optically masked target (TS=-41dB) the data acquired during the early learning phase of using three captive bottlenose dolphins an experiment suggested that they left their final discrimination decisions to about 2.5m range (Goodson, unpub. data).

The limiting factors affecting detection of very small sonar targets relate to the target's physical size, geometry and the insonifying wavelength. Progressively reducing the target's dimensions to below 1 wavelength of the incident sound, results in the back scattered echo energy returned towards the source becoming very small (Fig. 4). For very small targets the animal's perception will therefore be limited to the centre line of the transmit axis. Larger targets may be perceived in off-axis positions as the outer conical zones of the transmitted beam are defined by lower frequency and lower power components. If a recording of a sequence of clicks made by the animal as it scans its sonar transmissions across a hydrophone, is slowed down by a large factor (16:1), then the human ear can perceive a significant shift in the apparent pitch of the individual dolphin click. This azimuthal shift in pitch may well provide the initial centring clues during target acquisition. At short ranges, the perception of a phase difference between the echo received by the left and right receptors must explain the ability of an echolocating dolphin to track an elusive fish target down to the capture point in total darkness. The lack of head scanning movements when a dolphin is in the final 'locked on' (mewing) phase of a fish chase and the animal's apparent ability to react to the target's sudden direction changes without employing head scanning actions, would seem to support this (Goodson, unpub. data).

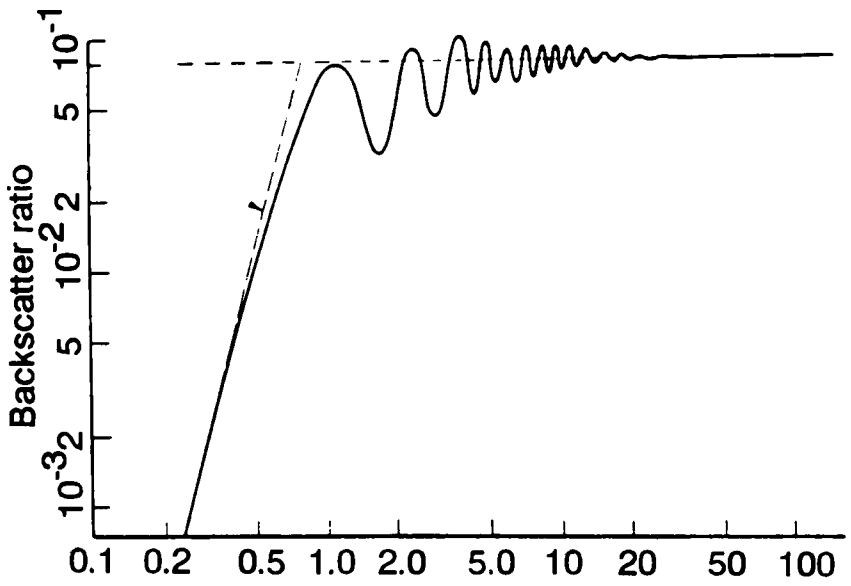

Fig. 4. Acoustic backscatter from a rigid sphere, as a function of the insonifying wavelength (after Clay and Medwin, 1977).

THE PROPERTIES OF GILLNETS

The deployment of gillnetting made from modern polymer materials is an efficient method of fish capture which, although intended to discriminate its target species by choice of mesh size, also indiscriminately captures much larger species through entanglement. Gillnets can be exploited by a wide range of fisheries, from relatively small scale inshore artisanal to large scale off-shore operations. The technique has proliferated throughout the world during recent years and is rapidly replacing traditional fishing methods. The nets are frequently deployed at night in order to capture fish which approach the surface nocturnally. Before the UN ban on large-scale pelagic driftnetting came into force in 1992, vessels in the Tasman Sea albacore tuna fishery each deployed long lengths of gillnet, typically 39km per boat, which hung below the surface in a curtain some 10–15m deep (Coffey and Grace, 1990). Alternatively, in shallow water much smaller nets may be permitted to sink close to the seabed (Karlsen and Bjarnason, 1987). A wide variety of cetacean species are taken as incidental catches and those that escape may only do so after causing significant damage to the nets (IWC, 1994). It seems probable that many of these animals are captured during their own foraging. In a large number of cases the netted animal is unable to break away and once entangled, suffocates. From the fisherman's perspective,

the damage to expensive netting and the associated down time is significant (Lien *et al.*, 1988) and an economic incentive exists to employ methods which minimise the problem.

The Target Strength of gillnet webbing

The Target Strength (TS) of various gillnet materials* have been assessed by Au (1994), by Hatakeyama *et al.* (1994), by Pence (1986) and for tuna purse seine nets by Leatherwood *et al.* (1977). The quoted results differ depending on methodology and materials and the highest values assessed result from insonification normal to the plane of the deployed webbing. Insonification at other angles results in reduced echostrengths and for an azimuth change of 15°, Au (1994) determined a reduction in the perceived TS of 3.8dB. Although he did not examine the worst approach angle scenario, his measurements imply that the peak TS value should be reduced by some 7.6dB in order to allow for a dolphin/net interception along combined azimuth and elevation angles exceeding 15° from the normal. For monofilament gillnet webbing, Au (1994) measured a peak TS value of –58dB. For net detection estimates, the use of the peak value is likely to mislead and a worst case TS value (-66dB) needs to be considered as the general case. Hatakeyama and Soeda (1990) refer to directivity data (provided by Pence) which indicates that small changes in azimuth angle (3–4°) at frequencies of 150kHz and 170kHz should result in a reduction in the perceived TS by 10dB. Thus the 'worst case' TS estimate of –66dB (for a monofilament salmon gillnet with animals intercepting the plane of a net at angles other than 90° in both azimuth and elevation) may still be an overestimate.

In this context it may be argued that foraging animals must spend a significant proportion of each dive projecting their echolocation signal for maximum range in the horizontal plane. However, the actual angle of incidence of a horizontally projected signal at the gillnet interface may not be normal in the elevation plane, as strong thermal gradients near the surface will modify the incident angle at the net by refraction. This effect is likely to be pronounced in tropical waters and may result in a diurnal changes in the bycatch. In addition (for moored nets), tidal displacement will deflect the plane of the net from the vertical.

THE NET DETECTION PROBLEM

Given that the acoustic reflection characteristic of the unmodified gillnet webbing is inadequate for long range detection, an estimate of the increase in TS theoretically needed to alert dolphins can be made from the foraging behaviour and targeted prey of the animals at risk. From observations of the (Amble) dolphin's sonar behaviour and from consideration of the size of the larger fish observed caught by this animal, we can deduce that swimbladdered fish, with a TS in the order of –35dB (re a 2m radius sphere; Foote, 1980) are frequently sought, and are believed to be detectable at ranges between 60 and 70m.

Using the basic sonar equations (Urick, 1983; Au, 1994) to predict the spreading and attenuation losses due to range for a monostatic sonar functioning at 120kHz, we can demonstrate that the equivalent detection range of an unmodified gillnet (TS= –66dB) when compared with a targeted large fish (35–40cm salmon nominal TS=-35dB) at 70m range will be less than 12m.

Knowledge of the actual source level employed and of the animals detection threshold in noise is not essential for this comparison, given that the ability to detect fish of this TS at the stated range has been observed.

Since the prior detection of a fish and the initiation of interception sonar behaviour is believed to exclude the detection of over-range targets, even assuming the simplest scenario the problem of dolphin/net detection cannot be solved unless the net position is always perceived before the fish is detected! That this assumption may be simplistic is witnessed by the (unique) South African shark net bycatch problem (Cockcroft and Ross, 1991; Peddemors *et al.*, 1991), where prior knowledge of the net position could be presumed. However, it may be argued that for the (Amble) dolphin at least, any enhancement of the gillnet TS to a value that is less than about –35dB will be ineffective in the presence of fish. For other animals at risk, the maximum size of fish prey regularly taken can be used to establish a minimum TS value that must be matched or exceeded by the gillnetting if its position is to be detected before that of a fish.

Of course, detectability alone is not enough to ensure that animals avoid entanglement. The echoes from the net obstruction once detected must also be classified as an impenetrable barrier to be avoided. The characteristic distributed echo returns from a curtain of gillnet webbing will appear diffuse and may easily be classified by the animal as penetrable volume reverberation, as would similarly distributed echo returns from seaweed, algae blooms or even the bubble wakes left from passing boats.

Although the addition of reflecting objects to a gillnet to achieve the 'minimum' TS criteria described is possible, net handling imposes serious operational constraints. The physical size of these additional devices, their spacing, shape and buoyancy all need to be considered (Goodson *et al.*, 1994).

Some assumptions about dolphin behaviour and net perception

(1) Dolphins in a resting mode appear to swim relatively slowly (0.5 to 1.5ms^{-1}) and seem to only maintain minimal active monitoring of their immediate environment. Although the evidence is slight, our observations suggest that the occasional loud click thought to be emitted by the dolphin may be intended to maintain a position check. 'Dozing' dolphins sometimes appear slow in reacting to rapidly approaching boats on a collision course.

(2) When travelling fast (5 to 8 ms^{-1}) in known territory, the dolphin does not appear to employ its active sonar; our evidence suggests that active sonar is only used when foraging. Human fishing activity (an occasional bottom set cod net) within the Amble dolphins home range did not result in any reported interactions. The animal was aware of the deployment of the net and presumably treated it as part of its 'normal' environment. Seal/net conflicts in the same general area are a regular complaint of the local fishermen.

(3) While foraging actively for food, the sonar range examined is probably defined by the anticipated prey behaviour and the balance of effort required to intercept, *versus* the size of the reward. The slow click rates employed by our study animal suggest a 60–70m

* When measuring Target Strength (TS) the target dimensions need to be fully ensonified by the sonar beam. If the target's dimensions exceed the beam width, as in a fishing net, the echostrength becomes range dependent. Unless the measurements conditions are fully specified the TS values, conventionally assumed to be in dB re a 2m radius sphere, are not comparable.

maximum search range. Although acoustic searches beyond this range for large targets may well be possible in good acoustic signal/noise conditions, the effort involved in capturing large fish targets detected at extreme ranges is probably uneconomic.

(4) Observed behaviour patterns suggest that the dolphin is searching a large volume of water by swimming slowly in a circular pattern while clicking at these slow repetition rates. From the estimated sizes of the largest fish seen to be caught, the probability of *T. truncatus* detecting a large (TS= –35dB) fish at the maximum range in mid-water is quite high. Target detection frequently occurs at ranges less than the search range maxima, suggesting that the animal is turning onto the bearing of a fish at closer range.

(5) The final attack phase is usually fast (some chase sequences last less than 4 seconds) with maximum speeds estimated at about $8ms^{-1}$. Much longer sequences can occur with inter-click intervals which suggest quite short dolphin/target ranges. These seem to indicate that the target fish may be detectable but less accessible due to the seabed topography. Initial target detection commonly occurs at ranges well under the search maxima.

(6) The dolphin's echo-perception, exploiting its own high frequency signal components, does not appear to be degraded by high levels of low frequency noise. Off-line spectrographic analysis of the recorded signals demonstrated that the dolphin's fishing activity frequently continued while a fishing boat, entering or leaving harbour, passed at very close range, as the presence of foraging click signals is clearly discernible extending well above the relatively low frequency ship noise spectrum (Mitson, 1989).

IMPLICATIONS FOR PASSIVE ACOUSTIC NET MARKERS

Sonar perception of a fish target is not believed to be impaired in the presence of a competing (or cooperating) dolphin sonar. The lack of *a priori* knowledge of the echo/source timing precludes other animals acquiring range information from such echoes. The sharp directivity of the transmission and the apparent focussing of attention to the precise target range during a chase/interception 'mew' can be seen to be an excellent technique to reject such interference. Gillnet detection as a byproduct of a second animal's signal echoes is thus not likely.

Attempts to enhance a gillnet's TS by the addition of simple sound scattering mechanisms such as ropes or 'bead chain' (e.g. Hembree and Harwood, 1987; Dawson, 1994) have not been very effective. However, the mechanisms employed so far are ostensibly inefficient as most of the incident echolocation energy is dispersed omni-directionally. Strong specular echo returns can only be produced from target dimensions which exceed several wavelengths of the incident sound. The very high TS's measured by Au (1994) for 'light switch chain' (-36dB) and for 'poly rope' (-33dB) are the peak values which are specific to vertical deployment with horizontal insonification at one (2.4m) range. At all other angles of incidence the proportion of energy reflected back towards the source from a line reflector (long thin cylinder) is much lower (Urick, 1983; Hatakeyama *et al.*, 1994). The TS is also dependent on range as the length of target insonified by the transmitted beamwidth changes. These factors may partially explain the disappointing second year results noted by Hembree and Harwood (1987) when their 'bead chain' was deployed diagonally within the net structure.

Clearly if a significant proportion of the intercepted acoustic energy is reflected back directly towards the source, independently of the approach angle, then the perceived echostrength will remain consistently high. However, most simple shapes, large enough to return specular reflections, involve flat reflecting facets which are highly orientation and wavelength sensitive and these will rarely be positioned to reflect echoes back directly towards the approaching animal.

Reflecting shapes which return the intercepted radiation back along a reciprocal bearing can be constructed, e.g. the radar 'diamond' commonly found on navigation buoys and small boats effectively increases the TS detected by a ship's radar. However, the acoustic equivalent of an idealised 'corner reflector' has several design parameters which need to be taken into account if the result is to be efficient.

Target Strength – directivity

The strength of echo returned by a target depends on several factors, the most important being the shape and size of the target, the material of its construction and the intensity of insonification and its angle of incidence. The smaller the target, the less the returned energy. However, as the target's size in cross-section becomes $<1\lambda$ of the incident sound, the echo strength returned decreases quickly (λ = the acoustic wavelength in the medium). Small gas bubbles can exhibit resonant peaks in some circumstances and may be an exception to this generalisation. Since λ for sound in seawater at the peak frequency of 120kHz is 12.5mm, this represents a minimum target dimension for *T. truncatus* below which the intercepted energy will be scattered rather than reflected.

The reflecting target's dimensions must be evaluated in terms of the wavelength (λ) of the incident acoustic wave (see description in Clay and Medwin, 1977; Urick, 1983). As a simple guide, if the re-radiating target cross-section equates to a flat disk of single λ diameter, the reflected energy will be re-shaped as a spreading cone some 60° wide together with lower intensity side lobes (note that when the echoes are perceived by a monostatic sonar, this angle appears to be 30°!) For smaller target dimensions, the reflected energy is scattered over wider angles and tends towards an omnidirectional distribution. For larger apertures, the width of the reflected cone of sound will be progressively narrowed and hence more intense (for a 2λ diameter aperture the cone becomes 30° etc.) Conventional acoustic engineering utilises 'wave numbers' ($k=2\pi/\lambda$) to simplify the problems of estimating TS variation with size in a given medium. When the wave number defined by the surface dimensions (radius=a) and $ka>5$, then the object is assumed to reflect 'geometrically'. When $ka<5$, 'Rayleigh' scattering effects dominate. Diffraction effects result in a rippled amplitude response as the dimensions approach $ka=1$ and these less predictable sizes are normally to be avoided (Fig. 4).

The most predictable reflecting shape, which has frequency independent characteristics and a consistent TS independent of the incident angle, is a large sphere, but attempting to obtain large TS's by increasing size will rapidly lead to net deployment problems. However, some non-spherical target shapes can offer significant size advantages.

Cylinders of significant length (with a diameter where $ka>1$) will only return strongly directional echoes towards the source if the incident wave approach angle is normal to the straight cylindrical surface. However, the energy is spread omnidirectionally in the other plane by the circular cross-section. To be effective this shape would require accurate vertical deployment within the net structure and even so, unless the animal approached horizontally, the perceived returns would be minimal.

Thin cylinders ($ka<1$), i.e. ropes or bead chains, are much less effective, as the sub-wavelength cylindrical crossection is a Rayleigh scatterer and the specular return due to the length insonified is sharply directional.

Flat disks deployed in the plane of the vertical net wall suffer the same disadvantage, in that the maximum return only occurs for incident signals normal to the surface. Although these reflections are relatively intense, in a practical deployment they cannot be assumed to occur towards the approaching animal (there is a special case where $ka=1$ which, although inefficient, may be considered a useful economic option).

It should be clear from these examples that the angle of incidence to a reflecting surface is critical.

Acoustic impedance

The target material affects the percentage of energy reflected *versus* that transmitted. Most animal and fish tissues are relatively transparent to sound, and more incident energy passes through the target than is reflected. The best sound reflection will occur from materials with a ρc value very different to water, e.g. a gas bubble reflects incident energy well (ρc is an expression of acoustic impedance and is the product of ρ, the density and c, the sound velocity for the material.)

Synthetic net materials, especially the monofilament varieties, are relatively transparent to sound. Traditional net materials, twisted from natural fibres, tend to trap significant quantities of air which are retained for quite long periods of immersion and hence exhibit much higher TS's. Fish TS in the swim bladder species is dominated by the bladder gas bubble (Foote, 1985). For species without a swim bladder, the bone skeleton may reflect sound better than the flesh, but as the proportion of bone is small, the overall TS of such fish is significantly lower. Molluscs such as squid and octopus are predicted to have low TS's relative to body size.

Efficient sound reflecting materials must exhibit a significant mismatch in acoustic impedance when compared to water; both very dense materials and very low density materials can be good reflectors.

Dense materials such as rock or metal with high ρc values reflect echoes which are in-phase with the insonifying signal. In contrast, gas-filled objects (including foamed plastics) are classed as 'pressure release' and produce echoes characterised by a phase reversal between the incident sound and its echo, a perceptual detail that a dolphin may be capable of exploiting when classifying targets as potential food. Evidence that a dolphin can detect the difference between an initial 'rarefaction' and a 'compression' pulse is reported by Ridgway *et al.* (1981). The possibility that echoes from gas bubble filled objects could be perceived as 'food like' and therefore act as 'attractors' must be considered.

A further disadvantage of gas-filled objects is the difficulty of ensuring accurate shape retention with increasing water pressure. Thin-walled plastic tubes, balls etc., all tend to collapse or deform badly with hydrostatic pressure and predictable reflection characteristics cannot be assumed.

Any material selected for deployment at sea must be examined for its longevity in saltwater corrosive conditions. Most metals are very susceptible to electrolytic corrosion and connections made with dissimilar conductive materials can result in very rapid dissolution.

Deployment – reflector distribution

The distribution pattern of any deployed reflectors must also be considered. It is desirable that the dolphin perceives the enhanced net as a continuous barrier rather that a series of minor obstructions. Experiments with spinner dolphins, using net crowding techniques, have shown that escape apertures less than 1m x 1m in size seriously deterred the animal from attempting to pass through (Perrin and Hunter, 1972). If this factor can be transposed to distributed point reflectors, then an equivalent distribution density of $1m^{-2}$ provides a useful starting point for experimental evaluations.

The TS of reflectors must to be as high as possible in order that the barrier created can be perceived in the presence of fish targets. However, physical size, shape and total mass must be compatible with net handling. Specifically the shape chosen must pass through net handling gear without damaging the net to which it is attached. Similarly the attached device must be retained on the net efficiently without creating entanglement problems in storage. The total mass of the reflectors must not seriously alter the net buoyancy or behaviour when the net is set. The distributed pattern of reflectors must not impair the primary function of the net which is to catch fish. Finally, the extra cost of net modification must be seen to balance the significant down time losses currently incurred through net damage.

Preferred echo-enhancing shapes (Fig. 5)

One practical option is to create a disk reflector surface as a segment taken from a larger sphere i.e. a bi-convex lens shape. The surface curvature must be selected to return the echo into a suitably restricted range of approaching angles. The device must be mounted in the plane of the net and will then generate quite large TS's without excessive physical dimensions. This reflector will be least effective at grazing angles of approach to the net.

A corner reflector 'diamond' shape, with included 90° facets is probably the most efficient relatively simple shape. Almost all the incident energy is double reflected back into the approaching dolphin's path. However, the angular shape may be incompatible with net handling operations, although it could be deployed in fixed gear and in beach protection 'shark nets'.

Reshaping a sphere into a faceted polygon can offer some enhancement if the size is carefully optimised: if the facet size is small ($ka<1$) there is no advantage, as the object behaves as a sphere of the same overall size; if very large, then the echo return pattern will possess deep nulls between peaks.

A cast metal 'icosahedron', with the faceted sides replaced with corner reflecting recesses, is an effective and compact target. However, in this context, the shape complexity may make mass production uneconomic.

A simpler shape with few of the perceived disadvantages of the previous examples, is the 'bi-conic' or 'diabolo'. This in effect is a cylindrical corner reflector constructed from two conical 90° sections mounted point to point.

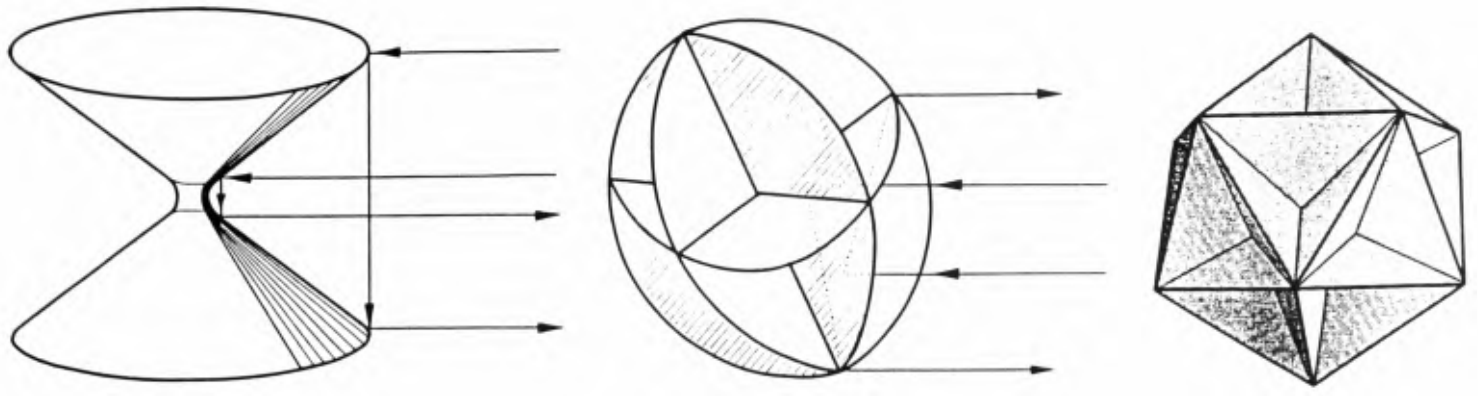

Fig. 5. Strong echo forming target shapes which return significant energy directly back towards the source.

Reflections are returned towards the source by double reflection as from a line reflector, energy in the other plane being spread cylindrically. These shapes may be made compatible with net handling and a variety of mass production techniques appear possible and requires more detailed study.

An additional reflection mechanism offering a high TS for a given size is the 'focussing sphere' (Folds, 1971). This device comprises a thin wall spherical metal shell containing a high density liquid filling (SG 1.8 – 1.9) with a high sound propagating velocity. The sphere size and the liquid filling are selected to bring the incident (planar) wave front to a focus on the back wall of the sphere where total reflection occurs. The liquid lens then refocuses the returning echo back along the incident path. For a given size, this device can offer the strongest echo return towards the source, but the TS is frequency dependent. The concept of liquid filled spheres as net markers does not lend itself to practical deployment in a fishing industry context and in any case the liquid fillings, some based on CCl_4, could involve handling problems.

Target dimensions

The dolphin 'click' signal comprises a relatively wide band transient pulse with a duration of less than 1ms. When this transmission is sampled on-axis, its energy spectrum is observed to peak near 120kHz, within a 10° (-3dB) beamwidth, (Au, 1980). If the signal is sampled outside this angle, the spectral peak is observed to fall as a direct result of the limited acoustic aperture of the melon. Measured at 60kHz, the projected beamwidth will be approximately 20° wide. Since an animal's acoustic sensitivity is best between 60 and 80kHz and still excellent at 120kHz (Johnson, 1966; Seeley *et al.*, 1966), it would seem a desirable compromise that echo-reflecting net markers should provide enhanced echo returns at all these frequencies.

Fig. 6 compares the computed maximum TS's predicted for a range of dimensions, with a 60kHz insonification, for some of the shapes discussed. These were based on formulae listed by Urick (1983) and from J. C. Cook (pers. comm).

For a nominal TS of –35dB at 60kHz, the computed size for each shape will be:

Sphere = 7.1cm diameter	(ka>5)
Corner reflector = 2.3cm sides (4.6cm dia.)	(ka>2)
Diabolo= 5.6cm diameter	(ka>5)

Clearly other target shapes can be considered, especially as the conventional design requirement of a constant TS with angle can be relaxed in this application. However, a successful net marking reflector must meet not only the acoustic but also mechanical and economic criteria to be acceptable to the fishing industry.

This above discussion has concentrated on passive reflectors with dimensions optimised for detection at the maximum foraging ranges searched by the smaller delphinoids. The concept is unlikely to be as effective for the larger echolocating animals as their echo-perception is assumed to exploit much lower spectral components. To be effective for these, the passive reflectors would need scaling in size but this is likely to exceed the mechanical limitations imposed by commercial net handling.

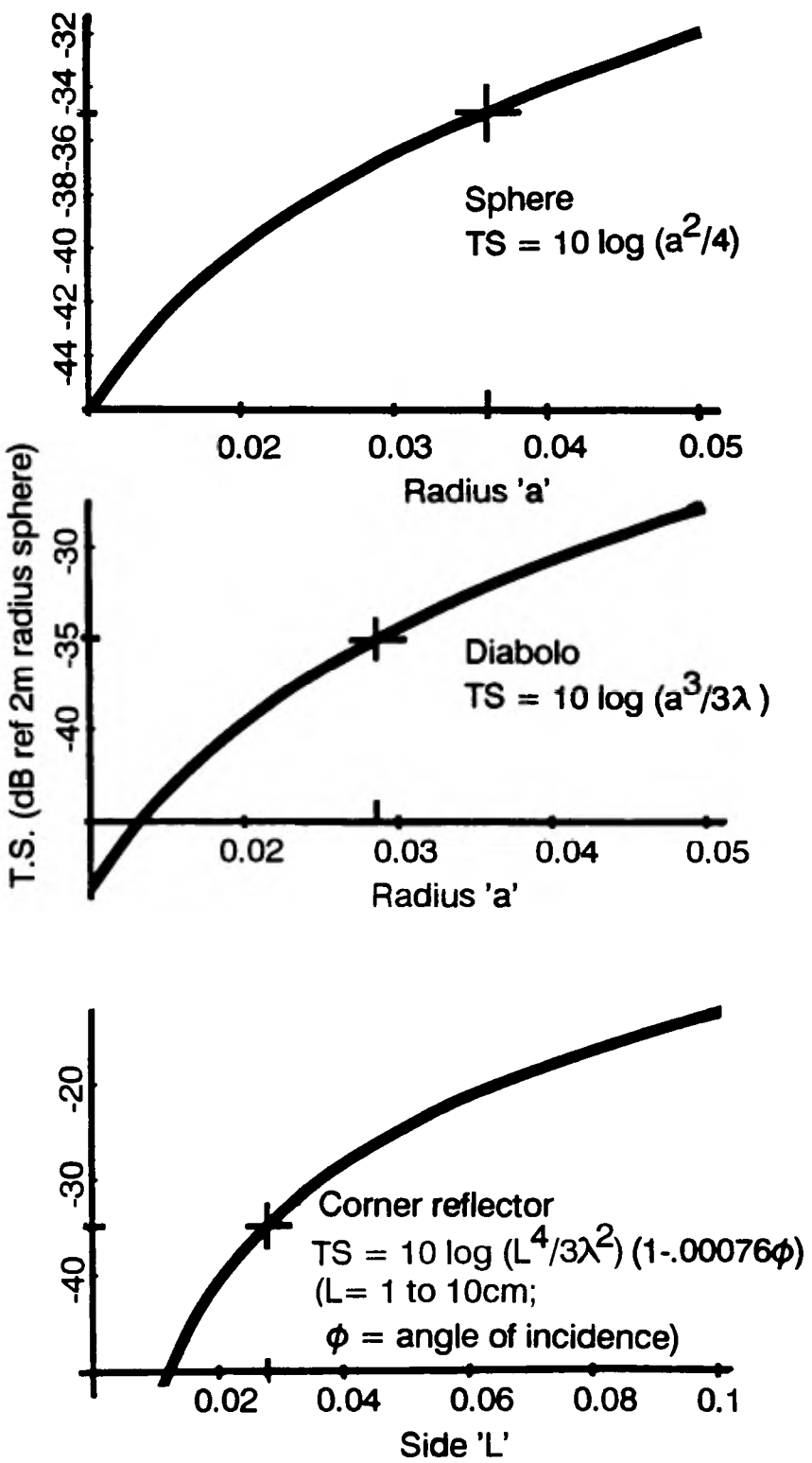

Fig. 6. Computed TS for a range of sizes, a=1cm to 5cm at an ensonifying frequency of 60kHz.

CONCLUSIONS

The sense most likely to perceive a fishing net obstacle is the dolphin's active sonar but this is only likely to be in operation when the animal is foraging for food. At other times, active sonar cannot be assumed to be a factor. If a dolphin is fishing and has already detected and locked its sonar repetition frequency onto the range of a target fish, then echoes from greater ranges are suppressed and perception of a fishing net prior to entanglement is unlikely unless the TS of the net is enhanced very significantly. Advance warnings from echoes generated by other dolphins in close proximity are unlikely to provide any interpretable information about the obstacle's presence.

Increasing the gillnet TS by the addition of wires, ropes or thin 'bead chain' will be ineffective if these devices are intercepted at incident angles other than normal. True vertical deployment of these acoustically 'thin cylinders' is essential if the technique is to be of benefit. Enhanced echo reflector shapes can be designed to return strong specular echoes directly towards the approaching animal and such devices are more likely to be perceived independently of the azimuth/elevation angles of approach. The distribution of reflecting devices along the net may need to approach a $1m^2$ pitch spacing if the echo structure is to be classified as an impassable barrier by the animal.

In order that an animal can perceive the net position before locating a fish, the gillnet TS needs to be increased to be at least as detectable as the maximum size fish prey normally taken. The stomach contents of autopsied bycatch victims should be examined in an attempt to obtain this information for all vulnerable animal groups.

If the reflecting surface of the TS enhancer is manufactured from a pressure release material, single surface reflections may be perceived as 'food-like' and could act as attractants. The same effect may occur with time as the captured target species accumulate in the net. The mass, buoyancy and shape of the added reflectors need considering carefully as these parameters will affect the deployed behaviour of the gillnet and its handling during deployment and recovery.

The passive reflector target shapes which seem worthy of practical evaluation should include the 'diabolo', 'diamond' corner reflector and derivatives of these. In practice, however, any design which demonstrates a measurable reduction in cetacean bycatch must also satisfy additional mechanical and economic parameters imposed by the commercial gillnet fishery if it is to be accepted without legislation.

Additional economic and ecological incentives in favour of significantly increasing the fishing net TS can be found in the context of lost netting. Lost fishing gear, particularly bottom set nets, continue to fish for long periods as 'ghost' nets, the recovery of such gear is likely to be simplified if the nets can be more easily located by a ship's echosounder.

Goodson *et al.* (1994) describe how the principles described in this paper were put into practice in the development of a prototype modified net and in initial field trials.

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Field Testing Passive Acoustic Devices Designed to Reduce the Entanglement of Small Cetaceans in Fishing Gear

A.D. Goodson

Signal Processing Research Group – Bioacoustics & Sonar, Electronic and Electrical Engineering Department, Loughborough University of Technology, Loughborough LE11 3TU, UK

R.H. Mayo

Department of Civil Engineering, Loughborough University of Technology, Loughborough LE11 3TU, UK

M. Klinowska

Research Group in Mammalian Ecology and Reproduction, Physiological Laboratory, University of Cambridge, Downing Street, Cambridge CB2 3EG, UK

P.R.S. Bloom

The Dolphin Centre, Flamingo Land, Kirby Misperton, Nr Malton, North Yorkshire YO17 0UX, UK

ABSTRACT

Field trials to examine the behaviour of wild bottlenose dolphins in the presence of passive acoustic deterrents supported in a surface set gillnet configuration were carried out in September 1991 and 1992 in the Moray Firth, Scotland. Leading animals were tracked using electronic theodolites as they interacted with these barriers which were placed across their regular travel paths. Underwater acoustic behaviour was recorded from hydrophones via radio telemetry. Avoidance behaviour was consistently initiated at ranges greater than 50m and occasionally greater than this. On only two occasions behaviour that might have resulted in entanglement was observed. In addition a sea trial using commercial tuna gillnet gear was undertaken in which a sidescan sonar was used to evaluate the acoustic detectability of both modified and unmodified components. The potential of passive acoustic deterrents for the reduction of cetacean bycatches in commercial fisheries is discussed.

KEYWORDS: INCIDENTAL CAPTURE; FISHERIES; NORTH ATLANTIC; BOTTLENOSE DOLPHIN; ACOUSTICS

INTRODUCTION

The problem of incidental catches of marine mammals (and indeed other non-target species) in fishing gear is well known (IWC, 1994). As discussed in Goodson *et al.* (1994), one approach to the problem has been to investigate ways of making nets more apparent to the animals. Although a number of attempts to increase the acoustic detectability of fishing nets have been made, the methods employed have been largely ineffective in achieving a reduction in cetacean bycatch (see review by Dawson, 1991). In general, the techniques employed did not consider the wavelength-dependent resolving power of dolphin sonar signals, the directivity of the reflectors or the behaviour-related restrictions imposed by the animal. Furthermore, the problem is now seen to include target classification, i.e. it is not simply a problem of detection (Au and Jones, 1991; Au, 1994). In other words, it may be difficult for dolphins to interpret weak diffused echoes from nets as a life-threatening hazard, when experience has taught them that similar volume scattered echoes, returned by algae or by entrained air bubbles, are penetrable zones to be ignored, especially when a discrete fish target can be detected on the far side (Goodson, 1992; 1993).

As described in Goodson *et al.* (1994), our approach differs significantly from these earlier attempts in that we seek to enhance the detectability of the fishing net under all conditions to a level at least equivalent to that of the larger prey sought by the foraging animal. This objective cannot be achieved by simply altering the dimensions, material or other base characteristics of the gillnet mesh, as the reflectance of the webbing structure is primarily limited by its geometry (assessed in wavelength terms). Even if the webbing were to be constructed from a perfectly reflecting fibre material, the overall Target Strength (TS) enhancement that could be achieved is unlikely to exceed 10dB above that of unmodified monofilament nylon. Goodson *et al.* (1994) estimated that enhancements greater than 25dB may well be required. To achieve such improvements, the devices added need to be efficient acoustic reflectors returning echoes directly back towards the source (analogous to 'cat's eyes' road markers which reflect car headlights back to the driver). Some limitations of dolphin sonar in the context of net-like targets and parameters to be considered when attempting to apply acoustic engineering techniques to the design of efficient passive acoustic reflectors have been discussed elsewhere (Goodson, 1990; Goodson *et al.*, 1991; 1994; Goodson and Datta, 1992).

Whilst an efficient reflector design must be optimised to suit the characteristics of the individual odontocete sonar, a consideration of the wavelengths involved suggests that a common solution for the delphinid species similar to the bottlenose dolphin (*Tursiops truncatus*) and for the smaller phocoenids seems to be practical. In summary then, to at least have the possibility of success in addressing the bycatch problem, the following acoustic characteristics would be required of a sonar reflector:

(1) echoes from the approaching animal's sonar must be reflected directly back towards the animal, regardless of its approach direction in either azimuth or elevation;
(2) the device must be large enough (in acoustic terms) to intercept and return a specular echo with sufficient energy to become a more detectable target than the

largest fish normally foraged for – the individual devices should be detectable at the maximum search range of the animal;

(3) the reflecting devices must not generate echoes which can be incorrectly classified as 'food-like' or the devices may function as attractors;

(4) the distribution of the devices across the face of the net must be perceived (at close range) as an impenetrable barrier.

These minimum parameters have been quantified, largely through detailed studies of wild bottlenose dolphin foraging behaviour, and several physically small prototype reflectors have been engineered which appear to meet these requirements (Goodson *et al.*, 1994). For a bottlenose dolphin foraging in relatively shallow water, a reflector with a TS of approximately –35dB (reference a 2m radius sphere) appears to be optimum.

This approach has been used to identify a commercially available device which possesses acoustic and mechanical characteristics that meet many, but not all, of the parameters needed by an optimised reflector. The present paper describes a series of experiments that have been devised in which the distribution of these devices, supported within a simulated surface gillnet configuration, could be closely studied in interactions with wild bottlenose dolphins. These experiments are similar in concept to those described by Silber (1994). However, our approach also includes the monitoring of cetacean echolocation signals underwater in the vicinity of the barriers, video recordings and a high order of achievable precision in the electronic theodolite tracking technology (Mayo and Twigg, 1993). The preliminary results presented here confirm that the devices tested function effectively to deter echolocating bottlenosed dolphins at ranges in excess of 50m and occasionally from as far away as 170m. These initial experiments allow interaction data to be obtained at a faster rate than can be achieved in a commercial fishery and without placing the animals at risk of entanglement. At this stage the experiments were not designed as statistical tests of efficiency but were rather qualitative studies to determine the value of continuing the current line of research.

The practical problems that fishing nets modified with this reflector technique may cause to commercial fishermen have also been examined in a short sea trial off Cornwall, in which an experimental net was shot and hauled and examined with a side scan sonar for its acoustic detectability.

MATERIALS AND METHODS

Wild dolphin interaction trials held in the Moray Firth

The site chosen for the first field test carried out in September 1991 was the Moray Firth, NE Scotland. This was chosen for a number of reasons. The bottlenose dolphins in the area are already being studied and a catalogue of approximately 150 photo-identified individuals has been compiled (Wilson *et al.*, 1992). Although not used in the trials described here, the potential to identify individual animals may be important for future work. Animals are regularly sighted within 200–600m of shore near the entrance to the Cromarty Firth, where there is good visibility from adjacent 50m cliffs and the seabed in the zone of interest is flat (hard sand) with a minimum water depth of 7m. A larger scale experiment was carried out in the same area in September 1992.

Equipment and procedures

As shown in Figs 1 and 2, in 1991 a single barrier, consisting of a buoyant head-rope from which thin rope tails were attached, was deployed perpendicular to the shore, across the predicted path of the dolphins. The acoustic reflectors were attached at 2m intervals to the rope tails, which were spaced 2m apart. The head-rope was 200m long, half unchanged and half supporting a grid of reflectors, comprising an obstruction 100m x 7m deep.

In September 1992, a larger scale experiment was carried out using two 200m long barriers of reflectors distributed on a 2m x 2m spacing. On the last two days of the two week study concluded with one barrier reconfigured with a reduced numbers of reflectors (6m x 2m spacing).

Details of the differences between the 1991 and 1992 trials are illustrated in Fig. 1 and Table 1.

A detailed list of equipment for both years is given in Table 1. The experiment extended that described by Silber (1994), with the dolphins being tracked by their surfacing positions using an electronic theodolite (with data logger), and underwater acoustic activity monitored with sonobuoys. The theodolite employed was also capable of working as a distance measuring device and in this mode the instrument could be used to accurately measure its own height above sea level. Subsequent measurement of horizontal and vertical angles enabled the Northings and Eastings of each surfacing position and of the head rope barrier, to be calculated and plotted. The precise times of these readings were also recorded. As only one theodolite of this type was available it was usually not possible to track more than the leading animal(s) from each passing main group, even when several distinct sub-groups were present. To back up the theodolite readings, two video cameras and voice-logging recorders were used. The underwater sounds, received from the sonobuoy hydrophone by radio telemetry, were recorded on a four-track instrumentation machine, together with timecode and a voice log. A second receiver simultaneously fed the telemetry to an R-DAT digital recorder. In general, observations could be maintained only between dawn and dusk, as the team was too small to provide full 24-hour cover.

Initial handling trials at sea

A short sea trial took place in Cornwall in June 1992, where both modified and unmodified panels of gillnet were shot and hauled in order to evaluate handling problems. Additionally the acoustic detectability of echo-enhanced net panels was compared with equivalent un-modified sections at different ranges and angles using a 100kHz sidescan sonar.

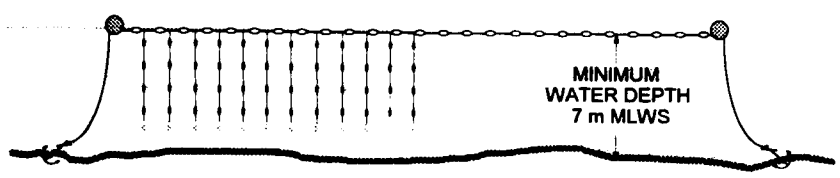
Equipment and procedure

A short sea trial to discover any practical problems associated with using modified nets was arranged with the support of the Sea Fish Industry Authority on board a UK gillnet fishing vessel, the 15.25m (overall length) *Britannia V* (FH 121). A test net, based on a commercial tuna net, was prepared (Table 2, Fig. 3). The reflectors had been prepared, by a commercial twine manufacturer, within a mixed fibre flat braid. This technique was chosen with a view to ease of handling and reducing the likelihood of 'buttoning', which would cause adjacent layers of netting to catch together. Braiding also avoids the torque effects that occur in a conventional rope when under tension.

Table 1

Equipment for Moray Firth 1991/92 Trials.

Equipment	1991	1992
Radio		
Telemetry from hydrophones	Wide band sonobuoy; Type UEL 30059 modified for extended life	SSQ904 sonobuoys modified for wide band operation
Telemetry receivers	*Yaesu* FT9600 (2); *Icom* R1; *AR* 2002	*Yaesu* FT9600 (2); *Icom* R1; *AR* 2002
Communications	Hand-held radios (4)	Hand-held radios (4)
Recording equipment	*Racal* Store 4 DS - high speed instrumentation recorder; *Aiwa* HD-S1 R-DAT recorder; *Nagra* IV SJ reel to reel	*Racal* Store 4 DS - high speed instrumentation recorder; *Aiwa* HD-S1 R-DAT recorder; *Nagra* IV SJ reel to reel
Timecode	*Yam* EBU timecode generator and reader	*Yam* EBU timecode generator and reader
Video equipment	*Sony* Broadcast Hi-8; *VHS* camcorder; *JVC* portable recorder	*Sony* Hi-8 V5000; *VHS* camcorder; *JVC* portable recorder
Theodolite	*Sokkia* Set 5, EDM prism and data logger	*Sokkia* Set 5 total station, EDM prism and data logger, *Sokkia* DT4 theodolite
Computer	*Walters* 386 notebook	*Walters* 386 notebook, *Apple-Mac* power book, Husky Hunter
Vehicles	*Ford* camper (base); *Shogun* 4 x 4 (all-terrain transport)	*Ford* camper (base); *Shogun* 4 x 4 (all-terrain transport)
Boats	7m hard chine double hull motor boat *Zodiac* inflatable with outboard motor	Orca - Ex Air/Sea Rescue launch Osprey - rigid inflatable
Test barrier	1 x 200m headline, half rigged to support a 2 x 2m grid of reflectors (see Fig.1); made to the same specifications as the headline of the Eastern Atlantic tuna gillnets	2 x 220m headlines rigged with reflectors initially at 2 x 2m spacings with leadlines (see Fig.1)



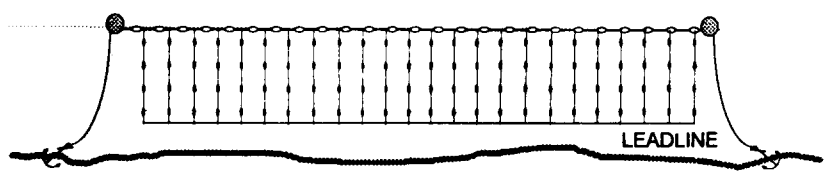


Fig. 1. Headline and reflector configurations.

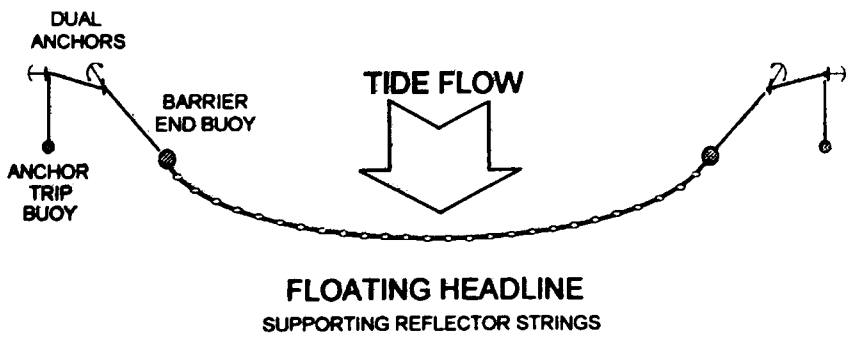


Fig. 2. Diagram of deployment plan for each headline barrier.

Table 2

Net specification for 1992 sea trial.

Mesh
Twine size: 210/18 (420 tex)[1] red nylon multifilament
Mesh size: 168mm stretched (6.625 inches)

Panel
Mesh long: 588
Mesh deep: 125.5
Stretched panel length: 100m

Rigging
Ranging ratio (E) 0.55
Staple settings: 2 full meshes onto the staple length
Staple length: 197mm (7.375 inches)
Set depth: 17.8m
Set length: 55m
Flotation: one polyurethane 350g buoyant float every 1.1m (44 inches)
Leadline: No. 4 reinforced, runnage 11kg/100m

Prototype Acoustic Reflectors
Target strength: nominal -35dB (ref. 2m radius sphere) rigged in a 2 x 3m grid across the face of the net
Reflectors: plastic, elliptical, air-filled, 20g weight in air, 20g lift in seawater (nominal); length 67mm, maximum diameter 33.5mm, axial hole 10mm internal diameter
Attachment sheath; braided polyethylene/polypropylene/worsted twine composition; runnage 35.3g/m
Reflector vertical spacings (from headrope downwards): 3m, 6m, 9m, 12m, 15m
Reflector string horizontal spacings: every 2m along the net.

[1] 210/18 is a Denier notation for twines.

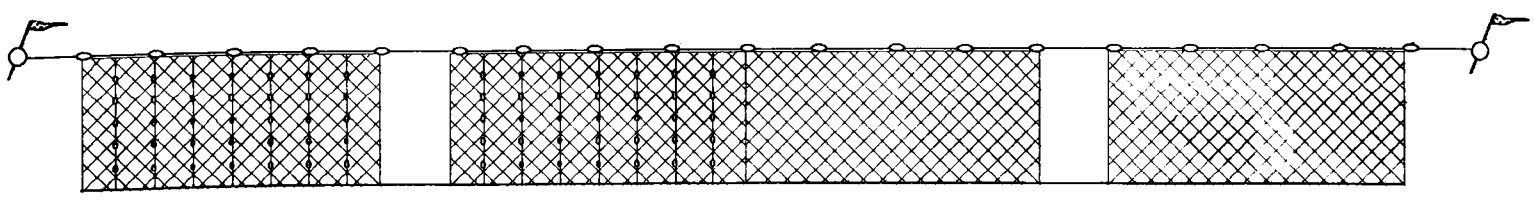


Fig. 3. Configuration of experimental gillnet for the 1992 sea trials, total length = 240m. Four off panels (each 55m long by 18m deep) and 2 modified panels with reflectors + 2 unmodified + 2 gaps (10m wide).

The prototype devices employed (small ellipsoid shaped pressure release reflectors) were applied to two of four panels of an experimental 240m long 'tuna' drift net and were distributed in a 2 x 3m grid pattern across the face of the net (see below). The study included the use of a *Waverley* 3000 towed sidescan sonar to examine the effectiveness of the modified net as an acoustic barrier. The sidescan sonar equipment operated at 100kHz, i.e. with a wavelength λ of 15mm in seawater. At this frequency the sonar has a broadly similar resolution to that of the bottlenose dolphin. The animal's resolution is limited by the highest frequency response in its audiogram, i.e. for the bottlenose dolphin around 120kHz to 130kHz, (Johnson, 1966) and by the presence of these frequencies as spectral components within its sonar transmissions, (Au, 1980). The sidescan sonar operated at a Source Level of 227dB reference 1 μPa which is very close to the maximum reported for a bottlenose dolphin (Au, 1980). However, it is important to appreciate that the dolphin's sonar functions as a forward looking (10°) spotlight system whereas the sidescan generates two very narrow vertical 'fan' beams (1.5° x 50°) which are projected at 90° to each side of its track. The sidescan image is built up on a paper record from successive transmissions as the tow fish, several metres below the surface, follows its parent vessel's course (Fig. 4).

Fig. 3 illustrates the net configuration employed in the gillnet trial. The first pair of 55m long panels were modified with a grid of acoustic reflectors spaced apart 2m horizontally and 3m vertically. A 10m wide gap was deliberately inserted as a potential 'passing place' between these. The remaining pair of panels were also separated by a 10m gap and the two 120m sections butted together. The reflectors in braided tubes formed vertical 'strings' attached to both headline and leadline. The complete net assembly, with marker dahn buoys attached by short bridle ropes to each end, was shot in very calm conditions in 50m water depth where it drifted throughout the period of study. The sidescan sonar was deployed 50m behind the vessel and a series of runs made with the tow-fish deployed between 15 and 20m depth at different ranges and angles to the experimental net.

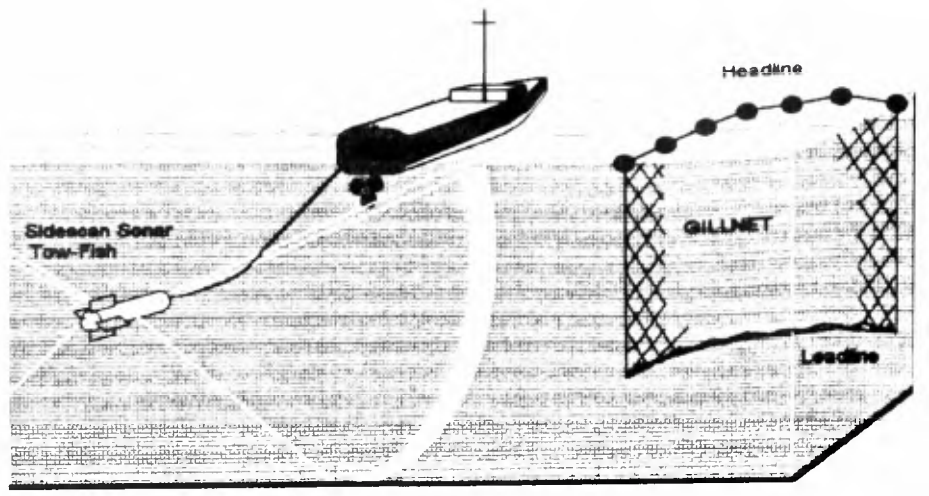


Fig. 4. Diagram of sidescan sonar examining net.

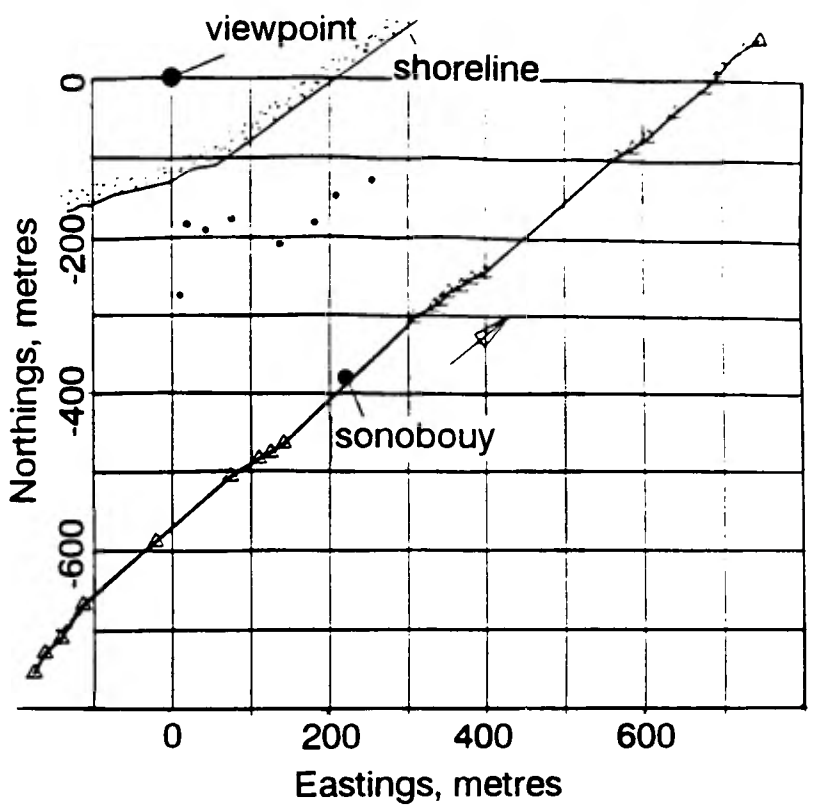


Fig. 5. The passage of the leading animal (direction shown by arrow, surfacings by triangles, the line represents minimum distance between surfacings) of a group of five bottlenose dolphins (including one accompanied by a calf) before deployment of the headline barrier. Deployment of the sonobuoy is clearly not associated with any deviation in the line of travel. The solid dots show the positions of buoys marking crab pots.

RESULTS

Moray Firth

September 1991

Control sightings and recordings, made before the barrier was deployed (e.g. Fig. 5), confirmed that dolphins passing in small groups, and in loose associations of up to about 30 animals, did swim parallel to the cliff, in both directions, at a predictable distance offshore ($2\frac{1}{2}$ days of observation, an average of about 30 animals per day). The presence of a moored sonobuoy close to this track line had no discernible effect of the passing animals' behaviour (which was usually travelling). As the barrier was first deployed on the afternoon of 27 September, a group of dolphins approached. There was considerable acoustic activity and all the animals diverted to avoid the barrier, taking an inshore passage very close to the edge of the kelp (Fig. 6). Late the following morning the inshore anchor of the barrier dragged, but for the first afternoon and most of the next morning animals were observed passing, in both directions, between the inner end of the barrier and the shore in a narrow zone of very shallow water. After some difficulty in obtaining stable moorings closer to shore, the barrier was finally repositioned during the morning of 29 September to obstruct the inshore passage.

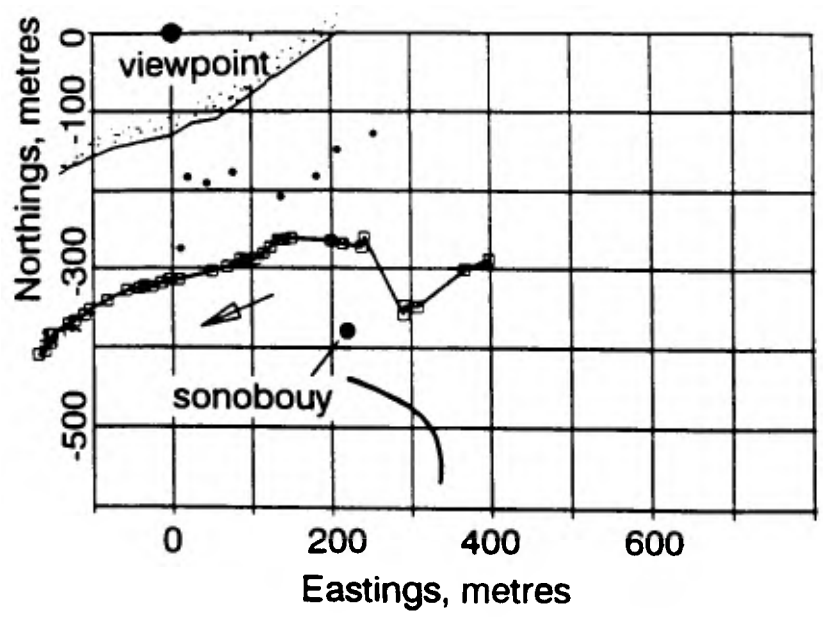


Fig. 6. The passage of the leading animal of a group of 8–10 (including 2 juveniles) after deployment of the headline barrier; Squares indicate surfacings. Although the initial approach is exactly on the line shown in Fig. 5, there is a clear deviation inshore to avoid the barrier.

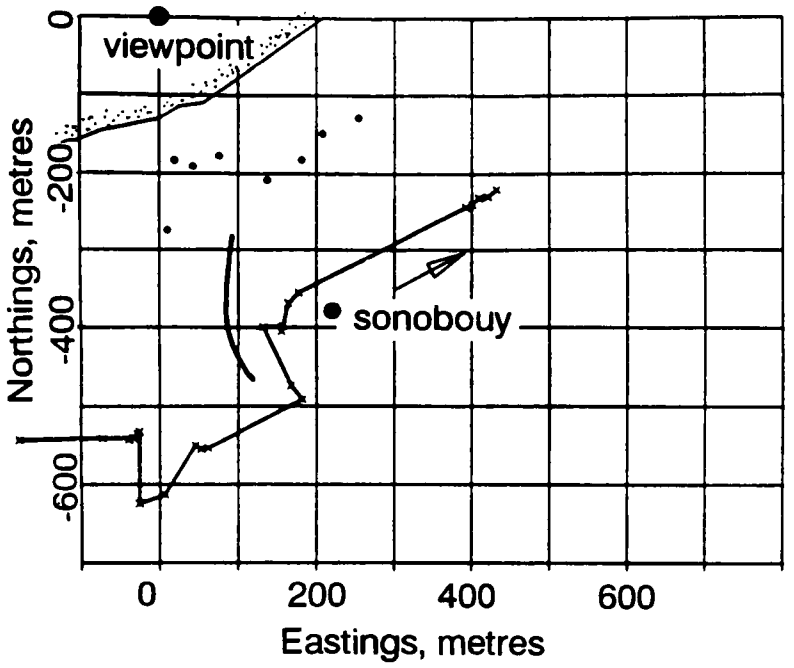


Fig. 7. The passage of a pair of animals leading the first sub-group of the second main group on 30 September 1992, after final deployment of the headline barrier closer inshore. (For further explanation, see Fig. 5. Surfacing positions shown here by crosses.)

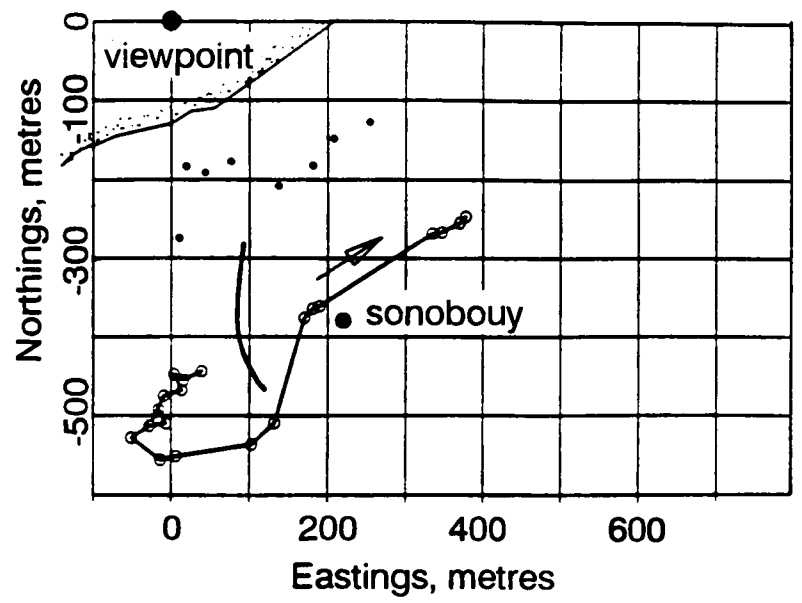


Fig. 8. Passage of a single animal, a trailing member of the second main group on 30 September 1992, first sighted 55 m from the headline barrier. Note that in this figure the arrow only indicates the general travel direction. (See text, Fig. 5, Fig. 9 and Table 3 for further explanation.)

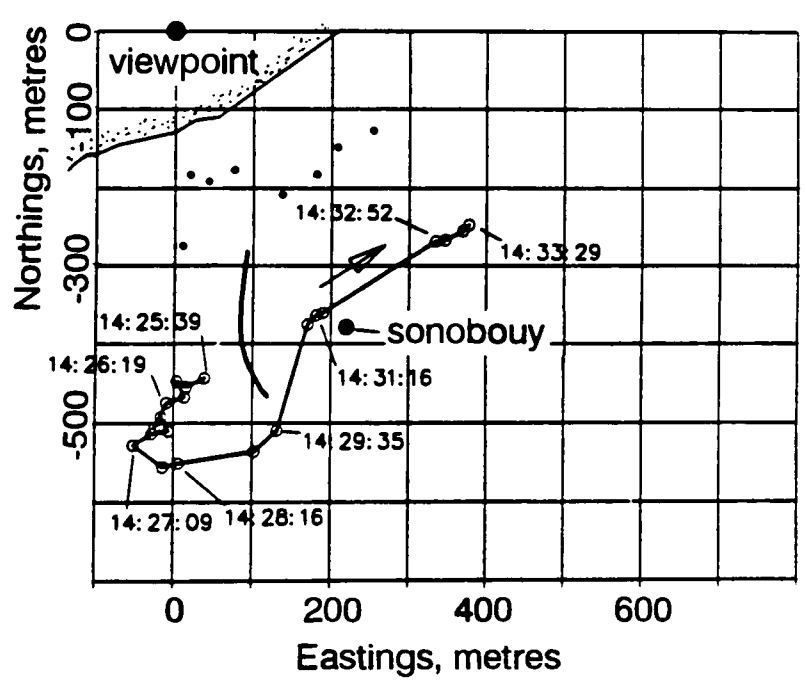


Fig. 9. Time between surfacings of the animal from Fig. 8. Surfacing positions, minimum calculated speeds and times between surfacings are tabulated in Table 3.

In the early afternoon of the final working day (30 September), two distinct main groups of about 30 animals, each with several sub-groups, were observed sequentially passing the outer end of the barrier over about an hour. The track of a pair of animals leading the first sub-group of the second main group is shown in Fig. 7. After tracking this pair through the test zone and while other sub-groups were still passing, a single animal was seen to surface some 55m from the centre of the barrier. The subsequent track of this animal is plotted in Figs 8 and 9. It retreated, initially at a speed of about 3–4ms^{-1}, to a distance of 170m. This apparent retreat from the barrier was interrupted several times, with the animal backtracking briefly while swimming at much slower speed (Table 3). It finally altered course to join the track of the rest of the group and, closely following this, swam past the outer end of the barrier. Then, as had been observed for the previous passing groups, the single animal appeared to investigate the back of the barrier before leaving the area, continuing along the usual line of passage. The similarity between these two main tracks can be seen by comparing Figs 7 and 8. It has not been possible to establish from the photographic evidence whether the same or different animals passed during the days of the experiment. It is possible that some individual identification information may be obtained from analysis of 'signature' whistles. However, from the experience of the photoidentification team (Wilson, pers. comm.), it seems likely that the groups were different.

Subsequent analysis of the recorded underwater sounds demonstrated no obvious echolocation activity which can be assigned to the approaching single dolphin until seven seconds before the first surface plot made as it retreated.

Table 3

Surfacing times, positions and minimum swim speeds from Fig. 6 (land referenced).

Dolphin Tracking Project - Conversion of Readings

Tracking Reference No: DT30-3 (Dolphin Track 3 on 30/09/91)
Theodolite Height: 55.20m (Corrected to Sea Level at track time)
Station Point 1: OmN OmE,

X-Y m	Northing m	Easting m	Time (H:M:S)	Distance m	ΔTime (Secs)	L. Speed (ms^{-1})
447.0	-445.3	38.7	14:25:39			
456.8	-456.5	15.7	14:25:46	25.62	7	3.66
448.9	-448.9	3.6	14:26:02	14.31	16	0.89
469.2	-469.0	13.4	14:26:11	22.36	9	2.48
476.4	-476.3	-9.6	14:26:19	24.11	8	3.01
507.3	-506.7	-24.3	14:26:28	33.82	9	3.76
493.7	-493.4	-16.2	14:26:39	15.56	11	1.41
511.4	-511.4	-6.6	14:26:47	20.39	8	2.55
514.8	-514.1	-27.8	14:26:55	21.40	8	2.68
531.4	-528.9	-51.5	14:27:09	27.94	14	2.00
557.0	-556.8	-13.7	14:28:06	46.95	57	0.82
552.1	-552.0	6.2	14:28:16	20.44	10	2.04
547.2	-537.5	102.6	14:29:05	97.55	49	1.99
527.0	-510.3	131.6	14:29:35	39.76	30	1.33
413.2	-376.5	170.1	14:21:02	139.18	87	1.60
407.2	-364.8	180.9	14:31:16	15.97	14	1.14
408.3	-361.6	189.5	14:31:25	9.10	9	1.01
429.1	-269.4	334.0	14:32:52	171.46	87	1.97
438.2	-268.2	346.5	14:33:07	12.57	15	0.84
449.6	-256.3	369.4	14:33:18	25.81	11	2.35
451.5	-248.4	377.0	14:33:29	10.95	11	1.00

At that time a burst of clicks at a repetition rate indicative of target detection at 20m range is apparent. Slow motion replay of the video record shows that at the first surfacing position the animal is swimming rapidly away from the barrier. This is the single recorded close approach to the barrier made during the study period, although a large number of animals (50 or more during daylight hours) passed the site each day.

September 1992

Pre-trial observations were carried out for several days prior to barrier deployment but poor weather resulted in few dolphins being seen (less than two per day on average). For the seven days the barrier was in place, on a typical day, two large (12–20 animals) groups and several smaller groups (<6 animals) would be seen. As in 1991, the reflectors appeared to be detectable to the dolphins at ranges in excess of 50m and were consistently avoided (Fig. 10). Figs 11 and 12 demonstrate composites of tracks taken by the lead animals and by close knit groups. The avoidance behaviour is clear. It is worth noting that a single animal was observed and tracked as it 'crashed' the barrier at slack water whilst apparently travelling on an intercept course towards a group which had safely passed around the end of the barrier a few minutes before – the animal in question was not echolocating and emerged from the barrier at high speed (6 ms^{-1}). The risk of entanglement therefore appears to remain high for a few non-echolocating 'stragglers' especially when these appear to be travelling in a low state of alertness. For the last two days of this trial the outer barrier had two out of three reflector string supports removed and the low density 6m x 2m distribution that resulted continued to generate avoidance behaviour although it seemed that detection/avoidance behaviours around this modified structure were initiated at shorter ranges. This spacing factor was examined in more detail in the 1993 trial (see Goodson and Mayo, In press).

Handling trials

Irrespective of their success or otherwise in reducing incidental catches of marine mammals in gear, the application of acoustic devices to commercial fishing nets may create practical problems for fishermen e.g.

(1) the increase in the volume of the modified net may overfill a standard net storage bin;
(2) the handling of the net during deployment, recovery and during transfer between net pounds on board ship may be impaired;
(3) the change in buoyancy caused by the reflectors may affect the deployment of the net in the water.

In fact during the field trials, the method of attachment of the reflectors functioned reasonably well during shooting and recovery although a potential for snagging may exist. The braided tubing was chosen to support the reflectors as this does not twist under tension and was intended to smoothly guide the devices while shooting to reducing the likelihood of the reflectors catching into adjacent net layers. However, the wetted braid tube trapped air bubbles which were slow to disperse and the consequent additional buoyancy hindered the net from quickly achieving its correct fishing geometry. The presence of trapped air in the braided tubes also appeared to temporarily enhance the acoustic TS. The most significant handling problems occurred while transferring the wet net after recovery between the net storage 'pounds' preparatory to re-shooting the net. Some improvement in the attachment method will be necessary before this technique can be applied in a large scale commercial test but the mounting problem can be reduced with a minor design change incorporated in the device moulding.

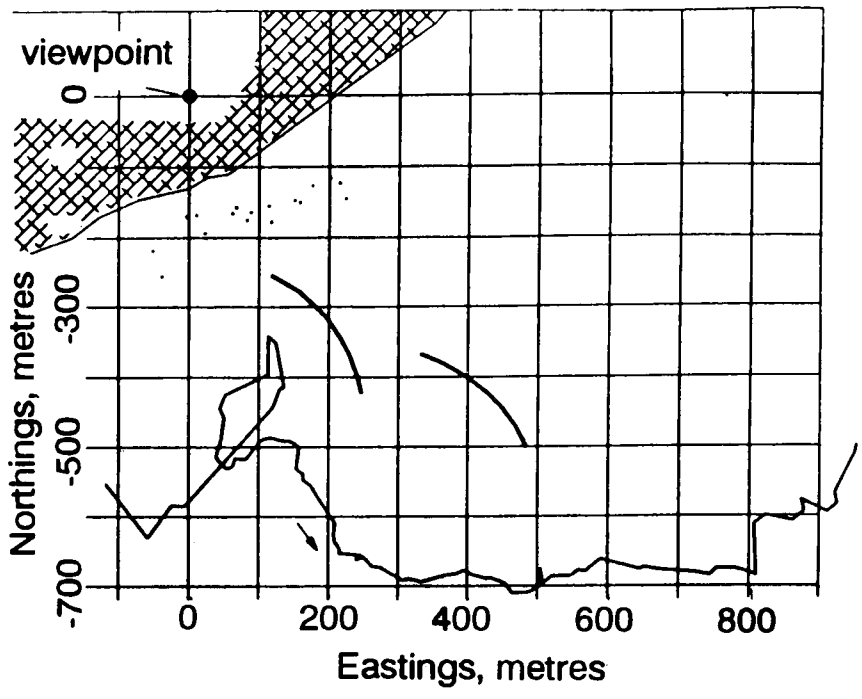


Fig. 10. Detection and avoidance behaviour, 1992 (see text).

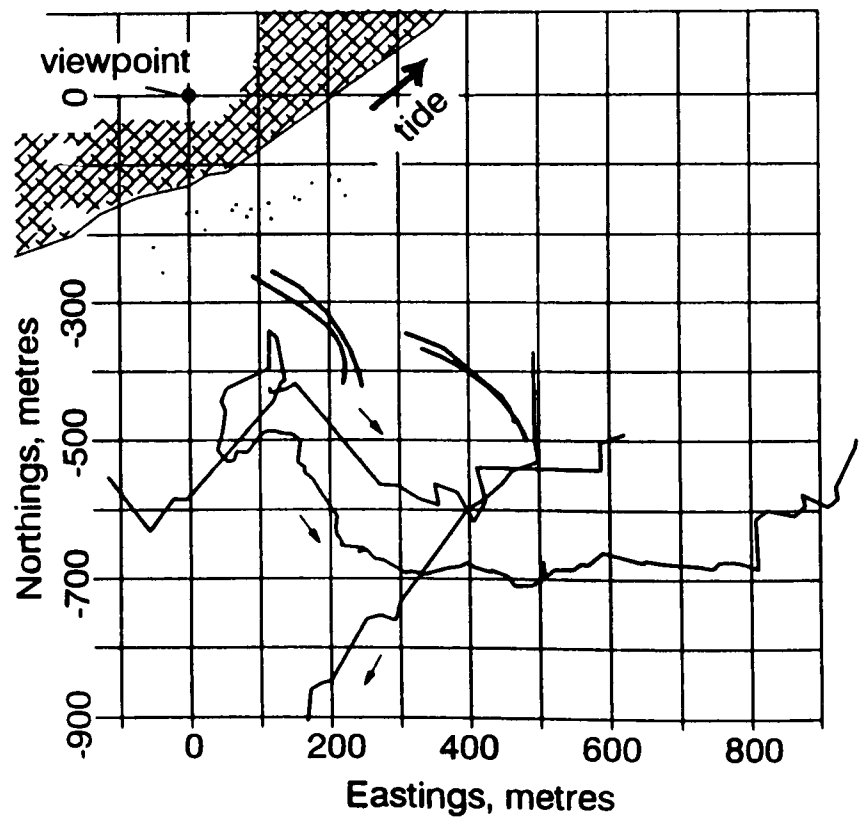


Fig. 11. Composite 1992 tracks – Ebb tide.

Sidescan sonar images

The (unusually) flat calm trial conditions were favourable for the sonar study and in these conditions the side scan images revealed considerable detail. The sonar images all clearly resolved the acoustically modified panels even though one of these panels remained incorrectly deployed (folded) for much of the study period. Fig. 13 shows a typical sidescan sonar image and the annotations indicate a number of interesting features.

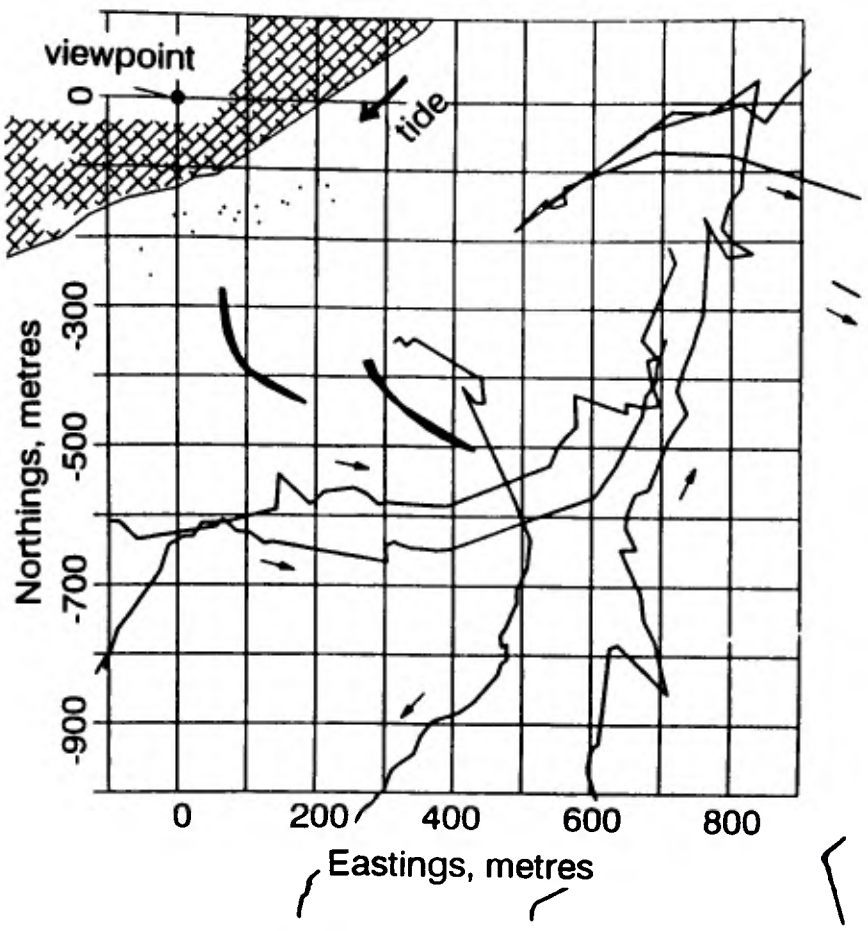


Fig. 12. Composite 1992 tracks – Flood tide.

The headline was the most detectable component in these very calm test conditions. However, in rougher seas, wave troughs will form which will mask the headline and its echoes from a horizontal (dolphin) sonar operating near the surface.

When viewed at 30m range, i.e. by a sonar towed parallel to the net, the echo component of the leadline/footrope is easily detected. However, the leadline constitutes a long 'thin cylinder' target structure and this strong echo (produced by the ensonified length dimension) is very directional. At all other angles, the detectability of the leadline component falls rapidly as the reflections are then directed elsewhere!

Very fine bubbles, created by the vessel's propeller, are driven several metres deep producing an acoustically opaque cloud which persists for quite long periods. An identical effect spread throughout the water column occurs when high sea states start to entrain air at the breaking wave crests. Such an acoustic 'fog' can severely impair the detection range of a small odontocete's sonar.

The reflector enhanced panels generate very detectable echoes and in-fill the vertical plane of the net between headline and leadline. By contrast the unmodified net segments appear completely transparent, even at short range, with no detectable echoes returning from this 18m deep net curtain.

The 10m wide passing places (net 'ends') are defined by the 4mm polypropylene vertical cords.

DISCUSSION

Moray Firth trials

The tracks reconstructed seem to indicate that whilst most animals approaching on a potential collision course detected the barrier and changed course at ranges greater than 50m, a few leading animals became aware of the barrier position at a maximum range of 150 to 170m – a much greater range than predicted. Two factors may help to explain this.

(1) The dolphins were approaching in a direction normal to the plane of the barrier. At a range of 170m a 10° beamwidth will excite nearly simultaneous echoes from the reflectors spread along approximately 30m of the barrier, which effectively increases the TS. This would not be the case if the animals approached from a more oblique angle, as the multiple echoes then arrive sequentially.

(2) The quiet sea (Sea State 2 or less) provided excellent acoustic conditions and the flat sandy seabed contributed little confusing reverberation.

The single animal discussed for 1991 may have been travelling in a low-awareness or resting state. Whether its behaviour was triggered by the acoustic activity of other animals beyond the barrier, or by one of the random loud clicks that have been occasionally noted from other resting animals, has not yet been established. However, if a real gillnet without reflectors had been in the position of the test barrier, this individual seems a likely candidate for entanglement. The single animal that 'crashed' the barrier in 1992 would either have become entangled or broken through the net. Supplementary methods of attracting such animals' attention would still be needed if mortalities are to approach zero, even if the overall approach ultimately proves successful.

One potential problem we had anticipated was that as the simple ellipsoid (air filled) reflectors under test produce 'soft' pressure release echoes, they might have appeared food-like and attracted dolphins. No such attraction phenomena was observed in either year and it is clear that the animals were able to classify these target echoes as 'alien' and took early avoiding action.

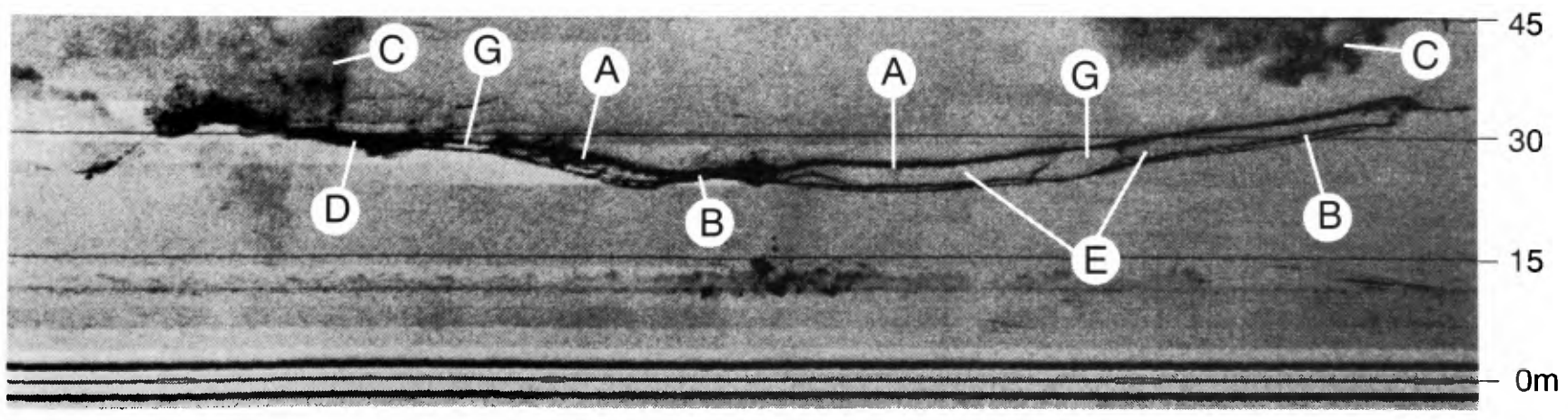


Fig. 13. Sidescan sonar images of the acoustic enhanced net (left) and the unmodified net (right). A=headline, B=leadline/footrope, C=aeration, D=enhanced panels, E=unmodified panels and G=gaps.

We recognise that the data obtained in these first field tests have limitations. Clearly the sample size is as yet rather small. In both years, at least one animal may have become entangled had 'real' modified nets been used. The concept of a 'control' needs refining and improved experimental design is required if one is to be able to prove that the observed 'capture' rate with a modified net is significantly lower than one would have expected from an unmodified net. Similarly, the behaviour of the animals was generally 'travelling' rather than 'foraging', which may also affect capture rates. Further trials are needed to investigate these aspects. In addition of course, particular problems (e.g. with respect to species and area) may require particular solutions: no single method is likely to solve every bycatch problem. Eventually, the only true test is application in a real fishery.

However, having said this, these were intended to be preliminary studies and the results appear promising and exceeded our expectations. Although the protocol employed needs further refinement, it is clear that the technique generates detailed interaction data at rates far faster than in conventional fishery monitoring and without any risk to animals.

Sea handling trials

The sonar images obtained, typified in the examples given in Fig. 13, demonstrate that the difference in acoustic detectability between the modified and un-modified panels is very marked and that the reflector modification effectively infills the 18m deep 'gap' between the headline and leadline.

It should also be noted that an approaching dolphin can only resolve small objects within the 10° wide 'spotlit' zone directly ahead of its path. During its approach it cannot acquire a comprehensive picture of the whole structure, as provided by these sidescan images, each of which took several minutes to scan at this resolution. At any instant the dolphin can only resolve targets that are contained in range by the time interval between its 'clicks' and in angle by the very narrow ensonified cone (beam) projected ahead. Only the highest frequency part of the dolphin's transmission spectrum (the very short wavelength signal components) are capable of resolving the acoustic dimensions of the larger supporting component parts of a fishing net and in most sea state conditions and from most approach directions even these may be missed.

CONCLUSIONS

The trials in the Moray Firth during 1991 and 1992 have demonstrated that the passive acoustic marking technique has the potential to deter small echolocating odontocetes from passive gillnets. The test on a Cornish commercial fishing boat demonstrated that when the devices are attached to a fishing net they function to effectively infill the relatively transparent zone between headline and leadline. The mechanical method of attachment to the nets needs improvement and alternative more efficient reflector designs will need to incorporate a safe/simple method of fastening them directly to the net mesh. For evaluation at sea, especially in an offshore fishery, accurate underwater tracking techniques are required (Woodward *et al.*, 1993) in order to localise positions and plot the underwater tracks of approaching cetaceans in relation to the fishing net. Behaviour changes induced by potential deterrent modifications need rapid evaluation (in relatively small scale comparative tests) if the current reliance on gross 'body count' bycatch statistics is to be avoided in the short term.

ACKNOWLEDGEMENTS

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Postscript

Developments on Issues Relating to the Incidental Catches of Cetaceans Since 1992 and the UNCED Conference

G.P. Donovan

International Whaling Commission, The Red House, 135 Station Road, Cambridge, CB4 4NP

ABSTRACT

Developments on issues relating to cetaceans and gillnets since 1992 are summarised. The most significant is the successful ban on pelagic driftnetting. Incidental catches by European Union vessels using driftnets are discussed. More effective enforcement of the EU ban on nets over 2.5km is required in both the eastern North Atlantic and the Mediterranean. The situation in the Mediterranean is serious and warrants immediate action. Some progress has been made in addressing issues related to the harbour porpoises in the North Atlantic. The situation of the vaquita remains extremely serious. New information on bycatch levels and/or new fisheries where cetacean bycatches have been identified is summarised. In general, the situation remains much as it did in 1992 – in almost no fishery can the impact of bycatches be assessed. Ways in which this may be remedied are discussed. In particular, the need to provide financial and practical support to developing countries is stressed.

KEYWORDS: INCIDENTAL CAPTURE; SMALL CETACEANS-GENERAL; LARGE WHALES-GENERAL; REVIEW; HARBOUR PORPOISE; VAQUITA; STRIPED DOLPHIN; MEDITERRANEAN; NORTH ATLANTIC; SOUTH PACIFIC; SOUTH ATLANTIC; NORTH PACIFIC; FISHERIES.

INTRODUCTION

The two Reports included at the beginning of this volume were accepted by the member governments of the International Whaling Commission (IWC) and submitted as part of the IWC's contribution to the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. The purpose of this short paper is to summarise developments concerning the issue of cetaceans and gillnets since those reports were written. Much of the information here is taken from the papers published in this volume.

PELAGIC DRIFTNET FISHING

Perhaps the most significant progress since the Workshop concerns high seas driftnet fishing, which was identified as a serious threat to cetaceans (e.g. Hobbs and Jones, 1993; IWC, 1994c). In 1990, the IWC endorsed Resolution 44/225 of the UN General Assembly, which among other things called for a review of the best available scientific data on the impact of large-scale pelagic fishing, noting the contribution that the Scientific Committee Workshop would make to this review (IWC, 1991a). Partly as a result of the Workshop, the UN adopted Resolution 46/215 on 20 December 1991. The active parts of this Resolution called for nations to ensure that:

(1) pelagic driftnet fishing effort should be reduced by half by 30 June 1992;
(2) driftnet fisheries should not expand into new areas;
(3) a moratorium on pelagic driftnet fishing should be implemented by 31 December 1992.

As reported by Nagao (1994), Japan ceased driftnet fishing in summer 1990 for all areas outside the Pacific and on 1 January 1993 for the Pacific. This was accompanied by enforcement and compensation measures. The Republic of Korea suspended such fishing from 30 November 1992 and China, Taiwan ordered vessels to surrender their driftnets by 1 January 1993. Both countries encouraged compliance with the ban by assisting with refitting fishing vessels as well as using patrol vessels to enforce it.

Despite occasional breaches (3 Chinese vessels were prosecuted by the Chinese authorities and one Honduran flagged vessel was seen but not apprehended), the moratorium appears to be holding (Anon., 1994).

DRIFTNET FISHING BY COUNTRIES OF THE EUROPEAN UNION (EU)

Eastern North Atlantic

In accordance with the UN Resolutions noted above, the EU adopted measures to phase out pelagic driftnetting. Initially, it was intended to limit driftnets to a maximum of 2.5km both within and outside EU waters but a request from France resulted in the eastern North Atlantic French albacore fishery being allowed to use nets of up to 5km in length until 31 December 1993, subject to the results of a scientific evaluation of the ecological impact of the fishery.

Although French vessels dominate this fishery (46 vessels in 1992 and 64 in 1993 – Goujon *et al.*, 1993), Irish vessels (about 5 in 1991 and 1992, about 18 in 1993 and 1994 – S. Berrow, pers. comm.) and British vessels (6 in 1993) also operate in the same area.

In response to the EU decision, France carried out a study to examine the impact of the tuna fishery on common dolphins, *Delphinus delphis* and striped dolphins, *Stenella coeruleoalba* (Goujon *et al.*, 1993). In the area surveyed, Goujon *et al.* estimated an annual fishing mortality of around 0.7% for common dolphins and 1.6% for striped dolphins.

Irish vessels carried observers to monitor the fishery in 1991 and 1993, and the Irish South and West Fishermens' Organisation has funded a pilot study to examine the ecological risk in the tuna fishery; preliminary analyses suggest that the Irish fishery has a much lower catch rate per km than the French (Berrow, pers. comm.).

The results of the French study are difficult to interpret, particularly for the striped dolphins. Whether the populations are thought to be able to sustain incidental catch levels depends on what assumptions are made about dolphin population dynamics (see below), the geographical range of the population and, in particular in this case, the vital rates of striped dolphins (Goujon *et al.*,

1993). The EU has decided not to renew the French exemption and now no EU registered vessel may carry more than 2.5km of gillnet (Article 9a, No. L42/18).

This regulation has led to a number of claims and counter claims about vessels from various EU countries using illegal nets in 1994. It is clear that monitoring and enforcement methods require strengthening.

Mediterranean

Despite the controversy over 'illegal' use of driftnets in the eastern North Atlantic, it is the situation in the Mediterranean that gives greater cause for concern.

Large numbers of cetaceans are known to be taken in driftnet fisheries in the Mediterranean, particularly in the fishery for swordfish and albacore. IWC (1994c) commended Italy for banning this fishery from 30 July 1990 and encouraged other Mediterranean states to do the same. However, since then the situation has become complex and confusing, with a number of 'relaxations' and 'rebannings' by both the Government and Administration Courts (Aguilar and Silvani, 1994; Di Natale and Notarbartolo-di-Sciara, 1994). It should be remembered that irrespective of national legislation, EU states should not be using nets >2.5km but nets of 10–12km are still being used. In fact the situation in the Mediterranean may even be worse now than in 1990; over 800 vessels from Italy (600+) and Morocco (200+) in particular are still operating. Although no good estimates of bycatches exist, prior to 1990 the Italian bycatch alone was thought to number several thousand animals (Di Natale and Notarbartolo-di-Sciara, 1994). In view of this, the Scientific Committee has again repeated its concern about the situation in the Mediterranean, particularly for the striped dolphin (IWC, 1995).

It is clear that immediate action is required. A first step would be for EU countries to ensure that EU regulations are met. In addition, the Action Plan for Cetaceans established by the 1991 meeting of the Barcelona Convention should be enacted as soon as possible (Di Natale and Notarbartolo-di-Sciara, 1994).

INCIDENTAL CATCHES OF HARBOUR PORPOISES

The harbour porpoise (*Phocoena phocoena*) appears to be one of the most vulnerable species to capture in fishing nets (IWC, 1994c). Indeed, phocoenids in general are often caught (e.g. Corcuera, 1994; Goodall *et al.*, 1994; Lal Mohan, 1994; Jefferson and Curry, 1994; Van Waerebeek and Reyes, 1994a; c) and, as discussed below, the vaquita, *Phocoena sinus*, is probably the world's most endangered cetacean (e.g. Vidal, 1995). There is some speculation that this vulnerability may partly reflect the nature of their echolocatory abilities when compared to delphinids (e.g. IWC, 1994c).

The Scientific Committee drew attention to catches of harbour porpoises on both sides of the North Atlantic at the Workshop and the UNCED review. Since then it has emerged that, for some countries, much larger catches occur than envisioned in 1990 (e.g. Denmark, see Lowry and Teilmann, 1994). Although some nations have increased their efforts to try and estimate bycatch levels in North Atlantic fisheries (e.g. see Berrow *et al.*, 1994; Lowry and Teilmann, 1994; Read, 1994), even where there are schemes, they are inadequate. Few reliable estimates derived from scientifically designed observer programmes exist, despite resolutions accepted by consensus in the IWC (e.g. 1994a) that such work should be given high priority.

There are however, some positive signs that Governments are beginning to recognise that the harbour porpoise/fishing gear problem must be addressed.

In the western North Atlantic, recent information on the harbour porpoise bycatch problem was considered at a Workshop to assess the status of harbour porpoises in those waters (Palka, 1994). Only for the US Gulf of Maine are bycatch estimates and population estimates available (Read, 1994). A series of recommendations for action and research based on the Workshop Report are given in IWC (1995). Recent US legislation requires that annual incidental catches of harbour porpoises must be significantly reduced to 1% or less of the estimated population size in the near future and a workshop to assess the potential of gear modifications to reduce bycatches in the sink gillnet fishery was held in September 1994 (Frady *et al.*, 1994).

In July 1994, a multi-national survey of the North Sea and adjacent waters was undertaken, although the results are not yet available (Anon., 1994). This should provide a useful baseline for any evaluation of the impact of incidental captures on harbour porpoises in the region, particularly the Celtic Shelf (Berrow *et al.*, 1994) and the central North Sea (Lowry and Teilmann, 1994).

In September 1994, the first meeting of ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas) took place (ASCOBANS, 1994). The range states agreed to a Resolution that defined a conservation and management plan for the region, including the reduction of direct and indirect interactions with fisheries (estimation of reliable bycatch numbers and research on gear and fishing method modifications are part of this).

VAQUITAS IN THE GULF OF CALIFORNIA

The vaquita has the smallest range of any marine cetacean, being restricted to the Upper Gulf of California (Vidal, 1995), and probably numbers only a few hundred animals (Gerrodette *et al.*, 1995). Despite a number of attempts to protect these animals from incidental catches, mainly in an illegal fishery for the endangered sciaenid fish, the totoaba, incidental catches still occur. On 10 June 1993, the Government of Mexico declared the Biosphere Reserve of the Upper Gulf of California, a move commended by the Scientific Committee (IWC, 1995). However, evidence of continuing incidental catches (D'Agrosa *et al.*, 1995) has led the Committee to recommend that further action to eliminate bycatches be taken urgently, if the extinction of the vaquita is to be avoided.

NEW INFORMATION

The Workshop has served to encourage a number of studies to improve our knowledge of bycatch levels. In many of these cases the work has been carried out in difficult conditions and without government support. For example, a considerable amount of new information is available from Central and South America. In several cases these studies identified new areas/fisheries (e.g. Félix and Samaniego, 1994; Haase and Félix, 1994; Siciliano, 1994; Zavala-González *et al.*, 1994) or improved our knowledge of existing interactions (e.g. Corcuera, 1994; Lescrauwaet and Gibbons, 1994; Van Waerebeek and Reyes, 1994c).

Although almost all the new information refers to smaller cetaceans, two previously unknown areas where large whales are taken in nets have been documented:

minke whales off Peru (Van Waerebeek and Reyes, 1994b); and sperm whales off Ecuador (Haase and Félix, 1994).

DISCUSSION

While there has clearly been some progress in addressing questions related to fishery/cetacean interactions, it is also clear that much work remains to be done.

Assessing the impact of bycatches

Several pieces of information are required if a quantitative assessment of the impact of bycatches on cetacean populations is to be made: reliable estimates of bycatch numbers; knowledge of stock identity and migration; reliable estimates of abundance. All these are difficult (and expensive) to obtain. Together they will provide us with an estimate of bycatch levels as a proportion of current population size. However, the interpretation of this remains problematic for a number of reasons associated with our lack of knowledge of the dynamics of small cetacean populations (e.g. Reilly and Barlow, 1986) i.e. what level of takes might be sustainable. Such knowledge is also required if attempts are to be made to relate current abundance to 'initial' abundance. Finally, this information needs to be considered in the context of other factors affecting the population (e.g. direct catches, habitat loss/degradation).

A number of attempts to obtain more reliable estimates of bycatch numbers have been made since the Workshop. Generally, to have any chance of success they require observers on vessels; if the cetaceans have an economic or subsistence value to the fishermen (i.e. they bring a substantial percentage of the animals to shore), monitoring of ports may be sufficient. It should not be impossible to use observers on either all, or a representative sample of a fleet in commercial fisheries, although this has rarely been done (e.g. Berrow *et al.*, 1994; Lennert *et al.*, 1994; Lowry and Teilmann, 1994). However, it is almost impossible where large numbers of small vessels are involved, for example in the many artisanal fisheries of the developing world. Other methods, such as questionnaires and interviews are difficult to interpret (e.g. Lien *et al.*, 1994) but may give some idea of the problem.

It is important to recognise that for almost all fishery/cetacean interactions we have, and probably will continue to have, only rough (usually minimum) estimates of bycatch levels (IWC, 1994c – Table 1).

The question of stock identity is a persistent problem in cetacean studies (e.g. Donovan, 1991; Perrin and Brownell, 1994) and our knowledge of small cetacean stock structure is poor for almost all areas and species. Despite the progress made in biochemical techniques (e.g. IWC, 1991b) there are no simple unambiguous ways to address this problem. It is important that a suite of techniques are used (Donovan, 1991) and that information on movements is also obtained.

The question of estimating the abundance of cetaceans has been more thoroughly addressed in recent years and guidelines for conducting surveys have been developed (e.g. Hammond, 1986; Hiby and Hammond, 1989; IWC, 1994b). However, such work is expensive. For example, the survey of the North Sea and adjacent waters carried out in July 1994 cost over £1,000,000. At present we have few reliable estimates of abundance for cetaceans affected by fisheries (IWC, 1994c – Table 1), particularly for developing countries.

It is unlikely that funding research on these three subjects will be allocated high priority in developing countries given their economic situation. It is important that Government and non-governmental agencies from the 'developed' world offer financial and logistical support for such studies to be carried out, particularly where the impact of bycatches is suspected to be high. In this regard it should be noted that many of the projects identified in the IUCN Action Plan for Cetaceans (Reeves and Leatherwood, 1994) address research relevant to bycatch problems.

Management actions

It is clear that in almost all cases it is impossible at present to determine reliably the impact of bycatches on cetacean populations; it is equally clear that action to reduce bycatches should not wait until it can be shown with certainty that levels are unsustainable.

Although there are some indications that passive and active acoustic modifications may eventually result in a reduction in bycatches in some fisheries (e.g. Goodson *et al.*, 1994; Lien *et al.*, 1994), it seems unlikely that any simple and effective gear modifications will be available in the near future.

One approach that has potential in some areas is a change of gear type e.g. from gillnets to longlines (Van Waerebeek and Reyes, 1994c; Corcuera, 1994). However, it is important to monitor the effect of such changes for several reasons. Firstly, cetaceans are only one part of the ecosystem – changing gear or methods may reduce cetacean bycatches but increase bycatches of other species (such as turtles, fish and sea birds) to unsustainable levels (e.g. see Joseph, 1994). Secondly, there is evidence from Venezuela, French Guiana and Ecuador that longline fishermen use dolphin meat as bait (Van Waerebeek and Reyes, 1994c; Félix and Samaniego, 1994). Finally, the new gear or method may also result in incidental catches or, in the case of longlines for example, direct kills by fishermen who observe cetaceans stealing fish from them.

A number of countries have taken legislative action since the Workshop (e.g. Philippines – Dolar, 1994; USA – Read, 1994; Peru – Van Waerebeek and Reyes, 1994c). However, it is clear that such action is only of value if it is enforced. The case of Peru provides a good example of this, as illustrated by Van Waerebeek and Reyes (1994c). The Government of Peru banned the capture and trade in small cetaceans in December 1990 but, in the absence of enforcement, the main effect appeared to be to make it more difficult to obtain information on catch levels, rather than a reduction in catch levels. A more recent law (August 1994) that elaborated enforcement measures and responsibility appears to be having more effect (Van Waerebeek, pers. comm.).

A number of lessons can be learned from the Peruvian experience. The most obvious is that while it is relatively easy to pass legislation and even to stress the need for enforcement, actually enforcing the law can be logistically very difficult, particularly in the case of fisheries involving large numbers of artisanal vessels in developing countries. It is not immediately obvious how this can be remedied. However, it is important that monitoring of the situation continues after legislation is passed (e.g. in the Philippines, where similar legislation was passed in 1992 – Dolar, 1994). Another factor that is relevant here is the need for education (e.g. Lescrauwaet and Gibbons, 1994); fishermen are more likely to obey a law if they can understand the need for it.

Several authors have stressed the need for the financial and subsistence needs of the fishermen to be taken into account when attempting to reduce bycatches. With the exception of 'deliberate' incidental catches (where the cetaceans have an economic or subsistence value), many fishermen see incidental catches of cetaceans as having a negative impact on their fishing, and may well be pleased to change the gear and/or operation if they can maintain their income (e.g. Corcuera, 1994; Crespo *et al.*, 1994).

CONCLUSIONS

Although some progress has been made, a considerable amount of work remains to be done. Incidental capture in fishing gear is probably the most serious threat to cetaceans today. The recommendations of the Workshop remain valid and it is to be hoped that Governments who have endorsed those recommendations in the context of the IWC and UNCED, do more than pay lip service to them. It is particularly important that financial and logistic assistance is provided to developing countries.

In closing, I would particularly like to stress certain points raised in the Workshop report.

(1) Fishing communities should be made aware of the reasons behind calls for a reduction in bycatches and become involved in the process of finding solutions.
(2) Research should focus on those fisheries where urgent action is required (as identified in the Workshop Report).
(3) Potential solutions must be evaluated in the context of all marine species, not only cetaceans.
(4) There is no universal cause or solution to the incidental capture of cetaceans in fishing gear. Each case should be evaluated in the light of local conditions.

ACKNOWLEDGEMENTS

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Résumés

Résumés

SECTION 1. PAPERS PRESENTED TO THE MEETING BUT NOT PUBLISHED. COPIES OF THE FULL PAPERS CAN BE OBTAINED AT COST FROM THE IWC SECRETARIAT.

SC/O90/G1. MORTALITY OF DOLPHINS IN SHARK GILLNET FISHERIES OFF URUGUAY. *Ricardo Praderi, Museo Nacional de Historia Natural Casilla de Correo 399, Montevideo, Uruguay.*

In the artisanal shark fisheries along the Uruguayan coast, sporadic accidental catches of small cetaceans have been recorded. The main species involved are: *Phocoena spinipinnis* (Burmeister's porpoise) and *Tursiops truncatus* (bottlenose dolphin). But, due to the kind of nets used (gillnets), a considerable number of *Pontoporia blainvillei* (franciscana) also die every year. In studying the incidental mortality of the franciscana, two factors are considered: fishing effort and types of nets used. The type and scale of fishing operations is, without doubt, the main determinant factor of the number of dolphins caught in nets. It is contingent upon climatic conditions, a factor which considerably limits the number of days suitable for fishing. The economic conditions of fishermen are also significant, because, in the absence of prior successful fishing, fuel and salaries are limited to the maximum. The type of nets employed is important in incidental mortality, because the nets with the largest mesh, used to catch large sharks, accounted for the largest number of dolphins killed (55% of the total) whereas the other two types of net used combined resulted in 45% of mortality. [24pp.]

SC/O90/G4. DRIFTNET FISHING IN THE SOUTH ATLANTIC. *Roger Krohn, Zoology Department, University of Cape Town, Rondebosch 7700, South Africa.*

Drift- and gillnetting by Japanese, Korean and China, Taiwanese fishing fleets has caused a large decline in the stocks of albacore (*Thunnus alalunga*), as well as large scale mortality of non-target species in the South Pacific. The first direct evidence to show that this activity has now extended its range to include the South Atlantic Ocean is presented. [6pp.]

SC/O90/G12. A REVIEW OF ENTANGLEMENT OF SMALL CETACEANS IN GILLNETS AND THE GILLNET FISHERIES OF THE INDIAN COAST. *R.S. Lal Mohan, Research Centre of Central Marine Fisheries Research Institute, West Hill, Calicut-673 005, India.*

The smaller cetaceans, *Stenella longirostris* (spinner dolphin), *Delphinus delphis* (common dolphin), *Tursiops truncatus* (bottlenose dolphin), *Sousa chinensis* (humpback dolphin) and *Neophocaena phocaenoides* (finless porpoise) get entangled in gillnets operated along the Indian coast. The Ganges river dolphin (*Platanista gangetica*) is a casualty in the nets operated in the rivers Ganges and Brahmaputra. Most of the entanglements occur along the southwest coast of India. The recent development of gillnets, mode of operation, structure of the nets, types of crafts and gear employed, species of fishes caught and the economics of the fishery are discussed. The important gillnet fisheries of India like pomfret fishery, shark fishery, skate and ray fishery, scombroid fishery, mackerel fishery, whitebait fishery, polynemid fishery, catfish fishery, oil sardine fishery, lesser sardine fishery, hilsa fishery, riverine catfish fishery and prawn fishery are described. Recommendations are made to try to make gillnet fisheries less harmful to dolphin populations. [70pp.]

SC/O90/G14. POSSIBILITIES OF REDUCING INCIDENTAL CATCH AND MORTALITY OF MARINE MAMMALS IN DRIFTNET FISHERIES. *Joel Prado and Andrew Smith, Fishing Technology Service, Fisheries Industries Division, FAO of the UN, Rome, Italy.*

The entanglement of cetaceans in fishing gear has been known for many years, but prior to the use of nylon twine in the fishing industry in the late 1950s it was not considered to be a problem. At this point driftnets and gillnets increased their efficiency by up to 50% and other species were sought which had not been traditionally fished by driftnets. Relatively recently this led to a high-seas development of gillnet fisheries for tuna, salmon and squid. Although the tuna and squid stocks are not considered overfished, the gillnet fishery for salmon has been subject to management measures agreed at an international level for a number of years. The international negotiations with regard to these measures have been very difficult, with each country trying to represent a number of vested interests. The problem of the catch of cetaceans is therefore only one factor in a complex controversy on high-seas gillnetting. Notwithstanding the demand for the banning of drifting gillnets on the high seas and the regulation of these nets in EEZs, it has got to be considered that during the last decade many developing countries have started fishing with driftnets for species which they had not previously harvested. Pragmatically, one has to consider not only what happens on the high-seas but also within areas under national jurisdiction where the management of the fisheries is vested in the coastal state and where the coastal state determines the allowable catch of the living resources in its exclusive economic zone. Therefore, in the context of good fisheries management practices, gillnetting does not pose a problem with regard to overfishing and the solution to the problem of the incidental catch of mammals will lie in seeking methods whereby the reduction of the amount of cetacean entanglements in the nets can be achieved. Although it is accepted that 'prevention is better than cure' it is proposed that an effective strategy for tackling the problem will contain elements of both. [12pp.]

SC/O90/G17. ENVIRONMENT, ACOUSTICS AND BIOSONAR PERCEPTION. OPTIMISING THE DESIGN OF PASSIVE ACOUSTIC NET MARKERS. *A.D. Goodson, Sonar and Signal Processing Group, Electronic and Electrical Engineering Department, Loughborough University of Technology, LE11 3TU, UK.*

The associated symposium paper 'Enhancing the acoustic detectability of fishing nets' (SC/O90/G16) discussed the foraging behaviour leading to fish detection and the extraction of target range parameters from recordings of the sonar emissions of a solitary *Tursiops truncatus*. The concept of increasing the target strength of fishing nets by adding simple sound scattering mechanisms has been investigated in recent years by a number of researchers. However, the methodology employed to date has not resulted in significant reductions in the incidental catch of cetaceans. These workshop notes attempt to examine some

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environmental acoustic factors which could affect behaviour and consider the design of passive markers optimised for detection by the small delphinoids. [5pp.]

SC/O90/G18. REVIEW OF CETACEAN NON-ACOUSTIC SENSORY ABILITIES. *Margaret Klinowska, Research Group in Mammalian Ecology and Reproduction, Physiological Laboratory, University of Cambridge, Downing Street, Cambridge, CB2 3EG, UK.*

This review provides a more detailed background to the discussion in SC/O90/G19 of the ways in which non-acoustic sensory abilities and behaviour might be exploited to prevent cetacean entanglement. [39pp.]

SC/O90/G19. SOME NON-ACOUSTIC APPROACHES TO THE PREVENTION OF ENTANGLEMENT. *Margaret Klinowska, Research Group in Mammalian Ecology and Reproduction, Physiological Laboratory, University of Cambridge, Downing Street, Cambridge, CB2 3EG, UK and A. David Goodson, Sonar and Signalling Research Group, Electronic and Electrical Engineering Department, Loughborough University, Loughborough, LE11 3TU, UK.*

The non-acoustic senses are reviewed for their potential to provide additional practical ways to prevent the entanglement of cetaceans in fishing nets and other gear. Two general approaches emerge. The first involves modification of gear deployment. It would apply to animals using environmental information such as the geomagnetic field, currents, temperature or salinity gradients as a travel cue, and simply consists of orienting the gear parallel to the environmental cue providing the travel path instead of across it. It should not be difficult, expensive or disruptive, to collect the extra data required to test this approach during routine fishery monitoring. However, if the target species of the fishery should happen to be using the same travel cues as the cetaceans, reorientation of gear will not be practical. Nevertheless, this approach deserves serious consideration, because it is easy to test, and if effective, would not be difficult or expensive for well-equipped modern fisheries to implement. The second approach involves gear modification. Increasing the visibility of gear underwater might be useful in some restricted circumstances, and it may even be worth exploring whether improving visibility above water would be helpful. Although little is known of the role chemoreception plays in cetacean food finding and social behaviour, it is a sense which can be invoked from a distance in water. Natural fibre nets, traditionally treated with a variety of oils, tars, etc., would be likely to leave a distinctive 'trail' in the water. The contents of any nets would be likely to provide a trail of excreta and other substances. Urgent investigation is required to elucidate the role such cues may have in attracting or alerting cetaceans to nets, because such broadcast chemical signals could well negate any other efforts to prevent entanglement. [7pp.]

SC/O90/G23. SOURCES OF A GLOBAL REVIEW OF MORTALITY OF CETACEANS IN PASSIVE FISHING NETS AND TRAPS. *Aleta A. Hohn and William F. Perrin, Southwest Fisheries Science Center, National Marine Fisheries Service, PO Box 271, La Jolla, CA 92038, USA.*

This provides a list of sources that may be useful during the IWC Workshop on Mortality of Cetaceans in Passive Fishing Nets and Traps. These sources include references pertaining to the species and numbers of cetaceans incidentally caught, types of gear, mitigation methods tried or suggested, coastal fisheries operating and possibly catching cetaceans even if such reports of incidental catches do not currently exist, and other potentially relevant papers. We have tried to include references on incidental mortality in passive gear from all regions of the globe where information exists. Generally, the list has been restricted to recent documents, within the past 10 years or so. Unpublished material has been included because much of it is very recent or contains details or information not otherwise available. All of the sources listed will be accessible during the workshop. [16pp.]

SC/O90/G25. CETACEAN MORTALITY IN PASSIVE FISHING NETS AND TRAPS IN THE BALTIC SEA: A REVIEW. *Carl Chr. Kinze, Zoological Museum, University of Copenhagen, Universitetsparken 15, DK-2100 Copenhagen O, Denmark.*

The dominant cetacean of the Baltic Sea is the harbour porpoise (*Phocoena phocoena*), and interactions between cetaceans and fisheries hence are almost totally with this species. A further 19 species have been reported occasionally from Baltic waters, usually in the westernmost part and may potentially become entangled in fishing gear. Since the end of the second world war, the harbour porpoise in the Baltic appears to have undergone a significant decline and in recent years the species has become very scarce in the Baltic proper. Amongst other factors, entanglements in passive fishing nets and traps has been mentioned as a cause of the decline. Harbour porpoises are or have been caught in gillnets and pond nets all over the Baltic Sea. Set gillnets are widely applied in Danish, Swedish and German waters whilst salmon drift nets are in use in the Baltic proper. Taking into account, however, the present distribution of the harbour porpoise in the Baltic Sea, incidental catches may only have an impact on the species in the westernmost parts of these waters, i.e. mainly in the Danish, German and Swedish parts of the Kattegat and the Belt Sea. [22pp.]

SC/O90/G26. REVIEW OF GILLNET AND TRAP FISHERIES IN THE BRAZILIAN REGION. *Graciela Cannella and Alfredo Ximenez, Laboratorio de Mamíferos Aguáticos e Ictiologia de la Universidad Federal de Santa Catarina, Caixa Postal 5132, Campus Universitario 88049 Florianópolis, SC, Brazil.*

This paper provides information on gillnet and trap fisheries that characterise each region of the Brazilian coast and on their impact on the marine mammals that frequent these areas. Artisanal fishing represents 50–60% of the total national fishing yield and is particularly important in the north and northeast regions. The southeast region concentrates most on industrial fisheries and together with the south has the highest fishing potential of the country. Different problems resulting from overfishing, fish handling, pollution, etc. are described. The impact of fishing activity on marine mammal populations cannot be assessed at present, given the lack of data. [39pp.]

SC/O90/G27. FRESHWATER DOLPHIN/FISHERIES INTERACTION IN THE CENTRAL AMAZON (BRAZIL). *Vera da Silva and Robin C. Best*, Laboratorio de Mamíferos Aquáticos, Instituto Nacional de Pesquisas da Amazonia (INPA), C.P. 478, 69011 Manaus, Amazonas, Brazil.*

The Amazonian freshwater dolphins, *Inia geoffrensis* (boto) and *Sotalia fluviatilis* (tucuxi), have been little studied and their actual populations and status are still unknown. As part of a general study of the biology and conservation of the aquatic mammals of the Amazon region, the Instituto Nacional de Pesquisas da Amazonia (INPA), in Manaus has undertaken a study of these two dolphins. The increasing fisheries pressure in the Amazon has greatly augmented the potential for dolphin/fisheries interactions which could adversely affect the status of the dolphins, both through higher rates of incidental mortality in fishing gear, and through direct competition for certain fish species. This paper summarises data for 67 dolphins (33 *Inia* and 34 *Sotalia*) collected between May 1979 and March 1984 in the central Amazon region. This collection is the result of our contacts with local, and our institute's fishermen and is by no means a quantitative sampling of all dolphin mortality for this region. [11pp.]

* Robin C. Best died on 17 December 1986. He was a Research Associate of the Vancouver Public Aquarium.

SC/O90/G30. INFORMATION ON FISHERIES OF PAKISTAN. *Mohammad Sadiq Niazi, Deputy Director, Marine Fisheries Department, Government of Pakistan, Westwharf, Fish Harbour, Karachi-74000, Pakistan.*

Pakistan is located in Asia having India to its east and Iran to the west, and the northern Arabian Sea to its south. It has a coastline of about 1,050km and has an Exclusive Economic Zone (EEZ)

extending offshore to 200 n.miles (370km). The marine environment of Pakistan has been divided into two maritime provinces, viz. Sind maritime region and Baluchistan region. The former area, stretching about 350km, has Karachi harbour as its main base. It is characterised by a broad continental shelf (extending about 110km out from the coast to a depth of 200m), a coastline marked by the numerous small creeks and deltas of the Indus river, and by a muddy, easily trawlable bottom. The Baluchistan coastline, which extends some 700km, is characterised by a number of bays (Sonamiani, Ormara, Pasni, Gwadar, Jiwani) and the absence of any substantial river systems. The continental shelf of the Baluchistan coast is narrow (15 to 50km) and falls off steeply into very deep water. It has a comparatively hard bottom which makes it very difficult for bottom trawling. The shelf area is estimated to be about 35,740km^2 in Sind and 14,530km^2 on the Baluchistan coast (50,270km^2 total). [8pp. + Addendum 26pp.]

SC/O90/G31. FISHING OPERATIONS AND DEATH OF MARINE MAMMALS IN THE WATERS OFF KAMCHATKA. *V.N. Burkanov, Kamchatka Department of Nature, Pacific Geographic Institute, Far East Branch of the USSR Academy of Sciences.*

The Kamchatka region is one of the richest in the world. Throughout the year Soviet, Japanese, North Korea and China, Taiwanese and US vessels intensively harvest fish and other food species there. Numerous marine mammals are present including five Phocidae (*Phoca largha, Pusa hispida, Eryghothus barbatus, Histriophoca fasciala, Phoco vitulina richardi*), two Otariidae species (*Eumetopias jubatus, C. ursinus*), walrus (*Odobenus rosmarus*), sea otter (*Euchydra lutris*) and no less than 20 cetaceans (Cetacea). Species interactions between man and marine mammals during fishing give rise to serious potential problems of which little detail is known for Kamchatka. This paper attempts to give a general outlook on the impact of different fishing patterns on marine mammals. [3pp.]

SC/O90/G32. DOLPHINS IN THAILAND. *Suraphol Sudara, Chulalongkorn University, Bangkok, Thailand.*

Ten species of dolphins have been recorded in Thai waters, both in the Gulf of Thailand and in the Andaman Sea. Order Odontoceti (toothed whales): (1) *Sotalia plumbea* (Thai name: white-grey loma); (2) *S. bornecnsis* (Thai name: white loma of the south sea); (3) *S. chinensis* (Thai name: loma of the north sea); (4) *Steno bredanensis* (Thai name: spotted loma); (5) *Stenella malayana* (Thai name: bottlenose Malayan loma); (6) *Delphinus delphis* (Thai name: common bottlenose loma); (7) *Tursiops truncatus* (Thai name: bottlenose, short mouth loma); (8) *Orcaella brevirostris* (Thai name: bowl head, dorsal fin loma); (9) *Neophocaena phocaenoides* (Thai name: bowl head, smooth back loma); (10) *Stenella longirostris* (spinner dolphin). [3pp.]

SC/O90/G33. A REVIEW OF GILLNET AND TRAP FISHERIES IN MICRONESIA AND THE CENTRAL PACIFIC. *Eugene T. Nitta, NMFS, Southwest Region, Pacific Area Office, 2570 Dole Street, Honolulu, Hawaii 96822–2396, USA.*

Numerous variations of gillnet and trap fisheries occur throughout Micronesia and in Hawaii. The levels of effort and techniques are dictated in large part by the physiography of the islands or atolls where the fisheries occur. Conditions such as the width of the reef flat, whether or not there is a lagoon, depth of the waters immediately seaward of the finging reef, and currents and tides are all considerations in the selection and use of gear. These fisheries are now conducted with modern gear such as monofilament nets and lines, steel rebar and wire screening, outboard motors, fibreglass and aluminium boats and scuba; a significant change from traditional gear made almost entirely from natural materials. In many locations the distinctions between recreational, subsistence and commercial fishing by gillnet and/or traps are difficult to make because of the lack of formal markets or infrastructure, nonreporting of mixed subsistence and commercial catches and the continuation of some semi-traditional or cultural practices involving the sharing of catches, subsistence or otherwise. Commercial landings data, therefore, probably do not accurately reflect the true scale of local gillnet and trap fisheries in many areas of the Pacific. Cetacean interactions with gillnets and traps in what would be considered inshore reef fisheries in the central and western Pacific are rarely, if ever, reported. Gear set on the reef flats nominally separates most cetacean species from these fisheries. On occasion groups of small whales or dolphins become disorientated and trapped inside stoll lagoons and are sometimes taken for food in some areas of Micronesia. There are unconfirmed reports of humpback whales carrying away inshore gillnets in Hawaii over the past few years. This is in contrast to the reported high rates of incidental catch of cetaceans and other marine species in the high seas drift gillnet fisheries in the North Pacific and South Pacific regions. [38pp. + Revision 5pp.]

SC/O90/G35. DRIFTNET FISHERIES AND THEIR IMPACT ON NON-TARGET SPECIES. *Simon P. Northridge, Marine Resources Assessment Group, 8 Princes Gardens, London, SW7 1NA, UK.*

The major driftnet fisheries of the world are reviewed in terms of the numbers of vessels fishing, area and season of operation, major commercial species landed, and in a few cases in terms of fishing effort. Gear types are described and estimates of the amounts of netting deployed are made. The accidental captures of non-target species are described where they are known, and some indications of catch rates by species are also given. In some instances, broad estimates of total catches by species for individual fisheries are also given. Populations of non-target species which might most be at risk from entanglement in drift nets are discussed. Driftnet fisheries which have been little documented but which might be considered as potentially detrimental to individual species are also identified. [100pp.]

SC/O90/G36. REVIEW OF THE INCIDENTAL CATCHES OF CETACEANS IN JAPAN. *Teruo Tobayama, Kamogawa Sea World, Kamogawa-shi, Chiba-ken, 296 Japan, Yoshio Inagaki and Masahiro Ryohno, Hiyoriyama Marine Park, Toyooka-shi, Hyogo-ken, 669–61 Japan and Kenji Hiratsuka, Kamogawa Sea World, Kamogawa-shi, Chiba-ken, 296 Japan.*

Data on incidental catches of cetaceans in Japanese waters from 1970–1989 were gathered from 25 aquaria in Japan in 1990. In the last 20 years, a total 352 animals from 18 species caught incidentally were observed by aquaria. These were mainly caught by set nets (81%), seine nets (8%) or gillnets (7%). Major species were *Lagenorhynchus obliquens* (47%), *Neophocaena phocaenoides* (21%), *Grampus griseus* (7%), *Phocoena phocoena* (6%), *Tursiops truncatus* (5%) and *Balaenoptera acutorostrata* (4%). [6pp.]

SC/O90/G37. LARGE SCALE TRAP NET FISHERY IN JAPAN. *Tooru Sakuma, Japan Fisheries Agency, Kasumigaseki, Chiyodaku, Tokyo, 100 Japan.*

This paper summarises the large scale trap net fishery in Japan. These can be divided into two types: 'salmon' (operating in Hokkaido, mainly September to October); and 'other' (operating year round along the coast of the other Islands) that take sardines, atka mackerel, scombrids and other species. [3pp.]

SC/O90/G38. THE GROUNDFISH GILLNET FISHERY IN THE GULF OF MAINE: FISHING GEAR AND METHODS. *Stephen C. Drew, MBO, Box 936, Manomet, Massachusetts 02345, USA.*

This paper describes the gear and operations of the Gulf of Maine groundfish gillnet fishery. Monofilament gillnets with stretched mesh size ranging from 5.5 to 9 inches (140–229mm) are set on the bottom and anchored at both ends. Such nets commonly present a profile from eight to twelve feet in height. Several sections of net, each net 300 feet (91.5m) long, are joined end-to-end to make 'strings'. The length of a string of gear generally ranges from 1,500 to 3,600 feet (457–1,100m), with some strings over 6,000 feet

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(1,830m). In common practice, one boat may fish 30 to 70 nets, divided among 3–6 strings. The species most often targeted are cod, pollock and spiny dogfish (on a seasonal basis). Nets which target flatfishes are rigged to fish with the leadline on the bottom and the float rope 2–3 feet above the bottom, with the net webbing slack. A few multifilament and multimonofilament nets are also used. Over 150 vessels participate in this fishery on a year-round or seasonal basis. Most vessels fall into the 35–55 foot (11–17m) length range, fishing one-day trips, leaving their nets in the water and attempting to haul them on a daily basis when weather permits. Nets which target flatfish are often soaked longer, since these species live longer while entangled. A minority of gillnetters fish farther than 40 miles from shore, making trips lasting two to eight days, hauling their nets daily and bringing the catch ashore at the end of each trip. [4pp.]

SC/O90/G39. DISCUSSION PAPER ON MANAGEMENT OPTIONS TO CONTROL MARINE MAMMAL MORTALITY IN PASSIVE FISHING GEAR. *James M. Coe, NMFS, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, USA.*

Public and political expectations have often clashed with industrial, managerial and biological views and capabilities over controlling the fisheries bycatches of a wide range of species. Domestic and international attention to this problem is increasing as the real or perceived value and wastage of living marine resources increases. This paper discusses some general features of the fisheries resource management process and makes some recommendations in hopes of provoking vigorous discussion of the priorities and practicalities of marine mammal bycatch control. Bycatch is the collection of non-target species caught but not retained in any fishery. Bycatch may be unharmed, injured or dead when discarded. It includes both commercial and non-commercial fish and shellfish, marine mammals, birds, turtles and invertebrates. Bycatch is a fact of life for most fisheries. It typically becomes a management issue when a second or third party attaches some value to the discarded animals. The higher the value, the more likely some authority will be created or invoked to justify management actions to control, reallocate, or eliminate the bycatch. The legal notions of property, due process, and reasonableness are ever present in the application of these authorities. Marine mammals have virtually zero commercial value to passive gear fishermen. As bycatch they are cumbersome, aggravating and occasionally dangerous. On the other hand, a significant segment of the population attaches considerable value to marine mammals, wishing to protect them from harm in fisheries through statute and regulation. By establishing an economic consequence to the taking of marine mammals in the act of fishing, some control may be exercised over that taking. This type of artificial valuation of marine mammals *will* be necessary if their bycatch in passive fishing gears is to be reduced or eliminated. This implies the creation of authority permitting governmental agencies to apply appropriate measures. This type of authority varies widely around the world as does the value people and cultures attribute to marine mammals. Within the US Exclusive Economic Zone (EEZ), the Marine Mammal Protection Act and the Endangered Species Act provide this authority under certain conditions. On the high seas, this type of authority is absent except as extended through bilateral or multi-lateral agreements. Energetic international debate is developing over the ways and means to manage the resources of the high seas, focusing on bycatch in large-scale driftnet fisheries. [10pp.]

SC/O90/G40. MITIGATING CETACEAN MORTALITY IN FISHERIES: APPROPRIATE ALTERNATIVES. *Ronald Joel Smolowitz and Clifford Goudey, Massachusetts Institute of Technology, Center for Fisheries Engineering Research, Mass., USA.*

The United States has a commercial fishing industry that is very important to its economy. Concerns about marine mammals have the potential of significantly impacting commercial fishing. Efforts are underway to develop cetacean-saving gear so that fisheries can be conducted without harming cetacean populations. Gear development proceeds best when the fishermen are economically motivated to innovate to solve the problem. Proper motivation can result in the most economically efficient solution. [11pp.]

SC/O90/G41. INTERACTIONS BETWEEN THE NEW ENGLAND SINK-GILLNET FISHERY AND THE HARBOR PORPOISE, *PHOCOENA PHOCOENA*. *P. Michael Payne and Charles T. Yustin, Manomet Bird Observatory, PO Box 936, Manomet, Massachusetts 02345, USA and Gregory Power, NMFS, Northeast Fisheries Center, Woods Hole, Massachusetts 02543, USA.*

Under the 1988 reauthorisation of the Marine Mammal Protection Act the New England sink-gillnet fishery was classified as a Category I fishery. This was due to a known, but not yet quantified, bycatch of harbor porpoise (*Phocoena phocoena*) by gillnetters in the Gulf of Maine. In August 1989 the National Marine Fisheries Service/Northeast Fisheries Center initiated sea sampling aboard vessels participating in this fishery. Sea sampling effort was distributed according to fishing effort by region and season. Sea samplers observed gillnetters on 234 days during this study period on approximately 80 different vessels. The percent coverage represented by this level of sampling effort (number of days sampled per month/the total number of days fished in the fleet per month) by DSSP samplers ranged from <1.0% of total fleet effort during each month, June through August, to approximately 3.2% coverage (September). Most fleet effort (therefore sea sampling effort) occurred in NMFS/NEFC Fishery Statistical Areas 513 and 514 located from approximately Muscongus Bay to Cape Cod in the western Gulf of Maine. From August 1989 to July 1990 sampling occurred on 158 sea days, and monthly sea sampling effort ranged from 4 days per month (July 1990) to 30 (September 1989) in these two areas. Fifteen harbor porpoise were taken between October 1989 and April 1990. All documented harbor porpoise takes occurred in NMFS Fishery Statistical Areas 513 and 514. There were no porpoise captured from June through September 1989 or from May to July 1990. The seasonal take in NMFS Statistical Areas 513–514 is consistent with known movement patterns of harbor porpoise. Harbor porpoise move north, out of the western Gulf of Maine into the Bay of Fundy-eastern Scotian Shelf region from early-summer through autumn, then back through the western Gulf of Maine during late-autumn and spring. The lack of incidental take in remaining areas of the Gulf of Maine may reflect sampling effort disjunct from known harbor porpoise concentrations in the Gulf of Maine. [29pp.]

SC/O90/G43. HIGH SEAS DRIFTNET FISHERIES OF THE NORTH PACIFIC OCEAN. *Linda Jones, Michael Dahlberg and Shannon Fitzgerald, NMFS, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, USA.*

This paper reviews high seas driftnet fisheries in the North Pacific. For each of the fisheries it provides a summary of the available information on the following: flag state; ports; target species; regulations on fishing season and area; vessels and crew; fish handling methods; gear; operation details; economics and history; catch and effort data; interactions with cetaceans. The fisheries reviewed were for squid, albacore and salmon. [35pp.]

SC/O90/G44. FACTORS IMPORTANT IN INITIAL EVALUATION OF THE BIOLOGICAL SIGNIFICANCE OF CETACEAN BYCATCH. *T.D. Smith, G.T. Waring* and *T.W. Polacheck, Northeast Fisheries Center, Woods, Hole, Massachusetts, USA.*

This paper examines the information needed to evaluate the biological significance of cetacean bycatches and compares this with the data that are frequently available so that possible

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systematic biases in the appraisal of the biological significance can be anticipated and corrected for where possible, and so that statistical precision can be measured where possible. Such factors are considered here for data on bycatch rates, total fishing intensity, and population size. The interrelation of these data sources in the comparison of bycatch level and population size is then discussed. Examples are drawn from the tuna purse seine fishery in the eastern tropical Pacific (ETP) and the bottom-tending gillnet fishery in the Gulf of Maine (GOM) and nearby waters. [36pp.]

SC/O90/G45. [NOTE TO PARTICIPANTS] *John LaGrange, Captain, 'Cloud Nine', 533 North Rios Avenue, Solana Beach, CA 92075, USA.*

This note was presented by the captain of a gillnetter. He discusses the measures that were successfully used to reduce gray whale captures in nets, including closed areas and seasons and modifications to gear. He recognised that the solution for other species is not so simple, given the different behaviour, size and knowledge of other species. Some measures that may help are discussed including limiting total gear and suspending nets some distance below the surface. Problems and methods of reducing caught animals are described. [5pp.]

SC/O90/G46. GILLNETS AND MARINE MAMMALS. *K.S. Norris, Institute of Marine Sciences, University of California, 100 Shaffer Road, Santa Cruz, CA 95060, USA.*

Possible ways in which marine mammal bycatches can be reduced can be classified as: (a) behavioural solutions; (b) gear-related solutions; (c) operations related solutions and (d) regulatory related solutions. Only the first two are discussed.

Behavioural solutions. If a marine mammal is patrolling a net to take trapped fish from it, it automatically is placed at risk. Even if the animal is somehow warned of the danger involved it may be attracted to the nets because easy food lies there for the taking. Warning a marine mammal away from a net is not likely to be enough, although it might help avoid kills of animals blundering into undetected nets. A first step is to determine how the marine mammal in question becomes entangled. Second, it will be useful to keep in mind the sensory capabilities of the animals' being trapped, as opposed to the kinds of signals that may be produced by a drifting net. Not all odotocetes echolocate equally well. Delphinids in general, produce broad band clicks arranged in trains, while the phocoenids, such as the Dall's porpoise, produce very different rather narrow band signals at very high frequencies. Dall's porpoise signals have been called 'black and white sonar' as compared to the richer signals of the delphinids. Their signals are expected to be useful at short ranges; a few dozen yards, as opposed to the delphinid clicks that may be useful at hundreds of yards. Phocoenid clicks may not be useful for fine discrimination but may well be good enough to discriminate prey species. The dolphins and porpoises that produce the narrow band high frequency clicks are uniformly species that live in murky water environments. The high frequency of these signals is above the hearing of their prey so they can echolocate with impunity, in terms of alerting prey to their presence. Other senses should also be considered such as vision, touch and manoeuvrability. Knowledge of the diurnal behavioural cycle may be useful. Marine mammals have preferred times for various activities in their lives such as sleep, feeding, etc. If nets fish for more than 24hrs, a consideration of these is restricted in its usefulness, i.e. one cannot design a netting system that avoids marine mammal activity. What one can do is to learn during what activity period most marine mammal kills occur, and this might be tied to behavioural state. Such information might help define the causes of kills.

Gear-related solutions. If marine mammals blunder into nets it would be useful to warn them of the net's presence. However, a 'warning' might be an attractant into danger because the net might represent a source of food and the warned marine mammals might rush in. Behavioural observations are needed about how marine mammals regard these nets. Do they seek them, or avoid them? How do the different species that are taken react? Use of passive or active acoustic devices may be useful. If a net food is the same size range as the normal food of the marine mammal concerned there will be an attraction for the marine mammal. Therefore, if mesh size is regulated to exclude the major marine mammal foods (i.e. by use of meshes too large to take such food) the attraction should be reduced and we should be dealing with incidental take related to nets undetected by the marine mammal. In this case, a different set of solutions is indicated than if active attraction is involved. An assessment of the food types utilised by a given marine mammal species is needed. How does what the mammal eats match the kinds of fish the net takes or releases? [4pp.]

SC/O90/G48. A REVIEW OF GEAR AND ANIMAL CHARACTERISTICS RESPONSIBLE FOR INCIDENTAL CATCHES OF MARINE MAMMALS IN FISHING GEAR. *Dawn Nelson, Memorial University of Newfoundland, Department of Psychology, St. John's, Newfoundland, Canada, A1B 3L1.*

World-wide incidental capture of marine mammals in fishing gear is a serious problem. Bycatch seriously affects some populations; losses to fishermen are, in some instances, substantial. Because of the extent of the problem, there have been many studies which have attempted to alleviate it. This paper provides an overview of these studies and their findings. Biological factors which influence entrapment of marine mammals include: (1) species distribution; (2) seasonal and migratory movements; (3) various behavioural traits; (4) sensory capacities and (5) attention and searching images. While additional information is needed on all of these factors, the most promising area in which solutions may be found and which requires the most investigation is that of attention. This biological trait interacts with a number of gear characteristics including: (1) target traits and strength; (2) location of sets and (3) rigidity and rigging characteristics. Solutions to bycatch problems for marine mammal populations and fishermen can be found by cooperative investigations involving both gear technologists and marine mammalogists. [26pp.]

SC/O90/G49. RESPONSES OF NAIVE, CAPTIVE DOLPHINS TO PROTOTYPE WHALE ALARMS. *Dawn Nelson, Dolphin Research Center, Grassy Key, Florida and Memorial University of Newfoundland, Department of Psychology, St. John's, Newfoundland, Canada and Jon Lien, Ocean Science Centre and Memorial University of Newfoundland, Department of Psychology, St. John's, Newfoundland, Canada.*

Every year, thousands of cetaceans worldwide become entangled in fishing gear. One possible explanation for this phenomenon is that certain types of gear may be difficult for cetaceans to detect. If this is the case, then enhancing the detectability of a net should cause a decrease in the number of entrapments. One possibility is to place sound generators onto fishing gear. Such devices need not frighten cetaceans away, but merely serve to inform them that there is something in their vicinity. It is thought that after encountering 'alarms' on nets, cetaceans will associate the alarm noise with the presence of a net and will stay away. Preliminary work with various types of alarms in Newfoundland waters indicated that the costs of humpback whale (*Megaptera novaeangliae*) collisions with fixed fishing gear were less when alarms were placed on the gear, possibly indicating that the whales were indeed attempting to avoid the nets. The purpose of this study was to discover what initial reactions captive dolphins might have to a novel sound generator. In order for the alarms to

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be most effective, cetaceans should initially be both curious and wary of them, so that they will approach cautiously and discover the net without becoming entangled. [10pp.]

SC/O90/G51. REACTIONS OF HUMPBACK WHALES TO NOVEL SOUNDS: CURIOSITY AND CONDITIONING. *Jon Lien, Ocean Studies Centre and Department of Psychology, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, A1C 5S7; Amy Verhulst, School of Oceanography, University of Rhode Island, Narragansett, Rhode Island, USA; Tim Huntsman, Whale Research Group, Memorial University of Newfoundland, St. John's, Newfoundland, Canada; Janice Jones, Environmental Studies, Oberlin College, Oberlin, Ohio, USA and Rosie Seaton, Biopsychology Programme, Memorial University of Newfoundland, St. John's, Newfoundland, Canada.*

Add-on acoustical devices, which produce biologically novel sounds, have been proposed as a means of alerting cetaceans to the presence of cryptic fishing gear. To accomplish this, there are two prerequisites: the whale must notice the sound and learn it is associated with nets. Experiments during the summer of 1990 were designed to evaluate the reactions of humpback whales to sounds from devices developed as net 'alarms'. In the first experiment, two underwater acoustical 'alarm' devices were installed in a small bay where humpback whales were plentiful. Positions of the devices were marked with buoys which could be observed from shore. Movements of the whales in relation to the alarms were measured from shore by a theodolite. Throughout the observations, alarms were switched on and off; the observers did not know which were activated, or when. Results indicate that humpbacks closely approached alarm positions when they were producing sounds; approaches were not as common when the devices were off. The second experiment paired the presentation of these same sounds with a standard biopsy procedure used to obtain skin and blubber samples from individually identified whales. Humpbacks were photographed for individual identification and were later biopsied with or without sound; behaviours observed were recorded. Later, individuals were approached a second time with and without the sound. Behaviours observed in both approaches were compared. Individual reactions to biopsies vary as do the reactions to later presentations of sounds alone. Circumstances prevented completion of this experiment; results presented will evaluate the humpbacks short-term memory for novel sounds when they are paired with more meaningful stimuli. [13pp.]

SC/O90/G53. THE FRENCH ALBACORE TUNA FISHERY IN THE NORTH ATLANTIC. *J. Bonnemains and M. Kanas, Robin des Bois, 15 rue Ferdinand-Duval, 75004 Paris, France.*

The French albacore tuna fishery in the North Atlantic uses driftnets 4.35 miles long and 49.5 feet deep and is currently practised by 37 ships of less than 82.5 feet in length roughly between June 15 – September 15 of each year. This fishery began in 1986 with 2 vessels. Testimonies by crew members as well as observers from IFREMER (French Research Institute for the Exploitation of the Sea) during the 1988–90 fishing seasons have contributed to the Robin Des Bois' study which is based on an observer report from a fishing trip of average duration between July 31 – August 15, 1990. Estimates of the number of dolphins taken incidentally each year by this fleet have not been disproved by Robin Des Bois' observers. The question remains as to whether certain indications of abundance can permit us to claim that this incidental take does not pose a threat to regional populations. There is a need for systematic studies which suspend nets below the surface for an entire fishing season by 1 or more boats, as similar studies in the South Pacific have had encouraging results. The French albacore tuna fishery – a small-scale artisanal fishery – needs to be part of a European regulated fishery so as to avoid proliferation of the number of vessels, collapse of resources and increasing numbers of marine mammal takes. [9pp.]

SC/O90/G56. HEALTH STATUS AND BYCATCH OF HARBOUR PORPOISE (*PHOCOENA PHOCOENA*) IN DANISH WATERS. *B. Clausen, National Environmental Research Institute, Moerkhoej Bygade 26, H, DK-2860 Soeborg, Denmark.*

The report summarises available information on the health status and bycatch of harbour porpoise (*Phocoena phocoena*) in Danish waters for the last 50 years and the conclusions which may be drawn hereupon. In general it is not known how much the stock of harbour porpoise in Danish waters has decreased, but we know that there has been a migration of large numbers of harbour porpoise in and out of the Baltic Sea. This migration seems more or less to have stopped after the second world war, but before the intensive fishery started. Further, the area of distribution of harbour porpoise in the inner Danish waters seems reduced. Recent sightings from 1983–1989 do not indicate changes in the population during this period. Necropsis of harbour porpoise caught in poundnets from 1960 to 1970 revealed heavily parasitised animals. Animals caught alive in poundnets usually die due to lungworm infestation if not dewormed shortly after capture. Various information on heavy metals and chlorinated hydrocarbons have caused concern for the health and especially reproduction among marine mammals. Finally, information has been received that harbor porpoise are often incidentally caught in Danish waters. Therefore, there have been investigations conducted in order to assess: (1) whether changes in the population size have occurred; (2) the health status of the population; (3) whether it is just the sick animals which end up in the fishermens net; (4) the levels of toxichemicals, and the possible influence of pollutants on the reproduction and (5) the impact of the bycatch. [12pp.]

SC/O90/G58. PRELIMINARY REPORT ON THE JAPANESE FISHING EXPERIMENTS USING SUBSURFACE GILLNETS IN THE SOUTH AND THE NORTH PACIFIC, 1989–1990. *Shigeo Hayase and Yoh Watanabe, National Research Institute of Far Seas Fisheries, 7–1 Orido, 5 chome, Shimizu-shi, Shizuoka 424, Japan and Takashi Hatanaka, Japan Marine Fishery Resource Research Center.*

In order to develop fishing methods and techniques for avoiding or reducing the incidental takes of non-target species including cetaceans without the reduction of target species, the Fisheries Agency, Government of Japan, conducted the following two types of fishing experiments. (1) Experimental trials were conducted from November 1989 to March 1990 in the Tasman Sea and east of New Zealand setting 178mm large mesh gillnets both at the surface (about 900 tans/operations) and at 2m below the surface (100 tans simultaneously) for comparing the fish and dolphins catches between two different fishery gears. (2) During 4–31 May 1990, trials were conducted on the Japanese squid fishing ground in the North Pacific by seven Japanese commercial squid driftnetters, using surface gillnets (subsurface nets at average 2m) (88 tans). All data used were obtained through radio communications. In the experiment in the South Pacific, 57,940 tans of surface gillnets and 6,898 tans of subsurface gillnets were deployed. The CPUEs (catch in number/1000 tans) on albacore, the target species, were 533.8 in the surface net, and 644.5 in the subsurface net, respectively. Thus the result indicated that there was no significant difference in albacore catch rates between the surface and subsurface nets. A total of 97 common dolphins, 17 striped dolphins, and 9 other cetaceans were caught by the surface nets. Only one Baird's beaked whale was caught by the subsurface nets. In the experiment in the North Pacific, 124,881 tans of surface nets and 16,021 tans of subsurface net (8,751 at 1m, 7,270 at 2m) were deployed, respectively. CPUEs (kg/1,000 tans) on neon flying squid were 1,330 for the surface net and 1,310 for the subsurface nets (2m). This result indicated that there was no significant difference in squid catch among these three types of fishing operation. A total of 44 dolphins (CPUE: 0.35 individuals/1,000 tan) by surface nets; 3 dolphins (0.34) by 1m nets and one dolphin (0.14) by 2m were caught. This suggests that alternative fishing methods submerging nets below the surface may be more or less effective in reduction of cetacean catch rate. Although

these trials are preliminary, the results suggest that subsurface gillnets may be effective for reducing cetacean bycatch while maintaining catch rate of target species at almost the same level as with surface net. Further extensive trials will be required to confirm these results. [11pp.]

SC/O90/G59. ENCOUNTERS WITH GILLNETS: PRELIMINARY RESULTS FROM A SIMPLE MODEL AND SIMULATION OF THE PROBABILITY OF ENCOUNTERS WITH LONG PELAGIC DRIFTNETS BY CETACEANS. *Gordon R.V. Anderson, Australian National Parks and Wildlife Service, PO Box 636, Canberra City, ACT 2601, Australia.*

Scattered observations on the distribution of entanglement sites of small cetaceans in long pelagic driftnets show non-random distributions along the net, with higher frequencies of entanglement toward the ends of the nets than in the central areas in some sets of observations. Explanations for the observed differences have included attraction of cetaceans to the net-end buoys and locating gear or differential soak times for nets shot and hauled from the same end. The preliminary results of a simple model and computer simulation of encounters of small cetaceans with a gillnet are described. The model: a two dimensional model of a single 50km driftnet; soak time of 10 hours; dolphin movement on random headings each ten minutes from a randomly assigned starting point, travelling at 100 to 2,000m/10 minutes, density of animals 100 per 50km by 200m strip parallel to the gillnet axis, strips from 0 to 20km, with equivalent density in quadrants beyond net ends. Simulations were run for swimming speeds of 100 to 2,000m/10 minutes in increments of 100m/10 minutes, with variance estimated from ten replicates for each speed. For the area beyond the net ends, 10 replicates were run for each swimming speed. Initial results indicate that for the area perpendicular to the net, the probability of encounters along the net is not uniform, with progressively greater differences between encounter rates in the central sections and the ends of the net with increasing swimming speed. For even quite modest swimming speeds, there is a significant chance of encountering the net for animals many kilometres away when the net is set and a significant encounter rate well into the soak period. There is also a probability that an animal well beyond the end of the net when it is set may move far enough during a ten hour soak time to encounter the net. Encounters along the net for animals moving from the areas beyond the net ends show strong peaks towards the ends of the net; the peaks spreading along the net with increasing swimming speed. Those peaks are strong enough to mask the lower probability of encounter towards the ends of the net for animals from the areas along the nets. The combined distributions for all areas fished by a net show strong peaks towards the net ends, with the form of the distribution dependent on swimming speed. While pelagic species of small cetaceans may travel considerable distances at speeds of 10 knots or more, foraging and resting movements may be very much slower. For inshore species, sustained speeds of 2–5 knots are reported commonly, although the horizontal distance covered in any 10 minute period may give a lower overall speed. (For a speed of 5 knots, the distance travelled in 10 minutes is approximately 1,300 metres). [7pp.]

SECTION 2. ABSTRACTS AS INCLUDED IN THE SYMPOSIUM BOOKLET (EXCLUDING THOSE WHERE A FULL PAPER WAS SUBMITTED AND MADE A DOCUMENT FOR THE WORKSHOP). ABSTRACTS ARE IN ALPHABETICAL ORDER BY AUTHOR.

PRELIMINARY REPORT ON DEATH OF CETACEANS IN GILLNETS IN NORTHEASTERN VENEZUELAN WATERS. *Ignacio Agudo, Fundacetacea Fundación Venbezolana para la Investigación, Defensa y Conservación de Mamíferos Cetáceos y Afines, P.O. Box 1273, Carmelitas, Caracas 1010, Venezuela.*

In Venezuelan waters between 9°55′-11°25′N and 61°50′-64°30′W, local fishermen use gillnets 50–200m long and 5–12m deep constructed of 8–13cm-mesh webbing (Mihara *et al.*, 1971; MAC, 1982). In February 1987, 1,537 nets were reported operating in the area. *Morro de Puerto Santo* of August 26 1988 reported the sale of six dolphins to the crew of a shark-fishing boat. The dolphins were cut into pieces and placed in refrigerated storage for use as bait on bottom longlines. The skulls were obtained and have been placed in the Estación Biológica Rancho Grande (EBRG). The six dolphins were identified as *Stenella frontalis* (EBRG 16884, 16889), *S. longirostris* (EBRG 16885, 16886, 16887) and *S. clymene* (EBRG 16888). According to preliminary reports, since the beginning of 1988 deaths of cetaceans in gillnets have been very frequent. They have been used both for bait and for human consumption (Dollinger, 1985). In addition to the above three species of *Stenella*, cetaceans involved include *Delphinus delphis, Tursiops truncatus, Sotalia fluviatilis* and *Balaenoptera* sp. There have been no systematic efforts to determine capture rates, total mortality, species composition or impact of the incidental kills on the cetacean populations.

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INCIDENTAL CAPTURE OF SMALL CETACEANS ON THE COASTS OF RIO DE JANEIRO, ESPIRITU SANTO AND BAHIA STATES, BRAZIL. *L. Capistrano, R. Ramos* and *A.P. Beneditto, Fundação dos Estudos do Mar (FEMAR) World Wildlife Fund-US Project No. 3807, Rua Marques de Olinda, 18, Botafogo – Rio de Janeiro, Brazil 22.230.*

Between October 1988 and September 1989 we surveyed approximately 1,400km of the Brazilian coast from the village of Parati in the north (23°13′S, 44°43′W) to Santa Cruz de Cabrália in the south (16°13′S, 39°04′W). Fishing activities occur throughout the area surveyed. The main types of gear used are gillnets, seines, trawlnets and handlines. According to the fishermen, small cetaceans are incidentally captured in gillnets and seines in almost all of the places visited. The animals are generally used for fishing bait; an exception is the village of Regência (19°40′S, 39°45′W), where they are used for human consumption. We collected 25 small cetaceans at three localities (Atafona 21°37′S, 41°01′W, Regência and Conceiçao da Barra 18°30′S, 39°45′W); 21 were from gillnets and 4 from strandings. Of these, 17 were of the marine form of *Sotalia fluviatilis*, 7 were *Pontoporia blainvillei* and one was unidentified. The gillnets varied from 146–2,000m in length and 2–10m in depth. Mesh size ranged from 3–20cm. Because of the very long coastline involved and the brief period of time available for the survey, no attempt has been made to assess the impact of the incidental kills on the dolphin populations.

DOLPHIN CATCHES IN TAIWAN. *Che-Tsung Chen, National Taiwan Ocean University, 2 Pei Ning Road, Keelung 20224, Taiwan.*

There is a long history of catches of marine mammals in Taiwan. The primary species has been *Tursiops truncatus*, caught by gillnet, purse seine, drag net, drives using nets, tuna longline, troll line and harpoon. The main landing ports have been Peng-Fu, Suao and Tung-Kang. The meat is sold locally for human consumption at an attractively low price. At Peng-Fu the

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fishermen use nets in a drive fishery to encircle the dolphins and hold them in inshore areas for sale to oceanaria in Taiwan and abroad. In recent years, about 60–100 dolphins have been captured during their annual migration in February. Local fishermen report that dolphins often interfere with hook-and-line fisheries, scaring the fish away and removing hooked tuna. Some dolphins are harpooned by fishermen when they follow the fishing vessels. Recommendations are made for future conservation and management of dolphins in Taiwanese waters.

BIOLOGICAL, ENVIRONMENTAL AND PHYSIOGRAPHIC FACTORS IMPLICATED IN THE INCIDENTAL CATCH OF BOTTLENOSE AND HUMP-BACKED DOLPHINS IN GILLNETS. *V.G. Cockcroft, Port Elizabeth Museum, PO Box 13147, Humewood 6013, South Africa.*

On the east coast of South Africa, gillnets are set to catch and deplete the numbers of sharks which may interact with bathers. Although the annual incidental catches of bottlenose and hump-backed dolphins (32 and 8, respectively) in these nets are low, neither population seems capable of sustaining such mortality and both appear to be in danger of local extinction. An analysis of biological, environmental and physiographic data for each animal captured provides some insights into the reasons for the incidental capture of these dolphins. The biological characteristics of the catch of the two species were generally distinct, although a few commonalities were evident. The majority of captures were single events, but mother and calf pairs of both species were often captured, although much more so for bottlenose dolphins. Most captured dolphins had almost full stomachs, implying that the capture of individuals of both species occurred either during or subsequent to feeding. Environmental parameters generally appeared to have no influence on captures. However, for the majority of captures of both species, current direction on the day of capture was different to that normally prevailing, possibly resulting in local prey movement and abundance. None of the physiographic factors analysed seemed to have an influence on capture. These results suggest that both bottlenose and hump-backed dolphins are captured during or immediately subsequent to feeding and although the exact mechanisms of capture are unknown, it is feasible that inattentiveness during or following feeding may result in capture. In conclusion, these data infer that efforts to prevent incidental captures should concentrate at the species level. Additionally, as both cetaceans and fisheries harvest in areas of relative prey abundance, it may be difficult to minimise captures without modifying fishing gear.

CAPTURE OF SMALL CETACEANS IN GILLNETS OFF THE PROVINCE OF SANTA CRUZ, ARGENTINA. *R.N.P. Goodall* and *M. Iniguez, 3410 Ushuaia, Centro Austral de Investigaciones Cientificas, Tierra del Fuego, Argentina. P. Sutton, Fundación Vida Silvestre Argentina, Buenos Aires, Argentina.*

The Province of Santa Cruz, Argentina (46°S to 52°20'S) has some 1,000km of coastline facing the southwestern South Atlantic, with low areas at the mouths of rivers and streams interspersed with long stretches of high cliffs. The province is sparsely populated, with few large towns. In the southern part of the province, fishing takes place sporadically during summer months with fixed gillnets set in the tidal zone perpendicular to shore for coastal fish. During brief coastal surveys in 1983 and 1986, we found 31 Commerson's dolphins (*Cephalorhynchus commersonii*) taken in nets at Bahia Laura, San Julian, Bahia Media Luna, Angelina and Cabo Buen Tiempo. Remains of Peale's dolphins (*Lagenorhynchus australis*) and spectacled porpoise (*Australophocaena dioptrica*) could have come from net fisheries. Coastal fishing with gillnets set from small beaches is common in the northern part of the province and in rivers such as the Rio Gallegos. One or more captures are known from Bahia Laura, but no recent cetacean mortality has been reported from Puerto Deseado, the largest port, where nets evidently are not set if dolphins are present. At least 20 ocean-going vessels of over 30m in length are based in Puerto Deseado and a few leave from the ports of Santa Cruz and San Julian. These work over the continental shelf with mid-water or bottom awl nets for shrimp, abadejo (*Genypterus blacodes*), merluzas (hakes, Merluccide) and others. In some of these fisheries, especially for abadejo in mid-water trawls, cetaceans are taken incidentally; the species involved to date are *C. commersonii* and *L. australis*. Monitoring for incidental catch in this province began only recently and the data are far from complete.

ASSESSMENT OF THE IMPACT OF DRIFTNET FISHING ON OCEANIC ORGANISMS: TASMAN SEA, JANUARY 1990, THE RESULTS OF THE GREENPEACE EXPEDITION. *Michael R. Hagler, Greenpeace Ocean Ecology Campaigner and Leader of the Tasman Sea Driftnets Expedition, Private Bag, Wellesley Street, Auckland, New Zealand.*

While numerous scientific observer programs had documented the devastating toll being exacted by driftnets on marine wildlife in the North Pacific, no data existed at all on their impact in the Tasman Sea or South Pacific region. Concerned about this lack of data, Greenpeace launched an expedition into the area during the 1989/90 albacore tuna fishery season. Driftnet fishermen in the Tasman laid an average of 40km per boat, per night between January 12 and 21, 1990. Japanese vessels deployed an average of eight individual nets, five kilometers in length, end to end: Taiwanese vessels deployed an average of five individual nets, eight kilometers in length, end to end. These nets were laid north/south across the expected easterly migration path of albacore tuna. Quantitative catch data were recorded for 23 complete nets and part of two additional nets of nine different days. Data recorded were fishing activities carried out between approximately [3?] to 41°S, and 156° to 161°E. Total net length surveyed for quantitative catch data was 126km, or an estimated 1.6% of the total length of driftnets deployed during this period. Eighteen nets were surveyed during net haulage; seven were surveyed during net soakage. Total catch records for nets which were quantitatively surveyed included 1,419 tuna (albacore and skipjack), 5 sunfish, 6 sharks, 7 billfish, 7 dolphins and 31 miscellaneous animals. A rare southern bottlenose whale was found entangled in an additional net. On the basis of mean calculated catch rates, twenty driftnet vessels in the Tasman Sea were predicted to have caught between some 780,000 to 900,000 tuna, 3,000 sunfish, 4,000 sharks, 3,000 billfish, 6,400 dolphins and 20,000 Ray's bream during the 3 month season. In the case of marine mammals, one dolphin was caught per 113 tuna, or per 11km of net during the net haulage (using calculated means). A major concern raised by this investigation was the apparent extent of 'high grading' (discarding of damaged target species) by Japanese driftnet vessels. These data fully support reports that this fishing practice is directly responsible for an unacceptable number of marine mammal deaths in the Tasman Sea and that it presents a hazard to non-target animals such as sharks and sunfish.

INCIDENTAL TAKE OF CETACEANS BY FISHING ACTIVITIES IN THE NEARSHORE WATERS OF THE NORTHEASTERN US, 1975–1989. *Scott D. Kraus, New England Aquarium, Central Wharf, Boston, MA 02110, USA. Colleen Coogan, National Marine Fisheries Service, 1 Blackburn Drive, Gloucester, MA 01930, USA. Patricia M. Fiorelli, New England Fishery Management Council, 5 Broadway, Saugus, MA 01906, USA.*

A total of 428 cetacean entanglements have been documented from 1975 through 1989 in the nearshore waters of the Gulf of Maine and the New York Bight. Gillnets, lobster gear, weirs and seines are the primary sources of entanglement. When the documented entanglements are analysed by species, mortality rates are inversely correlated with the size of the animals involved. In harbor porpoise encounters with gillnets, mortality exceeded 99%. The reported minke whale entanglement mortality is 64%, for humpbacks it is 12% and for finback whales 0%. These figures are probably overestimates of large whale mortality per entanglement, since some whales are likely to escape before they are discovered in fishing gear. In right whales, for example, 58% display scars indicative of entanglement at some time in their lives, but only three are known to have died incidental to fisheries activities (Kraus, 1990). However, because

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most entanglement reporting has been opportunistic the total number of entanglements is probably far larger than the 428 reported here. Further data from the NMFS marine mammal exemption program are not included here. For harbor porpoise, extrapolations from a limited systematic study conducted by Dr. James Gilbert in the early 1980s, combined with a review of the published literature, suggests that nearly 1,000 harbor porpoise are taken from the Gulf of Maine annually. This represents about 6.5% of the highest estimate of 15,300 for the Gulf of Maine harbor porpoise population (Read and Gaskin, 1988). Significant life history changes in the Bay of Fundy population indicating a serious population decline (Read and Gaskin, 1988) combined with this estimate suggest that the Gulf of Maine harbor porpoise population is being threatened by the gillnet fisheries of both the US and Canada.

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MORTALITY OF HARBOUR PORPOISES IN THE SWEDISH GILLNET FISHERY. *Ingalill Lindstedt, Institute of Marine Research, PO Box 4, S-453 00 Lysekil, Sweden.*

Data on the mortality of harbour porpoises (*Phocoena phocoena*) in fishing gear in Sweden in the years 1988–1890 are presented. In June 1988, a collection of harbour porpoises found dead in Swedish waters was started. Animals killed in the Swedish fishery as well as animals that have died of other causes are taken to the Museum of Natural History in Goteborg where they are examined. Data on the location of the catch, the kind of fishing gear used, etc. are obtained from the fishermen. During the first two years of this project 272 animals were collected of which 137 (50%) were found in fishing gear, of these 116 (85%) were from the coastal gillnet fishery. Currently most of the harbour porpoises incidentally killed in the commercial fishery are collected, this is supported by interviews among fishermen. The findings have been evaluated in terms of distribution of different kinds of fishing gear, seasonal and geographical distribution and sex and age of the animals. All major types of gillnets used in the Swedish fishery were represented, but most of the animals were taken in large mesh nets, (70–170mm) set for cod (*Gadus morhua*), pollack (*Pollachius pollachius*) and dogfish (*Squalus acantias*). Fishery statistics indicate that large meshed nets show the highest catch per unit effort. Most animals were taken in nets set at 10 to 60 meters. Few animals were taken in driftnets, probably because the fishery with large mesh driftnets for salmon largely occurs in the Baltic Sea where the harbour porpoise nowadays is rare. The number of animals caught in the gillnet fishery shows a peak in April, most probably reflecting the migratory behaviour of the species as well as seasonal changes in the fisheries involved.

SURVEY OF INCIDENTAL NET CATCHES OF MARINE *SOTALIA FLUVIATILIS, PONTOPORIA BLAINVILLEI* AND OTHER SMALL CETACEANS IN BRAZIL. *Liliane Lodi* and *Salvatore Siciliano, Projeto Baleia Jubarte, Parque Nacional Marinho dos Albrolhos, Praia do Kitongo s/no., Caravelas, Bahia, Brazil 45.900. Monica Borobia, St. Lawrence National Institute of Ecotoxicology, 310 Avenue des Ursulines, Rimouski, Québec, Canada, G5L 3A1.*

Unknown numbers of small cetaceans are killed annually by net entanglement in fishery operations in Brazil (Lodi and Capistrano, 1990). As a preliminary assessment of the nature and magnitude of catches, specimens were collected opportunistically from Pará (01°00'S 48°30'W) to São Paulo (25°15'S 48°00'W) States and available information complied from the literature. Marine tucuxi (*Sotalia fluviatilis*) and the franciscana (*Pontoporia blainvillei*) appear to be the most common species incidentally caught in gillnets (of various dimensions) from coastal artisanal fisheries throughout most of their range in Brazil. To date, 90 *Sotalia* are known to have been taken incidentally by 22 fishing villages in the surveyed region, with 73% of these catches from 1986–1990. Twenty-nine franciscanas were captured by three fishing villages between 1984–1988, from Espírito Santo (19°38'S 39°49'W) to São Paulo (24°43'S 47°33'W) States. Sex ratios for *Sotalia* (n=54) and *Pontoporia* (n=23) were similar, being approximately 1:1. Catches for both species were higher during the austral summer, with adult *Sotalia* (87%, n=45), and juvenile and subadult *Pontoporia* (62.5%, n=24) predominating. Other species identified from bycatches were the rough-toothed dolphin (*Steno bredanensis*) (n=3), the common dolphin (*Delphinus delphis*) (n=2), one false killer whale (*Pseudorca crassidens*) and one spotted dolphin (*Stenella frontalis*), all from the coast of Rio de Janeiro State. Target fish vary regionally, but the main species include mullet (*Mugil* spp.), croaker (mainly *Micropogonias furnieri*), weakfish (*Cynoscion* spp.) and marine catfish (Ariidae). Captured dolphins are stored and sold to serve mostly as bait for local shark fisheries (mainly Carcharhinidae) but in poorer villages for human consumption. From the coasts of Pará to São Paulo, at least 83 fishing villages operate gillnets year round. In spite of its low sampling effort our survey indicates that *Sotalia* and *Pontoporia* are highly vulnerable, especially considering the rudimentary nature of some fisheries. The impact of such interactions on dolphin populations, of yet unknown size, requires further evaluation for the achievement of sound management and conservation policies.

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PROPOSAL FOR COLLECTION OF INFORMATION ON THE VAQUITA (*PHOCOENA SINUS*) FROM FISHERMEN IN THE GULF OF CALIFORNIA. *Roman G. Maldonaldo, Coordinator of Nature and Exact Sciences, University Iberoamericana, Mexico Parq. Ave. No. #403, Z.C. 22200, Beaches of Tijuana, B.C., Mexico.*

The production and distribution of a simple brochure will provide an opportunity for fishermen to cooperate in efforts to preserve the vaquita. The fishermen may see the porpoise during or apart from fishing operations and potentially can collect data useful for scientific investigations. The brochure should include at least: (1) a complete description of the characteristics of the vaquita, including external proportions, with photographs; (2) a map showing all previous records; (3) a description, with illustrations, of the various types of nets in which the vaquita may be entangled; (4) a list of the kinds of observations of appearance, behaviour and fishery interactions that will be useful for research. The goal of this program, in addition to collection of data, will be to educate the fishermen and make them part of the program to save the vaquita.

ACCIDENTAL CATCH OF *SOTALIA BRASILIENSIS* IN SOUTHEAST BRAZIL. *Emygdio L.A. Monteiro Filho, Departamento de Zoologia, Instituto de Biologia, Campinas, SP, CP 6109, Cep. 13.081, Brazil.*

The estaurine complex of Cananéia is a mangrove region of high fertility, located in the south of the state of São Paulo, Brazil (25°01'S, 47°55'W). In this region, the local fishermen utilise two principal methods of fishing: the waiting net, which is extended in certain areas, although this method of fishing has not been used frequently; and the 'cercos' which is a fixed trap set in all seasons of the year in some mud banks, within the tidal range. *Sotalia brasiliensis* is frequently found in this habitat where it feeds in the surroundings of the mud banks. In 1984 a young female was found (approximately four months old) which had been killed in a waiting net in the mouth of a river. In 1989, young dolphins were found twice inside the 'cerco', with sufficient space for swimming and diving. In these occasions, the two dolphins were withdrawn from the 'cerco' with the help of a special net and subsequently were returned to the sea without any injury. However, these accidents in this region are rare and only one of the methods utilised (waiting net) may be harmful to the dolphins, although, without danger to the stock population.

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REACTIONS OF BOTTLENOSE DOLPHINS DURING THE FIRST ENCOUNTERS WITH MONOFILAMENT GILLNETS. *Dawn Nelson, Biopsychology Programme, Memorial University of Newfoundland, St. John's, Newfoundland, Canada and Dolphin Research Center, Grassy Keys, Florida. Jon Lien, Ocean Sciences Centre and Department of Psychology, Memorial University of Newfoundland, St. John's, Newfoundland, Canada.*

Reactions of captive bottlenose dolphins that had no previous experience with monofilament gillnets were recorded by underwater video camera. The dolphins were released in a familiar enclosure which contained a single gillnet. Trials continued for one hour. Later, latency of first behaviours directed toward the net, type and frequency of behaviours were scored from analysis of the videotape. Each animal was tested at least twice. In this presentation, videos of the dolphins' reactions to nets were shown. The relationship of behaviours during first encounters with gillnets to entrapment and net mortality will be discussed. Often the incidental entrapment of young dolphins in gillnets is considered the result of a failure to detect or pay attention to nets. This study suggests that exploratory behaviours and attention actually directed toward nets is responsible for many gillnet entrapments.

AN UPDATED WORLD REVIEW OF INTERACTIONS BETWEEN MARINE MAMMALS AND FISHERIES. *Simon P. Northridge, Imperial College Centre for Environmental Technology, Marine Resources Assessment Group Ltd., 8 Princes Gardens, London, SW7 1NA, UK.*

This review is presented as an update to a previous work (Northridge, 1984) on interactions between marine mammals and fisheries. Each of the FAO statistical areas of the world oceans are treated in turn and published information for each area is used to collate an updated account of the ways in which marine mammals and fisheries interact. Particular attention is paid to the accidental capture of marine mammals in fishing gear and some new fisheries with potentially significant impacts on marine mammal populations are noted.

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ACCIDENTAL CAPTURES OF MARINE MAMMALS BY FISHERIES IN BRITISH WATERS WITH PARTICULAR EMPHASIS ON GILLNET FISHERIES. *Simon P. Northridge, Imperial College Centre for Environmental Technology, Marine Resources Assessment Group Ltd., 8 Princes Gardens, London, SW7 1NA, UK.*

Records of accidental captures of marine mammals in British waters have been collected from a wide variety of sources. Such records indicate that accidental captures of marine mammals have occurred over a long period of time and in a wide variety of fisheries. Catches are reviewed by fishing method. Trawlers are economically the most important part of the fishing fleet in Britain and these vessels evidently catch a number of marine mammals every year. Although gillnet fisheries are economically far less important, the numbers of boats employing gillnets is very large. Accidental captures of marine mammals in these fisheries are discussed on a regional basis. Certain areas and types of gillnet fisheries appear to catch significantly more marine mammals than others. The reasons for this are discussed and recent trends in gillnet fisheries in Britain are reviewed in terms of changes in vessels size distribution and fishing effort by region.

DOLPHIN DETERRENTS TESTED IN SHARK NETS OFF NATAL, SOUTH AFRICA. *Vic Peddemors, Natal Sharks Board, Private Bag 2, Umhlanga Rocks, 4320, South Africa. Vic Cockcroft, Port Elizabeth Museum, PO Box 13147, Humewood, 6013, South Africa.*

Shark nets are permanently set off 44 beaches on the Natal coast to protect bathers from shark attacks. Although these nets have proved very effective in preventing shark attacks, they have also caught a substantial number of harmless animals, including dolphins (Cockcroft, 1990). Concern for the effect of these incidental shark-net captures on populations of *Tursiops* and *Sousa* led to experiments with dolphin deterrent devices in the nets. These deterrents included both active and passive devices which were manufactured as cheaply as possible to enable future mass production if the tests proved successful. (1) Active devices emitted sounds and were of three types: (a) *clangers*: hollow copper cylinders with a pendulum suspended underwater and set in motion through wave action; (b) *rattles*: loose metal balls rolling with wave action inside the plastic net floats; (c) *bell buoy*: a floating 7kg gas bottle with a pendulum suspended inside the sealed cavity and activated through wave action. (2) Passive devices did not produce audible signals: (a) *plasticised aluminium foil*: 25cm squares attached to 4m intervals along the net centre; (b) *aluminium disc*: 23.5cm diameter flat discs were attached to net ends; (c) *stainless steel twine*: a double strand of 0.16mm diameter stainless steel twine was included in the braid of a new net. 2(a) and 2(b) were intended to act as possible visual and echolocatory stimuli, whereas the braid was to act as an echolocatory stimulus. Dolphin behaviour did not change when in the vicinity of the nets containing the active devices, however, the net containing the rattles caught a juvenile dolphin after 15 days and a humpback dolphin was caught 300m from the bell buoy. Although shark catches did increase during the period of experimentation in the net containing clangers, the rattles and bell buoy appeared to cause no change to the shark catch rate. Electrolytic reaction between salt water and the aluminium foil resulted in clear plastic panels where sealing had broken. The aluminium discs tarnished (reducing visual stimulus), caused minor entanglements and cut the nets. No dolphin movements were observed around the nets during these two experiments and no shark or dolphin catches occurred. The stainless steel twine was not affected by corrosion but broke during normal net handling, resulting in numerous steel burrs which rendered the net unmanageable. These operational problems and an extremely low annual CPUE for dolphins led to the discontinuation of these experiments. Results from this work suggested that more data should be obtained regarding factors influencing the dolphin catches before continuing attempts to deter dolphins from these nets. Subsequent behavioural observations indicate that the dolphins are normally aware of the presence of the nets, suggesting that a form of distractant behaviour exists during capture. This usually takes the form of feeding behaviour, however, spontaneous behaviour such as play may be important, especially during the captures of younger animals. Experimentation has therefore started using nets of varying mesh sizes in an attempt to reduce catches of smaller/younger animals. This represents the first approach at modifying net selectivity rather than attaching possible deterrent devices to nets, although this is possibly not directly applicable to the problem of incidental captures elsewhere. The international lack of success with deterrent devices suggests that *ad hoc* experimentation of this type should be reduced in favour of gaining a better understanding of the species interacting with the fishery. It is also the authors' opinion that cheap, homemade devices would probably be insufficient to warn dolphins of nets and that electronic acoustic devices would be more effective.

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STATUS AND CONSERVATION OF SEA DOLPHINS ALONG THE EAST COAST OF ANDHRA PRADESH, INDIA. *Rayavarapu J. Rao, School of Zoology, Jiwaji University, Gwalior, 474 011, India.*

An investigation was carried out during the months of May and June, 1990 to study the mortality of dolphins in fishing nets in the coastal belt of Andhra Pradesh near Kakinada. Data were also collected from the Fisheries Department, A.P. It was reported by the fishermen that dolphins (*Tursiops aduncus*), vernacular name:

Gadumi, Torra) were occasionally caught in the gillnets. According to them sightings of dolphins are occasional and usually dolphins are sighted during October-April in groups of 6–10 animals. Along with sea turtles (*Lepidochelys olivacea*), dolphins were also killed along the east coast due to gillnet operation (Rao, 1985; Silas *et al.*, 1983). Fishermen reported that earlier dolphins were not used for any purpose: however, these days they use the flesh of dolphins as bait for sharks, which is a growing fishery on this coast. Fishermen also sell dolphins as food. The price for one dolphin varies from Rs500 to 1,000 (US$30–60). According to the reports given by the Fisheries Department, a total of 7,892 fishermen using 1,973 boats operate gillnets along this coast. Each gillnet measures 30–40m in length and 12m in width, with a mesh size of 15–25cm. Detailed information on dolphin mortality rate along this coast is not available. It was learned that no measures are taken by the gillnet operators to avoid incidental catch of dolphins. It is suggested that a conservation programme for the protection of dolphins be started along the coast, where a sanctuary was created in 1978 for the conservation and management of the saltwater crocodile (*Crocodyles perosus*). Incidental catch of whales along this coast in gillnets has not been reported.

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A TANGLED WEB: HARBOUR PORPOISES AND GILLNETS IN THE BAY OF FUNDY. *Andrew Read, Department of Zoology, University of Guelph, Guelph, Ontario, Canada, N1G 2W1. Laurie Murison, Grand Manan Whale and Seabird Research Station, PO Box 129, North Head, Grand Manan, New Brunswick, Canada, E0G 2M0. Per Berggren, Department of Zoology, University of Stockholm, S-10691, Stockholm, Sweden. Thomas Woodley, Andrew Westgate and David Gaskin, Department of Zoology, University of Guelph, Guelph, Ontario, Canada, N1G 2W1.*

We have been studying incidental catches of harbour porpoises (*Phocoena phocoena*) in the Bay of Fundy gillnets since 1985. Each summer harbour porpoises and groundfish move into the Bay of Fundy where the porpoises become entangled in gillnets set for the groundfish. In this paper we briefly review the fishery, the nature of the entanglement process, the effects of these incidental catches and explore potential resolutions to the problem. The gillnet fishery in the western Bay of Fundy is relatively small, composed of between 19 and 28 vessels each season. Typically, each fisherman use 15 webs (183 × 3.65m each) of 15cm mesh monofilament net, anchored on the bottom in depths of 35–100m (Read and Gaskin, 1988). The nets are usually set in the morning and retrieved the following day. Indirect evidence suggests that porpoises are entangled while the nets are on the bottom. We have received very few reports of live porpoises recovered from gillnets; most of the 300+ specimens we have examined exhibited rigor mortis and damage by benthic scavengers. In addition, many porpoises have remains of hagfish (*Myxine glutinosa*) in their stomachs, suggesting that the porpoises are feeding on hagfish that are themselves foraging on fish in the nets. It is unclear whether or not the porpoises can detect the nets. Preliminary evidence indicates that rates of incidental mortality from all gillnet fisheries, including those of the Gulf of Maine, lie between 2 and 10% per year. It is unlikely that the population can sustain such incidental catches, given their low potential for increase (Woodley and Read, 1990). Harbour porpoises have virtually disappeared from some areas in the Bay of Fundy in which they were formerly abundant, perhaps due to a decrease in total population size. There have also been changes in life history parameters, such as a decrease in age at sexual maturity and an increase in calf size, that are consistent with a reduction in density (Read and Gaskin, 1990). There are several potential resolutions to this problem, including area closures, gear modification, or elimination of the fishery. We suggest that the most efficient solution to this particular conflict is to replace gillnets with other, more selective forms of fishing gear such as longlines.

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THE IMPACTS OF PASSIVE NETS AND TRAPS ON THE GANGETIC DOLPHIN. *Tej Kumar Shrestha, Royal Nepal Academy of Science and Technology and Department of Zoology, Kirtipur Campus, Kathmandu, Nepal.*

Gillnetting is widely practised in the hydrographically unique mountain rivers of Nepal. Both fishermen and the susu (*Platanista gangetica*) rely on food from the rivers for survival and therefore interact in many ways. In the present paper, design and construction of various kinds of driftnets and gillnets are described. Entangling properties of the nets and their impacts on breeding and calving populations of dolphins are evaluated. Synthetic twine is widely used in the nets; this may be deadly, because it is not easily detected visually or acoustically by dolphins in the murky run-off waters generated by the annual monsoon (May-July). Dolphins are an indirect target of such fishing efforts and their populations are often negatively affected by interactions with fisheries. The fishermen compete for limited fish resources. In the process, dolphins become entangled in gillnets or are otherwise harvested inadvertently. The low water of winter attracts commercial gillnet fishermen, who use stretched gillnets and capture juvenile dolphins. Gillnets are often stretched across the river at night to capture everything that passes, placing them in direct competition with the dolphins. An estimate of mortality of juvenile dolphins and endangered game fish is made. Incidence of entanglement and effects of stranding events are evaluated. Possible ways and means to reduce dolphin kills in nets are discussed, including recommendations for regulation of mesh size. The dead and dying dolphins are retrieved immediately. Their eyes, foetuses and genitalia are used by folk healers as charms and in medicines. The need and opportunity for educating the riverside people about the value of the endangered dolphin are highlighted and suggestions are made for effecting fishing regulations and enforcement.

FRESHWATER DOLPHIN/FISHERIES INTERACTIONS IN THE AMAZON REGION (BRAZIL). *V.M.F. Da Silva* and *R.C. Best*, Laboratorio de Mamíferos Aquáticos, Instituto Nacional de Pesquisas da Amazônia, (INPA), Brazil.*

An analysis of the relative importance of different types of fishing gear in Amazon dolphin mortality based on samples of 33 *Inia geoffrensis* (boto) and 34 *Sotalia fluviatilis* (tucuxi) revealed the lampara seine was most lethal (82.8%) for *Inia*. Whereas, drifting (38.3%) and fixed gillnets 35.3% were the major contributors in *Sotalia* mortality. These three types of gear accounted for a total of 97% of all *Inia* captures and 88.2% of *Sotalia* incidental captures. The use of nylon gillnets in fisheries in the Amazon, although recent, is widespread throughout the whole region, with increasing fisheries pressure and the potential for dolphin-fisheries interaction is much greater. Competition between man and dolphin for commercial fish is still minimal in the Central Amazon. Food habits analysis have shown that only 43% of 53 identified prey species are of commercial value and that the dolphins generally prey on size-classes of fish below the size-classes of commercial interest. Interviews with fishermen in the boats, in the fishmarket and in the shops supposedly selling

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dolphin products were conducted in an attempt to quantify the overall incidental kill attributed to commercial fisheries operations. The results showed that in the Central Amazon dolphin catches are incidental and only a very small number of these carcasses are used for commercial purposes.

* Robin C. Best died on 17 December 1986. He was a Research Associate of the Vancouver Public Aquarium.

INCIDENTAL CATCHES OF SMALL CETACEANS IN DRIFTNETS DURING SALMON TAGGING EXPERIMENTS IN THE NORTHWEST ATLANTIC. *Garry B. Stenson* and *Dave G. Reddin, Science Branch, Department of Fisheries and Oceans, PO Box 5667, St. John's, Newfoundland, Canada, A1C 5X1.*

We examined incidental catches of cetaceans in surface driftnets used to obtain salmon (*Salmo salar*) for tagging experiments. From 1965 to 1989, 29 cruises with a total of 5,365nm-hrs (nm*hr) of fishing effort were undertaken in offshore areas from the southern Grand Banks of Newfoundland to West Greenland. In addition, 12 cruises totalling 887nm*hr of fishing effort, occurred in inshore areas around Newfoundland and Labrador between 1969 and 1981. Data on the species and numbers of individuals caught, dates and locations of capture and catch per unit fishing effort were obtained using trip summaries and onboard observations. Although earlier sets used multifilament gillnets, monofilament nets with mesh sizes from 102 to 140mm were used for the majority of sets. Four species of small cetaceans were identified as bycatch. Harbour porpoise (*Phocoena phocoena*) were the most frequently caught species in all areas except for the Labrador Sea, where white-sided dolphins (*Lagenorhynchus acutus*) were more common. Long-finned pilot whales (*Globicephala melas*) and common dolphins (*Delphinus delphis*) were also caught. Low numbers (1–3) of harbour porpoise were regularly caught in the West Greenland, Grand Banks and inshore areas. Occasional large catches occurred in some sets. CPUE averaged 0.008/nm*hr inshore (spring and summer), 0.01/nm*hr in West Greenland (summer), 0.03/nm*hr on the Grand Banks (spring) and 0.14/nm*hr in the Newfoundland Basin (spring). Although considered primarily an inshore species, harbour porpoise were found in waters of all depths, including the deep waters (>2,000m) of the Newfoundland Basin and Labrador Sea. White-sided dolphins were caught sporadically (6 trips only) but in larger groups than harbour porpoise. CPUE varied from 0.04–0.05/nm*hr in the Newfoundland Basin (spring) and Labrador Sea (summer) to 0.004/nm*hr on the Labrador Shelf. White-sided dolphins tended to be caught in warmer waters and along the shelf edge. None were caught inshore, in West Greenland, or on the Grand Banks proper. Catches of all species varied greatly along years and were highly skewed. No animals or seasonal trends were obvious although the large number of cetaceans caught during the only major trip to the outer slope of the Grand Banks in May suggest that this may be an important area for all four species.

ENTANGLEMENT OF TWO HUMPBACK WHALES AND ONE GRAY WHALE IN PASSIVE FISHING GEAR IN SOUTHEASTERN ALASKA. *Janice M. Straley, Glacier Bay National Park* and *Preserve Gustavus, Alaska 99826, USA. C. Scott Baker, Victoria University, Wellington, New Zealand.*

In August 1986, a humpback whale (*Megaptera novaeangliae*) calf (defined as a whale less than one year old and accompanied by another, larger whale, presumed to be the cow) was observed towing fishing gear in Frederick Sound. The gear consisted of 100m of small diameter, green, polypropylene ground line, trailing a large, 1m diameter, fluorescent-pink bag buoy attached to a 2m tall, weighted aluminium flag pole. This type of gear is used in long-line bottom fishing in southeastern Alaska. The pod consisted of the cow, calf and a companion. To disentangle the whale, the pole and buoy were cut loose and the ground line was reeled in and cut off in 8m sections. It was not obvious where the line was attached to the whale, it was assumed to be around the tail stalk. All but 5–8m of line was removed. This procedure took about three hours. All three whales stayed together during this time, not diving or fluking. The pod was then observed for 20 minutes and behaviour appeared to resume to normal. In July 1988, a 16m, gray whale (*Eschrichtius robustus*) became entangled and died in a gillnet set at the mouth of the East Alsek River. The net was set in accordance with state law. The whale was presumed to be feeding in shallow water, nearshore on a rising tide. It apparently became entangled in the haul out line of the set gillnet on the outgoing tide. The whale appeared to have been in good health. The entanglement occurred near the tail as there was no gear or scarring on the body of the whale. In August 1988, a humpback whale calf was observed towing a yellow, 1/2m diameter float in Icy Strait. The calf was accompanied by a larger whale presumed to be the cow. The whales were approached and the line disentangled in a similar manner described above. The fishing gear consisted of 160m of small diameter, green, polypropylene ground line. Entangled with this line were ground line snaps, circle hooks and salmon trolling gear (flashers and hoochies). This whale had apparently caught other fishing gear while towing this longline gear. This cow and calf were seen subsequently throughout the summer season. The two humpback entanglements occurred in gear left after a fishing opener. This could have been avoided by stricter regulations on gear removal. The gray whale entanglement and death could have been avoided by a closer watch by the regulatory agencies. It is known that gray whales feed close to shore and there were observations of grays and humpbacks feeding in the area prior to the incident. The biology and behaviour of individual cetacean species needs to be considered when establishing guidelines for reducing entanglement and developing methods for disentanglement in passive fishing gear.

THE SOUNDS OF SILENCE: ACOUSTICS OF FISHING NETS AND BAIT. *Sean Todd, Biopsychology Programme, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, A1B 3X9* and *C-CORE (Centre for Cold Ocean Research and Engineering), Memorial University of Newfoundland, St. John's, Newfoundland, Canada. Jacques Guigne, C-CORE, Memorial University of Newfoundland, St. John's, Newfoundland, Canada. Jon Lien, Ocean Sciences Centre and Department of Psychology, Memorial University of Newfoundland, Canada.*

A series of experiments were conducted to determine acoustic signatures of fishing gear and fish schools. The objective was to determine those signals which would be available to cetaceans in locating such objects and the acoustic interactions between fish and fishing gear. Sounds from different types of nets were measured in a flume tank under different water flows. Nets vary considerably in the noise they produce. Field data on number of the entrapments of humpback whales correlates inversely with noise of fishing gear. Acoustic signatures of a bait fish, capelin, were obtained for schools of different sizes and sex compositions in both laboratory and field tests. The presence of bait modifies and reduces noise associated with nets and may make them more difficult to detect. Complex fishing gear, such as traps, were studied as they filled with target species such as codfish. Sounds produced by this gear were also modified by the presence of fish. Sounds produced by fishing gear may be an important factor in determining the frequency of entrapment of at least some cetaceans, but the acoustic characteristics of fish in the nets modifies sound of the nets. Thus entrapment frequency is a function of net acoustics and how well the net is fishing.

ESTIMATE OF VAQUITA, *PHOCOENA SINUS*, MORTALITY IN GILLNET FISHERIES IN THE NORTHERN GULF OF CALIFORNIA, MEXICO. *Peggy T. Turk Boyer, The Intercultural Center for the Study of Deserts and Oceans, 2601 E. Airport Road, Tucson, AZ 85706, USA. Gregory K. Silber, Institute of Marine Sciences, University of California, Santa Cruz, CA 95064, USA.*

The vaquita, *Phocoena sinus*, is vulnerable to the point of extinction. While the species apparently suffers substantial mortality in gillnets, the magnitude of incidental mortality and its

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impact on the population are not known. We interviewed fishermen in an attempt to determine fishing effort in the northern Gulf of California and to quantify vaquita mortality levels in gillnets. Though some problems are inherent to these types of data, the information can guide management decisions until more complete studies on incidental mortality are conducted. A total of 70 fishermen were interviewed from three communities in the northern Gulf of California. Gillnet fishermen reported capturing 22 vaquita, at a rate of 0.05 vaquita/fisherman/year resulting in an overall mortality estimate of 32.3±14.1 (95%CI) vaquita/year. This estimate may represent as much as 10% of the entire vaquita population. The majority of vaquita (90.1%) were caught in the most frequently used nets which consisted of 25.4–30.5cm mesh. Ninety-five percent of the vaquita were captured in water depths between 9 and 50m and mean depth was 24.9±SD 17.61m. The greatest fishing effort and 75.0% of the porpoise captures occurred in March through June corresponding with the northward migration of totoaba (*Cynoscion macdonaldi*). The taking of totoaba is prohibited by law. In addition to vaquita, 43.5% of the fishermen reported capturing sea turtles, 32.6% caught sea lions, 28.3% caught common dolphins and 21.7% caught bottlenose dolphins. Of all reported incidental catches of reptile and marine mammal species, 95.7% occurred in 25.4–30.5cm mesh gillnets. We recommend that gillnetting activities in the northern Gulf of California be ceased immediately. If complete moratoriums are not feasible, restrictions should be considered with respect to mesh size, fishing location, water depth or season.

INCIDENCE OF GEAR ENTANGLEMENT FOR RESIDENT INSHORE BOTTLENOSE DOLPHINS NEAR SARASOTA, FLORIDA. *Randall S. Wells, Conservation Biology Department, Chicago Zoological Society, Brookfield, IL 60513, USA. Michael D. Scott, Inter-American Tropical Tuna Commission, c/o Scripps Institution of Oceanography, La Jolla, CA 92038, USA.*

Bottlenose dolphins residing in the shallow inshore waters along the central west coast of Florida are exposed to gear from a variety of commercial fishing activities, including gillnets, trammel nets, purse seines and crabtraps. We have found evidence of apparent gear entanglement on 11.0% of the 146 dolphins we have handled during our capture, sample, mark and release efforts during 1975–1990. Evidence of apparent entanglement includes direct observations, as well as records of cuts and scars around the torso, fins and gape of the mouth that match the diameters of lines commonly used in fishing gear. Mortality from entanglement with fishing gear, however, appears to occur infrequently. Only one of the resident dolphins is known to have died directly from entanglement during 1975–1989. A subadult male entangled in a beach-set pompano gillnet during a squall in 1976. Two other entangled dolphins would probably have died save for human intervention. One 9 month old female entangled in a mullet gillnet was released unharmed by our research team. A 7 year old male became tangled in a crabtrap floatline; the trap and float were cut free by boaters. A minimum estimate of the annual mortality rate due to entanglement is 0.001±0.0011 (1 confirmed mortality during 898 animal years), but could have been 0.003±0.019 (3 mortalities) if human rescue had not occurred. These mortality rates are minimum estimates because not all dolphin carcasses may have recovered or have shown signs of entanglement. Annual loss from the approximately 100 residents of the Sarasota population due to natural in incidental fishery mortality and emigration averaged 0.189 for young of the year and 0.038 for older animals (Wells and Scott, 1990). A disproportionately high number of subadult dolphins were involved in entanglement. At least 9 of 16 apparent entanglement records involved subadults; the scarring on the remaining adults occurred at an undetermined age.

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FIRST EVALUATION OF THE INTENTIONAL AND ACCIDENTAL CATCH OF CETACEANS AT SANTA CATARINA ISLAND, BRAZIL. *Alfredo Ximenez, Laboratorio de Mamíferos de Universidade Federal de Santa Catarina, Caixa Postal 5132, Campus Universitario, 88049 Florianópolis, SC, Brazil.*

Until 1985, the level of mortality of cetaceans caused by fishing activities in Santa Catarina State was unknown. In that year a program began which included collection, preparation and conservation of stranded specimens all along the littoral (172km) of Santa Catarina located between the parallels 27°10' and 27°50'S and the meridians 48°25' and 48°35'W. Between February 1985 and June 1990, 40 specimens have been obtained showing marks of gillnets and mutilation. One intentional take of *Pontoporia blainvillei* was recorded. The following species were stranded and collected: *Steno bredanensis, Sotalia fluviatilis, Tursiops truncatus, Stenella frontalis, Delphinus delphis, Pseudorca crassidens* and *Balaenoptera acutorostrata*. Also collected was the head of a specimen identified as *Tursiops truncatus* but the morphology of its skull shows combined characters of both *Tursiops* and *Steno*; this suggests that the specimen is an intergeneric hybrid that should be the central point for further studies. Artisanal fishing is developed in the region in ancient traditional communities that use several kinds of nets with mesh size between 40mm and 200mm. The impact of this kind of activity on the cetacean population still remains unknown. Nevertheless a well directed study could yield valuable information in the future.

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Phylogeography of Steller sea lions: relationships among climate change, effective population size, and genetic diversity

C. D. Phillips,* T. S. Gelatt, J. C. Patton, and J. W. Bickham

Center for the Environment, Purdue University, West Lafayette, IN 47907, USA (CDP, JCP, JWB)
Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907, USA (CDP, JCP, JWB)
National Marine Fisheries Service, Alaska Fisheries Science Center, National Marine Mammal Laboratory, 7600 Sand Point Way, NE, Seattle, WA 98114, USA (TSG)

* *Correspondent: caleb.phillips@ttu.edu*

The biology of the Steller sea lion (*Eumetopias jubatus*) has been the subject of intense scientific investigation. This is primarily due to the rapid decline of population size in the western part of the species' range since the 1970s and the subsequent Threatened and Endangered species listings that had direct impact on the management of one of the world's largest fisheries. The Steller sea lion has emerged as an indicator species representing the environmental health of the North Pacific Ocean and Bering Sea. In this study, to better understand the historical processes that have culminated in the extant populations of *E. jubatus*, a large genetic data set consisting of 3 mitochondrial regions for >1,000 individuals was analyzed from multiple phylogeographic and demographic perspectives. The results describe the role of climate change in shaping the population structure of *E. jubatus*. Climatically associated historical processes apparently involved differential demographic responses to ice ages (and putative glacial vicariance) dependent on population size. Ice ages during times of small effective population size promoted restricted gene flow and fragmentation, and ice ages occurring during times of large population size promoted gene flow and dispersal. These results illustrate that effective population size has a profound effect on how species respond to climate change, an observation with obvious implications for large mammals and endangered species under the present conditions of imminent anthropogenically caused climate change. In addition, the results confirm previous observations of strongly biased historic and contemporary gene flow involving dispersal from west to east. Furthermore, phylogenetic patterns in combination with available fossil data suggest the potential of an Asian origin of *E. jubatus*. The results of this study provide a detailed scenario for the history that has shaped contemporary populations of *E. jubatus*.

Key words: climate change, demography, environment, long-term effective population size, phylogeography

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An intensive research effort into the biology of the endangered Steller sea lion (*Eumetopias jubatus*) has resulted in significant advances in our understanding of the evolutionary history, population structure, demographic trends, physiology, ecology, and evolution of this species (Baker et al. 2005; Bickham et al. 1996, 1998; Harlin-Cognato et al. 2006; Hoffman et al. 2006, 2009; Kenyon and Rice 1961; Loughlin et al. 1987, 1992; O'Corry-Crowe et al. 2006; Phillips et al. 2009a, 2009b; Trites and Donnelly 2003). For example, population genetic and phylogenetic investigations have demonstrated clear population structure at rookery, region, and stock levels, with phylogenetic delineation increasing at broader geographic groupings (Baker et al. 2005; Bickham et al. 1996, 1998; O'Corry-Crowe et al. 2006). In addition, a population decline of >80% resulted in listing the western stock as endangered under the United States. However, the eastern stock has maintained stable numbers over recorded time but still retains a threatened listing. The determination of major coincident patterns in genetics, morphology, and demography recently has led to the formal description of these 2 forms as the subspecies *E. j. jubatus* (consisting of the Asian and western stocks) and *E. j. monteriensis* (eastern stock—Phillips et al. 2009a; Fig. 1). Refining our understanding of the processes that ultimately led to the current population structure can enhance our existing knowledge of mammalian evolution and guide the future management of Steller sea lions in the North Pacific and Bering Seas. As a result of extensive research conducted to support Endangered Species Act listing, we have a relatively broad understanding of many aspects of the biology and life-history characteristics of *E. jubatus* and a preliminary

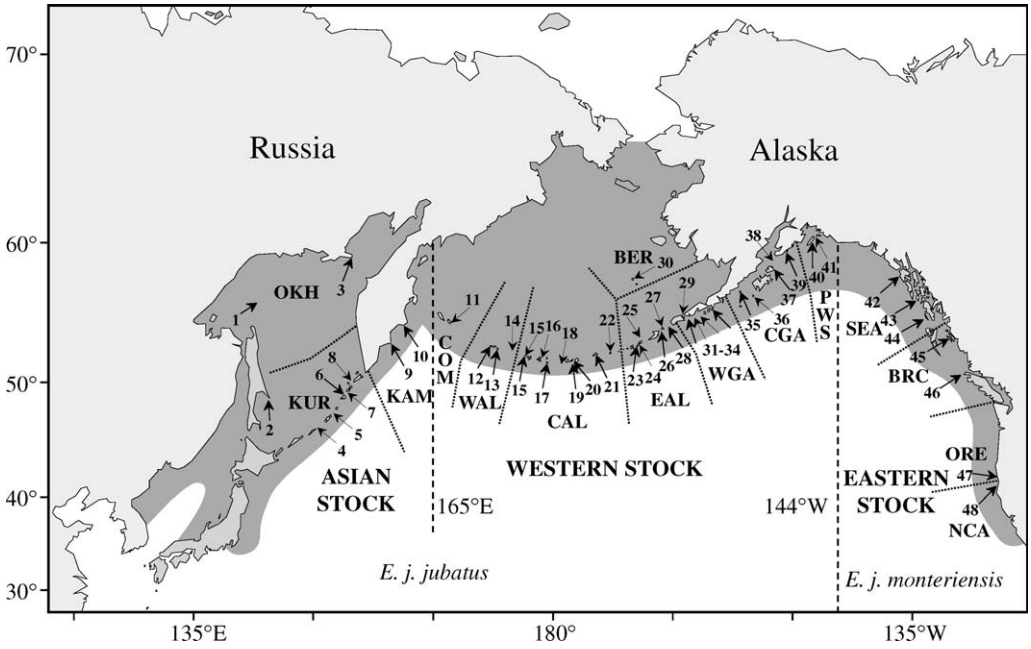

Fig. 1.—Map of the distribution of *Eumetopias jubatus* and recognized subspecies. Abbreviations for the regions are as follows: OKH = Sea of Okhotsk, KUR = Kuril Islands, KAM = Kamchatka Peninsula, COM = Commander Islands, WAL = western Aleutian Islands, CAL = central Aleutian Islands, EAL = eastern Aleutian Islands, WGA = western Gulf of Alaska, BER = Bering Sea, CGA = central Gulf of Alaska, PWS = Prince William Sound, SEA = southeastern Alaska, BRC = British Columbia, ORE = Oregon, NCA = northern California. Rookeries included in this study are indicated by arrows and numbered following Appendix I.

understanding of how the evolutionary history of the species has influenced observed contemporary genetic patterns. Given the distribution of *E. jubatus* around the North Pacific Rim (within a region where glacial movement has been particularly dynamic throughout the Pleistocene—Mann and Peteet 1994; Fig. 1) and the dependence of *E. jubatus* on linearly distributed rookeries for breeding and birthing (many of which are within areas known to have been covered by ice during previous glacial maxima—Grosswald and Hughes 2002; Mann and Peteet 1994; Westgate et al. 2001), the hypothesis of Harlin-Cognato et al. (2006) that genetic patterns are in part the result of phylogeographic occurrences driven by climatic change (changes in the extent of ice cover, glacial vicariance, and sea-level changes) is reasonable. Furthermore, the presence of a detailed and accurate phylogeographic history encompassing the entire range of *E. jubatus* is necessary to provide evolutionary context for the life-history characteristics documented in other studies.

The well-defined population model of *E. jubatus* is characterized by rookery dependence with high female philopatry. This information, in combination with a thorough genetic sampling of individuals through years of fieldwork, is useful for interpreting genetic patterns from a population genetics or phylogeographic perspective. In addition, a detailed working hypothesis of global climatic history based on ice core data (Loulergue et al. 2008) provides logical a priori phylogeographic expectations and a potential to build accurate phylogeographic inferences about *E. jubatus*.

We used a large genetic database of *E. jubatus* of >1,000 individuals (approximately 1.63% of the female population from 79% of known rookeries). Sequence data are taken from 2 mitochondrial genes, cytochrome *b* (*Cytb*) and nicotinamide adenine dinucleotide dehydrogenase 1 (*ND1*), and the hypervariable region 1 (HVRI) of the control region. Evolutionary signal is maximized from this data set by recovering cryptically recurrent substitutions from HVRI data (Phillips et al. 2009b). The end result is a robust and highly resolved genetic data set. Multiple analytical approaches have been used to test the major hypothesis that climate change has shaped contemporary genetic patterns of diversity and divergence in *E. jubatus*. These analyses help develop a long-term perspective on gene flow and elucidate the geographic center of origin of the species.

Materials and Methods

Sampling and molecular methodologies.—All tissue samples used in this study were hind-flipper punches taken from pups biopsied at natal rookeries a few weeks after birth and were obtained in accordance with guidelines of the American Society of Mammalogists (Gannon et al. 2007) under Marine Mammal Protection Act permit 782-1532-02. Sampling included specimens from 48 of 61 total known breeding rookeries distributed across the North Pacific Rim (Fig. 1). Because of strong natal philopatry observed in *E. jubatus*, this sampling strategy leads to a high probability that pup haplotypes observed at rookeries are the result of breeding at that particular rookery.

Sequence data for the complete *Cytb* (1,140 base pairs [bp]) and HVRI (238 bp) for 1,021 individuals were available from previous studies (Baker et al. 2005; Harlin-Cognato et al. 2006; Phillips et al. 2009b). In addition to these *Cytb* and

HVRI data, at least 1 individual representing each observed HVRI/*Cytb* haplotype combination also was sequenced for the entire *ND1* gene (957 bp). Because a large proportion of total observed HVRI/*Cytb* composite haplotypes were observed at a low frequency (69% $\leq$ 5 observations), the sample subsets of individuals for *ND1* likely provided an accurate overall depiction of the distribution of *ND1* haplotypes and provided a reasonable alternative to sequencing all 1,021 samples for *ND1*. Polymerase chain reactions for *ND1* were performed as described by Baker et al. (2005) using primers LGL 287 (CCTACGTGATCTGAGTTCAGACC) and LGL 563 (GGTATGAGCCCGATAGCTTA) with thermal profiles consisting of an initial denaturing cycle of 95°C for 5 min followed by 32 cycles of 95°C for 30 s, 50°C for 30 s, and 72°C for 2.5 min. For sequencing, internal sequencing primers Ejub-ND1-434seq(F) (CCATTATTCTCCTGTCAGTAC) and Ejub-ND1-636(R) (GGCCTGCTGCATATTCTACG) were used with a 50°C annealing temperature. Reactions were cleaned by centrifugation through Sephadex G-50 columns and then sequenced on an ABI 3730 platform (Applied Biosystems, Warrington, United Kingdom).

The *ND1* sequences were aligned in Sequencher 4.8 (GeneCodes Corporation, Ann Arbor, Michigan) and examined for the presence of insertions–deletions and stop codons in the coding region to check for any signs that nuclear inserts had been sequenced incidentally. A neighbor-joining tree was constructed in PAUP* version 4.0b10 (Swofford 2003) to identify all unique *ND1* haplotypes.

Data matrices construction and selection.—To maximize phylogeographic signal from the mitochondrial DNA (mtDNA) data set an approach involving the concatenation of HVRI and coding region sequences, followed by the preferential weighting of coding region data and subsequent phylogeny construction, was used—similar to that of Bandelt et al. (2002)—to characterize HVRI recurrent substitution. Characterized recurrent substitutions were incorporated into the data matrix as pseudo positions at the end of the file, and the original position was removed. Phillips et al. (2009b) demonstrated little indication of recurrent substitution in mtDNA coding regions of *E. jubatus*, justifying the application of this strategy. Using this method basal tree structure was determined largely by coding region data, areas unlikely to be subject to homoplasy at the taxonomic level and lineage age considered here, and resolution at more terminal branching was improved by the disclosure of recurrent substitution within HVRI. To confirm the appropriateness of this method an Approximately Unbiased (AU) test was performed. In this test phylogenies constructed from genetic data matrices that were either extended to describe recurrent substitution at HVRI, were not extended to express this variation, or did or did not include the *ND1* data (included as a variable here due to the nonexhaustive sampling strategy for this gene) were produced and then compared for explanatory power given each data matrix, following the methods outlined by Shimodaira (2002). The input phylogenies for this assessment were generated in MrBayes version 3.0 following all program author implementation specifications (Ronquist and Huelsenbeck 2003) and using the best fit model of evolution for each gene determined by the Akaike information criterion in ModelTest 3.7 (Posada and Crandall 1998; Table 1). For the AU test site-wise log-likelihoods for each nucleotide position in each data matrix were calculated independently given each phylogeny. Log files containing site-wise log-likelihood values served as input for the program CONSEL (Shimodaira and Hasegawa 2001) where the AU test was performed and the confidence set ($\alpha = 0.05$) was obtained.

Table 1.—Results of Akaike information criterion selected best-fit models of nucleotide substitution for each gene. α = gamma distribution shape parameter. HVRI(*Cytb*) refers to the hypervariable region 1 (HVRI) sequence extended to express recurrent substitution identified by cytochrome *b* (*Cytb*) weighting during neighbor-joining tree construction. Similarly, HVRI(*Cytb*/*ND1*) refers to the HVRI sequence extended to express recurrent substitution identified by *Cytb* and nicotinamide adenine dinucleotide dehydrogenase 1 (*ND1*) weighting during neighbor-joining tree construction.

Gene	Best-fit model	α
HVRI	HKY + I + G	0.8905
Cytb	HKY	Equal rates
ND1	HKY + I	Equal rates
HVRI(*Cytb*)	HKY	Equal rates
HVRI(*Cytb*/*ND1*)	HKY	Equal rates

Phylogeographic methods.—The complete single-locus nested clade phylogeographical analysis (NCPA) procedure conducted in this study followed the methodologies outlined in several other studies as follows. A haplotype network was constructed in TCS version 1.3 (Clement et al. 2000) following the rules of parsimony using the data matrix previously selected through AU testing. Next, the network was nested into clades following the nesting algorithm described by Templeton et al. (1987), Templeton and Sing (1993), and Crandall (1996). Testing for significant associations (χ^2) of clades with geography was performed in the program GeoDis by conducting 10,000 random permutations of clades (genetic variation) among sampling locations (rookeries—Posada et al. 2000; Templeton and Sing 1993). Geographic distances used were calculated as dispersal distances along the continental shelf, rather than great circle distances, to depict more accurately probable dispersal patterns in *E. jubatus*. Along-shelf dispersal distances (measured as distance between rookeries passing through any intermediate rookeries) are likely most appropriate because dispersal among rookeries by *E. jubatus* is thought to largely be confined to productive continental shelf waters, and great circle distances (point-to-point measurements around a sphere) would, in some instances, imply long dispersal routes through deep oceanic waters. Significant results from the GeoDis analysis were interpreted using the most recent inference key (made available 15 December 2008).

To cross-validate NCPA statistical significances an analysis of variance (ANOVA) was performed for each clade that returned a significant NCPA test statistic. For this analysis

each haplotype/nested clade was treated as a group and the nesting clade as the population to which the groups belonged. Covariance components were calculated from the observed distribution of haplotypes/nested clades among each rookery. Significance was determined by randomly permuting the geographic distribution of groups among each respective population for 1,000 iterations and recalculating the test statistics for each iteration to obtain the null distributions.

Additionally, data on methane concentration recovered from ice cores with dense coverage extending 800,000 years ago were incorporated for comparison with dated significant single-locus NCPA inferences. This data set consisted of 2,103 data points with an average time resolution of approximately 380 years (Loulergue et al. 2008). Because methane is a globally mixed and long-lived greenhouse gas, it is considered a valuable indicator of climatic oscillation (Houghton et al. 2001). In the North Pacific Ocean climatic oscillations clearly have promoted the advance and retreat of glacial bodies that likely have modified biotic distributions (Grosswald and Hughes 2002; Mann and Peteet 1994; Westgate et al. 2001). If demographic events inferred by single-locus NCPA within *E. jubatus* are largely the result of glacial vicariance, we would expect global methane values (i.e., climate) at the time of these events to correlate with single-locus NCPA derived inferences in a meaningful way. Because preliminary analysis verified the normality of the methane data (Kolmogorov–Smirnov test; $D = 0.068$, $P > 0.99$), and because sample size was large, significance of this relationship was assessed through a 2-tailed *Z*-test by treating methane concentrations at estimated dates of demographic events as random samples from a normally distributed population of values.

Because preliminary analysis of single-locus NCPA results indicated sequestering of the same demographic inference type into distinct temporal clusters, the probability of such a pattern arising by chance was assessed as a binomial probability. Eighteen unique inference outcomes exist in the most recently revised inference key. Therefore, the probability of success (i.e., obtaining any 1 specific inference in a single trial) was $1/18 = 0.0556$, and the probability of failure to obtain any 1 specific inference in a single trial was $17/18 = 0.9444$. The exact binomial formula is $P(k \text{ out of } n) = n!/[k!(n - k!)](p^k)[q^{(n-k)}]$, where n is the number of trials, k is the number of successes, p is the probability of success on a given trial, and q is the probability of failure on a given trial.

To date historical events inferred by single-locus NCPA for this assessment divergence dating using BEAST version 1.4.8 (Bayesian evolutionary analysis sampling trees—Drummond and Rambaut 2007) was carried out as described below for the Bayesian phylogeny, except with monophyly constraints added to ensure tree topology matched that observed in the haplotype network. Monophyly constraints were expressed in the starting newick tree used to initiate the analysis.

Divergence dating and Bayesian phylogeny estimation within the lineage of *E. jubatus* were performed simultaneously in the program BEAST. The basal position of *Callorhinus* within the family Otariidae, the sister relationship of the Arctocephaline clade to the *Otaria*, *Zalophus*, *Eumetopias* clade, and the *Zalophus–Eumetopias* split are well supported (Arnason et al. 2006; Higdon et al. 2007) and are the 3 node date priors included in this study. Multiple studies have assigned divergence dates within the family Otariidae, with dates estimated from fossil evidence representing a hard lower bound (Marshall 1990) and multiple molecular date estimates producing a range of values. For example, although the oldest available *Eumetopias* specimen (potentially an extinct form) recovered suggests a minimum *Zalophus–Eumetopias* divergence of 2 million years ago (mya—Repenning 1976), molecular dates for this split are 4.5, 6, and 8 mya, depending on the estimation algorithm and the loci included (Arnason et al. 2006; Higdon et al. 2007). As a conservative measure—conservative in that older molecular-based divergence estimates imply a greatly reduced rate of sequence evolution in otariids, which is not likely given the observed sequence diversity within *Eumetopias*—the dates estimated by Higdon et al. (2007), based on a 50-gene supertree that provided the most recent molecular dates, were used as date priors in this study (*Callorhinus* divergence, 8.2 mya; Arctocephaline–*Otaria*, *Zalophus*, *Eumetopias* clade split, 5.2 mya; and *Zalophus–Eumetopias* split, 4.5 mya).

Initial divergence dating within the *Eumetopias* lineage was performed using the 2 coding regions (*Cytb* and *ND1*), with each partition receiving its own model of DNA evolution as previously determined through model testing. In this analysis all codon positions were included. However, dates estimated from the inclusion of only 1st and 2nd codon positions gave very similar node dates, indicating that homoplasy at coding regions within the family Otariidae was not heavily influencing divergence estimation (data not shown). All program operations for this analysis strictly followed the program author guidelines. Dates estimated for the time to most recent common ancestor and the next most basal set of divergences within the *Eumetopias* lineage were recorded and retained as node date priors in a 2nd BEAST analysis to estimate dates of the more terminal nodes using only HVRI data. The objective of dating basal nodes with coding region data and terminal nodes with HVRI data was to partition substitutions from the 3 genes into areas of the tree where they retain the most phylogenetic information. From the final tree file the maximum clade credibility tree was obtained using TreeAnnotator (part of the BEAST package). In addition, because previous studies have demonstrated that the *Eumetopias* phylogeny contains substantial information about population history, a Bayesian skyline plot allowing for 5 discrete changes in population size was constructed using standard Markov chain Monte Carlo sampling procedures to estimate posterior distributions of theta ($\theta = N_{ef}\tau$, where N_{ef} is female effective population size and τ is generation length) through time using a flexible demographic model and directly from the sample of gene sequences (Drummond et al. 2005). Five demographic changes were allowed to identify historic demographic changes while at the same time not over-parameterizing the analysis. A generation time for *E. jubatus*

Table 2.—Approximately Unbiased (AU) test (Shimodaira 2002) of topological congruence based on site-wise log-likelihoods of 4 molecular data matrices for reciprocal gene trees. The tree receiving 1st-position ranking for each comparison is demarcated by bold and italicized numbering. See text for definition of acronyms.

	Data matrix			
Tree	HVRI/*Cytb*	HVRI(x)/*Cytb*	HVRI/*Cytb*/*ND1*	HVR1(x)/*Cytb*/*ND1*
HVRI/*Cytb*	0.003	4.00E-58	5.00E-05	3.00E-07
HVRI(x)/*Cytb*	0.212	***1***	0.001	1.00E-63
HVRI/*Cytb*/*ND1*	1.00E-04	5.00E-04	0.001	2.00E-30
HVR1(x)/*Cytb*/*ND1*	***0.872***	3.00E-06	***1***	***1***

of 10 years was assumed for this estimation (Calkins and Pitcher 1982; York 1994).

Results

Gene variability, recurrent substitution, and data matrix selection.—Approximately 1.6 million sequenced base pairs (bp) were included in this study. We identified 18 *Cytb* and 82 HVRI haplotypes from 1,021 individual *E. jubatus* (Appendix I). The *Cytb* network (not shown) contained no reticulations and consisted of 2 halves that largely describe the 2 previously identified subspecies. The halves of the cladogram are separated by an inferred haplotype and 2 amino acid changes. Conversely, the network produced from the 82 observed HVRI haplotypes (not shown) contained numerous reticulations. We sequenced 202 individuals, including at least 1 representative of all HVRI/*Cytb* composite haplotypes, for the 957 nucleotides of *ND1*, revealing 11 haplotypes (see Appendix II for accession numbers). A parsimony network constructed from these haplotypes included 1 inferred haplotype and no reticulations (not shown). In summary, relationships among haplotypes within the *Cytb* and *ND1* data sets were resolved although they exhibited only broadscale geographic resolution provided by the moderate number of observed variable sites (19 in *Cytb* and 12 in *ND1*). Conversely, the HVRI data set contained 41 variable sites within 238 bp; however, the frequency of reticulations throughout the network prevented an accurate depiction of the evolutionary relationships among haplotypes. The frequencies of all composite 3-gene mitochondrial haplotypes are described in detail in Appendix II.

Character changes mapped onto a neighbor-joining tree constructed from preferential weighting of *Cytb* and *ND1* recovered 86 substitutions at 19 sites within HVRI, a 30% increase in the number of recurrent substitutions that otherwise would be detected by character mapping using only the HVRI data. Furthermore, results of the AU test based on site-wise log-likelihood scores selected the phylogeny constructed from *Cytb*, *ND1*, and HVRI extended to express all of these 86 substitutions as the optimal for describing 3 of 4 data matrices (Table 2). Notable is the observation that the phylogeny produced from the most simplistic data set (that including *Cytb* and HVRI) was best explained by the most complex data set (that including *Cytb*, *ND1*, and HVRI extended to express identified recurrent substitutions, termed HVRI(x)/*Cytb*/*ND1* in Table 2). As a result, this data matrix was used for downstream phylogeographic analyses.

Phylogeographic and phylogenetic patterns.—The haplotype network constructed from the final data matrix generally maintains a network structure consisting of basal haplotypes that are frequent and widely distributed and terminal haplotypes that are sequestered geographically and occur in lower frequency relative to interior haplotypes (Fig. 2). From this network the divergence between subspecies is clearly demarked, although *E. j. monteriensis* is distributed across 2 parts of the network that are separated from each other by 2 widely distributed and 3 inferred haplotypes. An additional characteristic of this network is that, except for 1 instance, range-wide haplotypes (those observed in all 3 stocks) are sequestered to regions of the network otherwise consisting exclusively of haplotypes of *E. j. jubatus*. Of these range-wide haplotypes, their occurrence in *E. j. monteriensis* (eastern stock) is rare (6 of 7 of these haplotypes occur fewer than 4 times in *E. j. monteriensis*) and is restricted to southeastern Alaska (the westernmost region of *E. j. monteriensis*).

Eighteen demographic events were detected by single-locus NCPA, consisting of 5 contiguous range expansions, 5 instances of restricted gene flow with isolation by distance, 5 inferences of restricted gene flow or dispersal but with some long-distance dispersal, 2 past fragmentation or long-distance colonization events (or both), and 1 inconclusive outcome (Table 3). The inference of restricted gene flow with isolation by distance obtained at the total-cladogram level describes the overall demographic phenomenon of population structure of *E. jubatus*. The inference of past fragmentation or long-distance colonization (or both) for clade 4-2 captures, in part, the ancient divergence between *E. j. jubatus* and *E. j. monteriensis*. The relationship between subspecies within clade 4-2 and at the total cladogram level corresponds to the general pattern observed in the Bayesian phylogeny describing the subspecies divergence (Fig. 3). Tests performed for clades 4-1 and 4-3 both returned an inference of restricted gene flow or dispersal but with some long-distance colonization. These 2 clades are the largest subspecies-specific groupings in the analysis, and their associated inferences correspond with previously identified dispersal trends in *E. jubatus* described by dispersal generally occurring among adjacent rookeries with potential for longer distance migration due to their high vagility. The remaining inferences were recovered throughout portions of the network that describe further variation within subspecies.

As would be expected under the assumption of a low error rate of NCPA, of the 18 clades indicated as having statistically significant geographic associations through NCPA, 10 also

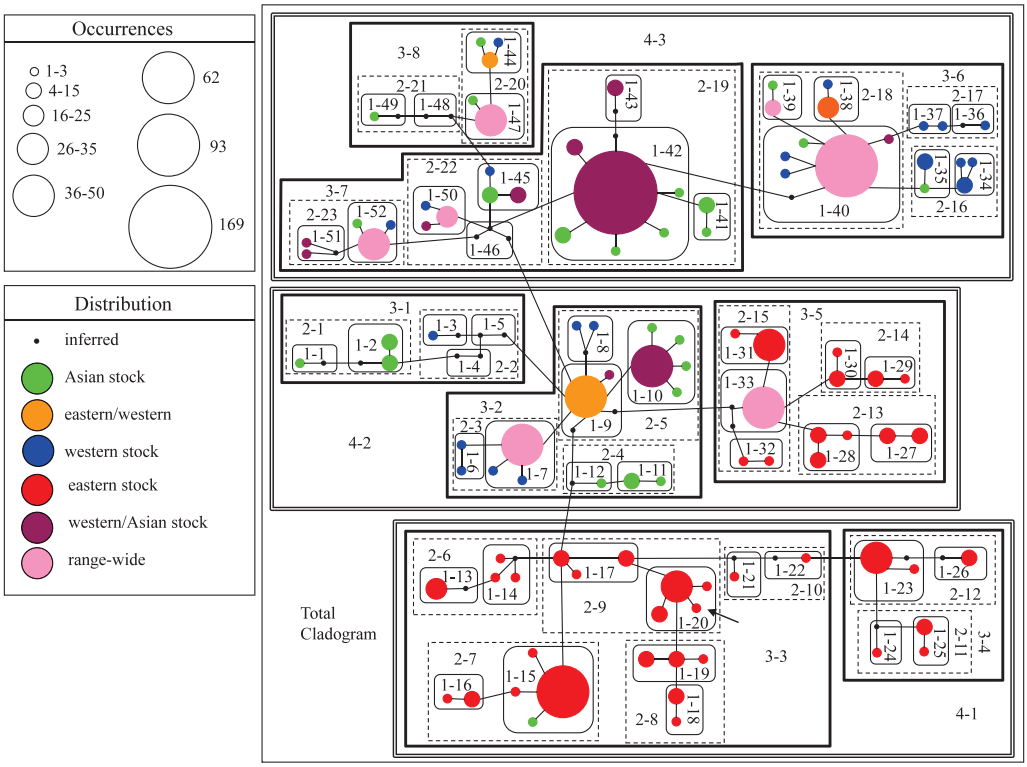

FIG. 2.—Nested design of the statistical parsimony network constructed from the HVRI(x)/*Cytb*/*ND1* data matrix. Circles represent observed haplotype linkages, and the distributions and frequencies are indicated by coloring and size, respectively. Lines connecting haplotypes represent substitutions defining their relationships. Small black circles indicate inferred haplotypes. Reference Table 3 for information about dating and single-locus nested clade phylogeographical analysis (NCPA) results. See text for definitions of gene acronyms.

yielded significant ANOVA test statistics (Table 4). Of these 10 clades, all but 1 received inferences involving some type of long-range movement or dispersal of haplotypes (contiguous range expansion, past fragmentation or long-distance colonization [or both], or restricted gene flow with some long-distance dispersal; events promoting significant among-group variation). Conversely, of the 8 clades returning nonsignificant ANOVA test statistics, all but 2 of these (inconclusive outcome and contiguous range expansion) involved restricted gene flow often with isolation by distance (events that would hinder accumulation of intergroup variation).

The mean methane concentration at dates estimated for the time to most recent common ancestor of all significant single-locus NCPA inferences was 468.44 parts per billion by volume (ppbv). Although this value is irrespective of the 95% highest probability density intervals (HPDs) surrounding the mean divergence dates, this value was significantly different from a mean methane concentration over the last 800,000 years of 519.97 ppbv ($Z = 2.41$, $P = 0.015$). By contrast the mean methane concentration at estimated times for all other clades was not significant ($\overline{X} = 499.16$; $Z = 1.64$, $P = 0.10$). Furthermore, dates for significant demographic inferences show a pattern of temporal clustering that generally correlates with periods of low methane concentrations and time periods previously characterized as periods of glacial maxima. The inference returned at the total-cladogram level dates to within the 5th glacial maximum and all other inferences form 2 distinct groupings most closely associated with the 2nd and 3rd glacial maxima (Rohling et al. 1998; Fig. 4). The HPDs for the date estimates are generally large and span the time frame of methane-inferred climatic oscillations. However, 1 *SD* from the mean dates generally resides within major climatic periods in which the mean is positioned. This important nuance justifies the overall confidence in the datings.

Comparing the patterns of demographic events with climatological cycling relative to estimated historic population sizes provided information on how the relationship between climate (glaciation) and population size potentially interacted to influence demography (Figs. 4 and 5). Notable is the observation that all inferences (6) clustering around the time of the 3rd glaciation describe processes involving restriction of gene flow. These 6 inferences refer to deeper clade nestings (3- and 4-step clades) and date to periods of low ancestral population sizes. The most common inference within this cluster was restricted gene flow or dispersal but with some long-distance dispersal, occurring 4 times. The binomial probability that 4 of 6 inferences within this time period would be the same by chance is 0.00013. In contrast, inferences clustering around the 2nd glaciation or earlier all refer to shallower nestings (1- and 2-step clades) corresponding to a time of population size increase in *E. jubatus*. In this cluster several inferences describe some sort of restricted gene flow; however, the most common type of inference within this cluster was contiguous range expansion, occurring 5 times.

TABLE 3.—Summary of significant results for the nested clade phylogeographical analysis (NCPA). Values within the D_c and D_n columns are distance (km), with an indication of whether each value was significantly large (>) or small (<), and its associated *P*-value. n.s. = not significant at $P = 0.05$. I − T = interior minus tips distance. Inferences were drawn from the key made available 15 December 2008. CRE = contiguous range expansion; IC = inconclusive outcome; RGF w/ IBD = restricted gene flow with isolation by distance; RGF/LDD = restricted gene flow or dispersal but with some long-distance dispersal; PF/LDC = past fragmentation or long-distance colonization (or both). Estimated dates are expressed as millions of years ago (mya).

Clade	χ^2 *P*-value	Nested clades	D_c	D_n	Chain of inference	Demographic event	Estimated date (95% HPD)
1-20	0.079	DDDDDD3	n.s.	1,158.44, >, 0.009	N, N, Y, N	CRE	0.074 (0.033–0.106)
		AAAAAAA	n.s.	n.s.			
		NNNNNN3	n.s.	n.s.			
		N3 (interior)	557.97, <, 0.027	n.s.			
		I − T	n.s.	−245.79, <, 0.018			
1-28	0.512	YYYY10	n.s.	n.s.	N, Y, N, N	RGF w/ IBD	0.063 (0.029–0.108)
		FF10	n.s.	n.s.			
		BB10 (interior)	n.s.	n.s.			
		I − T	798.94, >, 0.028	n.s.			
1-40	0.017	OOO1	n.s.	n.s.	N, N, N, N	IC	0.096 (0.035–0.106)
		S22	n.s.	n.s.			
		QQQ1	n.s.	4,636.34, >, 0.012			
		U1	n.s.	n.s.			
		S1 (interior)	n.s.	n.s.			
		I − T	n.s.	n.s.			
1-42	0.962	LLL1	n.s.	n.s.	N, Y, Y, N, N, N	RGF/LDD	0.084 (0.037–0.110)
		YYYYY1	573.06, <, 0.035	n.s.			
		KKK1	n.s.	n.s.			
		BBBB1	n.s.	1,694.58, <, 0.043			
		BB9	n.s.	1,788.31, <, 0.023			
		BB1 (interior)	2,683.14, >, 0.002	2,627.71, >, 0.001			
		I − T	1,788.89, >, 0.002	682.03, >, 0.001			
1-44	0.062	WWWWW1	n.s.	6,229.20, >, 0.015	Y, Y, Y, N, Y, N	CRE	0.066 (0.023–0.083)
		HHH1	n.s.	n.s.			
		DD1 (interior)	1,590.89, <, 0.008	2,529.35, <, 0.031			
		I − T	−2,370.46, <, 0.013	n.s.			
1-45	0.412	FF1	n.s.	3,456.28, >, 0.025	N, N, Y, N	CRE	0.066 (0.008–0.089)
		AAAA1 (interior)	730.57, <, 0.009	2,360.56, <, 0.035			
		I − T	−3,012.12, <, 0.007	−1,095.72, <, 0.038			
2-1	0.003	1-1	n.s.	1,472.79, >, 0.003	Y, Y, Y, N, Y, N	CRE	0.064 (0.028–0.104)
		1-2 (interior)	701.70, <, 0.003	785.10, <, 0.003			
		I − T	n.s.	−687.70, <, 0.003			
2-5	0.001	1-8	n.s.	3,149.34, <, 0.048	N, N, Y, N, N	PF/LDC	0.084 (0.050–0.149)
		1-10	1,578.65, <, 0.001	n.s.			
		1-9 (interior)	1,308.70, <, 0.001	3,820.98, >, 0.002			
		I − T	n.s.	214.14, >, 0.019			
2-6	0.020	1-13	84.84, <, 0.008	320.77, <, 0.015	N, Y, N, N	RGF w/ IBD	0.066 (0.038–0.133)
		1-14 (interior)	1,067.03, >, 0.017	818.87, >, 0.010			
		I − T	982.18, >, 0.010	498.10, >, 0.010			
2-15	0.541	1-31	499.05, <, 0.033	693.49, <, 0.032	N, Y, N, N	RGF w/ IBD	0.103 (0.048–0.151)
		1-32	n.s.	n.s.			
		1-33 (interior)	1,355.43, >, 0.022	1,097.88, >, 0.023			
		I − T	844.91, >, 0.026	409.38, >, 0.024			
2-18	0.014	1-38	n.s.	n.s.	N, N, Y, N	CRE	0.100 (0.051–0.135)
		1-39	3,972.66, >, 0.003	3,889.54, >, 0.001			
		1-40 (interior)	2,346.93, <, 0.001	2,507.12, <, 0.001			
		I − T	−956.26, <, 0.001	−595.78, <, 0.001			
3-2	0.001	2-3	2,555.97, <, 0.001	3,181.22, <, 0.001	N, Y, Y, N, N, N, Y		0.135 (0.084–0.215)
		2-4	772.33, <, 0.001	3,955.10, >, 0.011			
		2-5 (interior)	3,710.60, >, 0.002	3,602.98, >, 0.001			
		I − T	1,394.74, >, 0.001	317.59, >, 0.001			
3-6	0.283	2-16	n.s.	n.s.	N, Y, N, N	RGF w/ IBD	0.137 (0.082–0.169)
		2-17	n.s.	n.s.			
		2-18 (interior)	2,681.91, >, 0.019	2,621.61, >, 0.019			
		I − T	698.13, >, 0.044	369.85, >, 0.027			

TABLE 3.—Continued.

Clade	χ^2 *P*-value	Nested clades	D_c	D_n	Chain of inference	Demographic event	Estimated date (95% HPD)
3-7	0.001	2-19	2,597.13, <, 0.001	2,904.30, <, 0.001	N, Y, Y, N, N, Y	RGF/LDD	0.156 (0.092–0.186)
		2-23	2,362.18, <, 0.001	3,468.32, >, 0.001			
		2-22 (interior)	n.s.	3,254.88, >, 0.012			
		I − T	850.38, >, 0.001	238.66, >, 0.015			
4-1	0.001	3-4	377.60, <, 0.029	429.21, <, 0.044	N, Y, N, N, N, N, Y	RGF/LDD	0.200 (0.142–0.240)
		3-3 (interior)	622.81, >, 0.021	611.52, >, 0.011			
		I − T	285.21, >, 0.027	182.31, >, 0.033			
4-2	0.001	3-1	903.79, <, 0.001	5,834.77, >, 0.001	N, Y, Y, Y, N	PF/LDC	0.199 (0.140–0.253)
		3-5	922.29, <, 0.001	3,819.98, <, 0.001			
		3-2 (interior)	3,710.62, <, 0.001	4,298.91, >, 0.030			
		I − T	2,791.52, >, 0.001	n.s.			
4-3	0.001	3-6	2,579.44, <, 0.001	n.s.	N, Y, Y, N, N, N, Y	RGF/LDD	0.188 (0.097–0.539)
		3-8	2,845.69, <, 0.021	n.s.			
		3-7 (interior)	3,079.2, <, 0.006	3,225.80, >, 0.007			
		I − T	435.84, >, 0.001	135.70, >, 0.013			
T-C	0.001	4-1	611.30, <, 0.001	3,804.63, <, 0.038	N, Y, N, N	RGF w/ IBD	0.360 (0.145–0.876)
		4-3	3,196.13, <, 0.001	n.s.			
		4-2 (interior)	4,259.26, >, 0.001	4,051.00, >, 0.001			
		I − T	1,878.27, >, 0.001	162.55, >, 0.003			

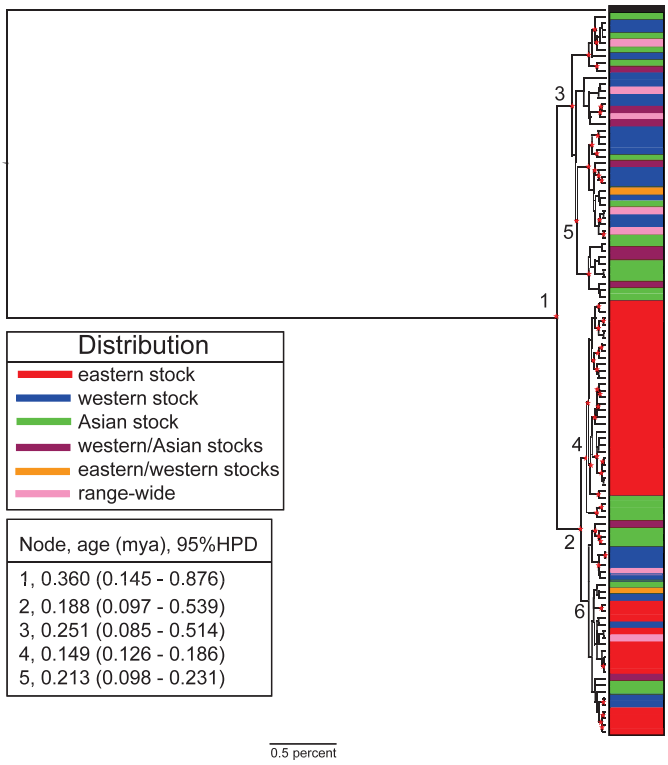

FIG. 3.—Maximum clade credibility Bayesian phylogeny. Haplotypes are color coded by their observed distributions, and the black outgroup haplotype is *Zalophus californianus* according to Wilson and Reeder (2005). Nodes receiving a posterior probability support value of 0.5 or higher are indicated by small red stars. Significant nodes containing clades, where the sequestering of haplotypes into distinct geographic regions is observed, are numbered, and the estimated divergence date and 95% highest probability density intervals (HPDs) for these nodes are listed. Although posterior support for node 6 was below 0.5, this node is numbered for reference in the text.

The probability of such a chance occurrence is 0.00017. No significant demographic inferences were recovered in more recent times, around the last glacial maximum, a period in which population sizes were estimated to be highest.

The time to most recent common ancestor for *E. jubatus* (Fig. 3, node 1), based on coding region data and outgroup node priors from Higdon et al. (2007), was estimated at 0.360 mya (95% HPD = 0.145–0.876). The initial divergence from node 1 resulted in the sequestering of all exclusively *E. j. monteriensis* haplotypes into a single, yet polyphyletic, grouping (node 2). Terminal to node 2 were all 40 haplotypes exclusive to *E. j. monteriensis* and 22 exclusive to *E. j. jubatus*, with 8 and 12 of these exclusive to the western and Asian stocks, respectively. Within this grouping 2 major clades were identified, 1 of which (node 4) was comprised exclusively of haplotypes of *E. j. monteriensis*, except for 4 haplotypes observed only in the Asian stock. Node 6, being sister to node 3 (Fig. 3), retained the remaining haplotypes observed exclusively in *E. j. monteriensis* in addition to haplotypes occurring across the species' distribution; however, the posterior probability of this node was <0.5. The basal clades terminal to nodes 4 and 6 consisted of haplotypes of *E. j. jubatus*.

On the other half of the phylogeny terminal to node 3 all but 5 range-wide haplotypes and 1 haplotype observed in the western and eastern stocks—3 of 48 occurrences of this haplotype were in the eastern stock—are haplotypes exclusive to *E. j. jubatus*. Although within this clade 11 haplotypes were observed throughout *E. j. jubatus*, 17 and 13 haplotypes were restricted to the western and Asian stocks, respectively. The divergence observed at clade 5 leads to 2 lineages, 1 of which contains haplotypes found either exclusively in the Asian stock or shared between the Asian and western stock, but none exclusive to the western stock.

Although posterior support for some nodes in this phylogeny was <0.5, the major phylogenetic pattern depicted supports

Table 4.—Results of ANOVAs for each clade receiving significant test statistics through the nested clade phylogeographical analysis (NCPA) statistical testing procedure. Descriptions of NCPA inference abbreviations are found in Table 3. *P*-values are for global F_{ST} calculated from the analysis, and significant statistics are bold and italicized. Significance was determined by 1,000 permutations of rookery occurrences of haplotypes among clades.

Clade	% variance among groups	% variance within groups	P-value$_{d.f.}$	NCPA inference
1-20	20.83	79.17	***0.050*$_{39}$**	CRE
1-28	10.43	89.57	0.223_{11}	RGF w/ IBD
1-40	0.00	100.00	0.500_{101}	IC
1-42	1.34	98.66	0.255_{183}	RGF/LDD
1-44	27.87	72.13	***0.011*$_{11}$**	CRE
1-45	7.87	92.13	0.157_{14}	CRE
2-1	51.26	48.74	***0.015*$_{11}$**	CRE
2-5	9.52	90.48	***0.001*$_{103}$**	PF/LDC
2-6	10.64	89.36	0.110_{24}	RGF w/ IBD
2-15	0.36	99.64	0.392_{79}	RGF w/ IBD
2-18	8.30	91.70	***0.005*$_{31}$**	CRE
3-2	5.89	94.11	***0.001*$_{151}$**	RGF/LDD
3-6	0.88	99.12	0.161_{157}	RGF w/ IBD
3-7	2.13	97.87	***0.001*$_{291}$**	RGF/LDD
4-1	0.80	99.20	0.169_{227}	RGF/LDD
4-2	16.17	83.83	***0.001*$_{302}$**	PF/LDC
4-3	2.00	98.00	***0.001*$_{494}$**	RGF/LDD
T-C	10.19	89.81	***0.001*$_{1,025}$**	RGF w/ IBD

previously hypothesized relationships among the 3 stocks and the 2 subspecies. However, the current results both describe the early divergence in the species history between the 2 extant and currently recognized subspecies and also indicate a complex history leading to the current distribution of haplotypes. Moving from the base to the tips of the phylogeny of *E. jubatus*, clear patterns of lineage sorting at different stages of completion are observable. Although terminal to the initial divergence all haplotypes of *E. j. monteriensis* (eastern stock) are sequestered to node 2 (Fig. 3), it is not until about 200,000 years later at node 4 that a large group of haplotypes of *E j. monteriesis* approach monophyly—1 Asian stock haplotype is within the eastern stock clade that is itself terminal to an exclusively Asian stock clade. The relationships among haplotypes terminal to node 6 present a pattern of less complete lineage sorting, with some tip clades exclusively *E. j. monteriensis*, with others still retaining many haplotypes of *E. j. jubatus*. Although node 6 was unsupported, a comparison of the completion of sorting between nodes 4 and 6 illustrates the stochastic nature of the lineage sorting process; although nodes 6 and 4 likely have similar coalescence times, sorting is closer to completion terminal to node 4.

Discussion

In this study single-locus NCPA was used to draw inferences on population history. Multiple independent statistical approaches were used to validate the inferences returned by single-locus NCPA. ANOVA returned patterns of group (clade) significance that correspond to what would be expected given the types of demographic events returned for each clade; demographic events that promote significant among-group variance allocation (those events that distribute genetic diversity among rookeries) were usually significant, and those demographic events that promote within-group variance retention were found most often to be nonsignificant. Furthermore, results from the single-locus NCPA, in combination with reconstructions of historical N_{ef} and ice-core inferred climatological cycling, suggest that the patterns of demographic events are related to the climate and population size at the time. The chance probability of such a pattern was assessed in this study by using *Z*-tests and binomial probabilities and found to be low. These combined statistical observations describe a pattern of phylogeography of *E. jubatus* that includes an interaction between population size, climate, and their dependence on linearly distributed rookeries.

Our results support the hypothesis that climate change has a major role in shaping the observed distribution of genetic diversity in *E. jubatus*. One of the major inferences pertaining to this hypothesis is that glacial vicariance has largely shaped the evolutionary history of *E. jubatus*. The observation that historic events related to restricted gene flow generally occurred during a time of low N_{ef} suggests that vicariance, in conjunction with genetic drift acting on low ancestral numbers of haplotypes, promoted geographic sequestering throughout portions of the distribution. In addition, inferences of occasional long-distance dispersal during this time potentially describe the species' ability to establish new territory via dispersal during a time of low N_{ef} and reduced competition for breeding territory. Conversely, all inferences of contiguous range expansion correlate with a population expansion as described by the Bayesian skyline plot (Fig. 5). This indicates that as N_{ef} increased the response to glacial vicariance changed. During this time the population of *E. jubatus* as a whole was expanding both in numbers and in range. Individuals would have been forced to disperse greater distances to find breeding territory as N_{ef} increased and glacial cover reduced the number of ice-free rookeries. Finally, the lack of significant demographic inferences recovered around the time of the last glacial maximum is likely the result of large, sustained N_{ef}, previous saturation of all suitable habitats, and perhaps a lack of phylogeographic resolution at this timescale.

In general, these results can be interpreted as descriptive of how abiotic factors can influence the evolutionary fate of a species. Specifically for *E. jubatus*, one of the results of this study is that relatively warm periods have promoted population expansion and dispersal by increasing available rookery habitat. Perhaps the most important aspect of the current results is the implication that future climate change has the potential to affect distributions and demography of contemporary populations of species in ways similar to that documented in this study. It is clear that climate change causes stress, including the necessity of finding new breeding sites, adapting to new food sources, and so on. It can be inferred from the present study that population size influences the capacity for dealing with such stressors, because the genetic signatures resulting from similar climatic patterns are distinctly different for large and small populations.

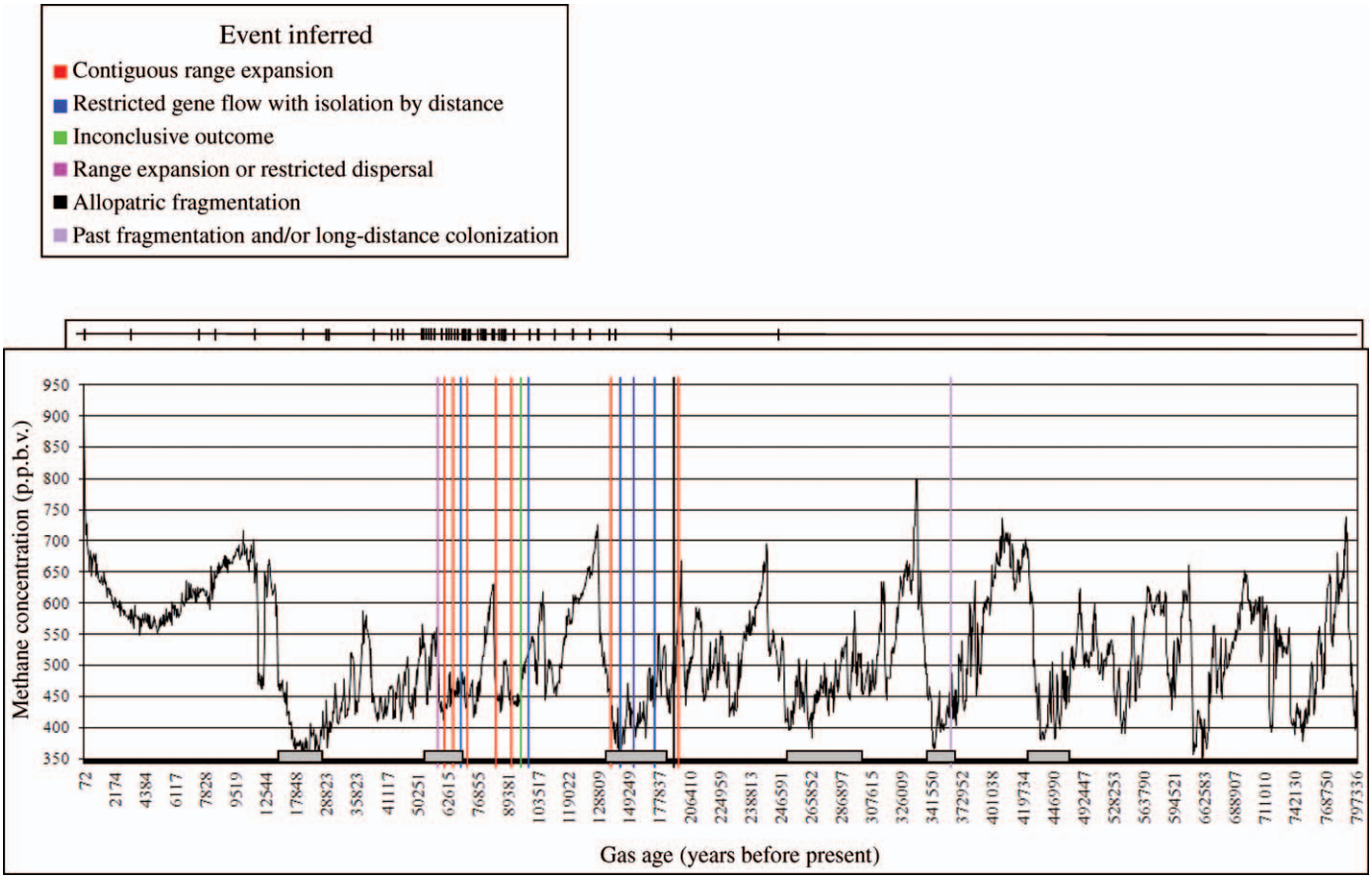

Fig. 4.—Histogram of methane concentration (in parts per billion by volume) over the last 500,000 years. The nonlinearity of the x axis is a result of heterogeneity of methane sampling over time (Loulergue et al. 2008) and should be considered when interpreting this figure. Dates of time to most recent common ancestor for significant single-locus nested clade phylogeographical analysis (NCPA) clades are plotted onto this histogram, and the type of inference obtained for each clade is color coded. Small black hash marks above the histogram define point estimates for nonsignificant clades. Gray rectangles along the bottom of the histogram indicate time spans of 5 previous glacial periods, as defined by Rohling et al. (1998).

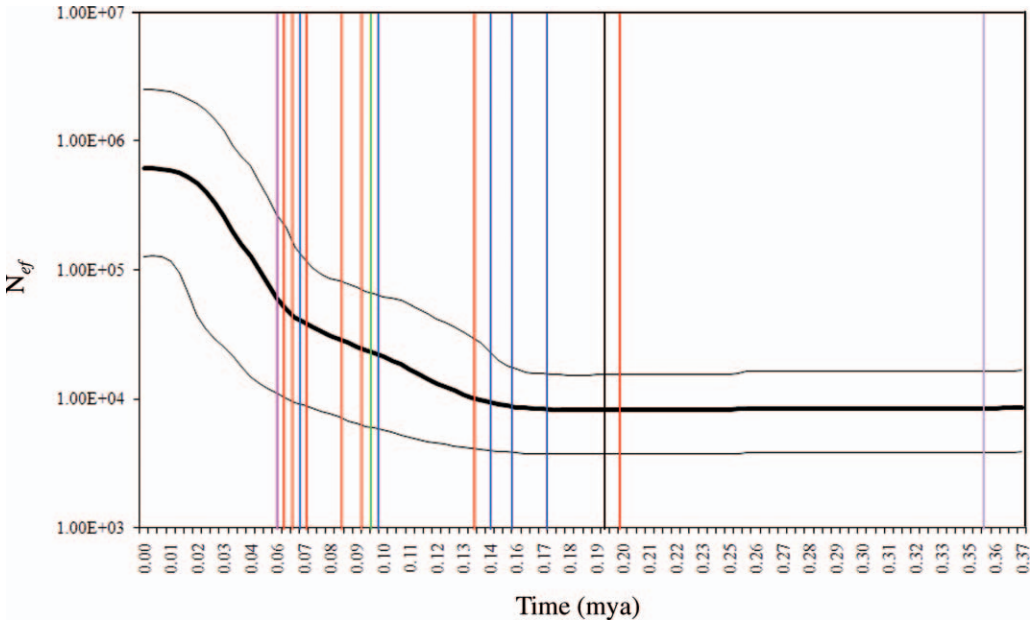

Fig. 5.—Bayesian skyline plot with mean population size and 95% highest probability density intervals (HPDs) plotted against time. As in Fig. 4, significant NCPA inferences are plotted and color coded.

Although the Bayesian phylogeny presented in Fig. 3 describes relationships among haplotypes similar to those presented in the haplotype network, this perspective provided additional insight into both historical and contemporary processes. This tree describes the ancient divergence between subspecies, with node 1 representing the base of the lineage of *E. jubatus* describing the initial documentable divergence 0.360 mya. Following from this estimation, during the 5th glacial period when population sizes were low, the distribution of *E. jubatus* was split by glacial vicariance into at least 2 disjunct populations initiating subspecific differentiation. The observation that 3 Asian stock haplotypes form the base of the large *E. j. monteriensis* clade terminal to node 4 describes an ancient ''out of Asia'' relationship between the extreme ends of the distribution of *E. jubatus* and indicates that Asian portions of the species' range served as the source population for the eastward expansion. Although node 6 is unsupported, the relationship observed between sister clades here is similar to that observed at node 4, with an *E. j. jubatus* clade forming the base of a clade consisting largely of *E. j. monteriensis*. That no haplotypes were observed in the Asian stock and *E. j. monteriensis*, but not the western stock, indicates the lack of contemporary dispersal between the Asian stock and *E. j. monteriensis*. However, the observation that 6 of 7 range-wide haplotypes belong to *E. j. jubatus* clades does indicate recent directional dispersal from west to east. The oldest *Eumetopias* fossil was recovered from the Onma formation in Japan dated to the Pliocene about 2 mya (thought to represent an extinct member of the genus *Eumetopias*—Kaseno 1951; Mitchell 1968; Repenning 1976). This information, paired with the findings from the current study, indicates a potential geographic center of origin for *Eumetopias*.

In this study a novel method was used to account for generally cryptic recurrent substitutions. This improved resolution by decreasing the phylogenetic obscurity produced by homoplasy while improving confidence in branching order. Potentially, this approach is applicable to any phylogenetic analysis in which coding genes, or otherwise conservative loci, are used in combination with a more rapidly evolving locus in which recurrent substitutions produce homoplasy. In the event of evidence for coding region homoplasy, these regions should not be weighted to resolve hypervariable region recurrent substitutions. To determine the appropriateness of using this method several aspects of the data set should be considered. First, the estimated time to most recent common ancestor is an important parameter, because the greater the age of the lineage, the more time for homoplasy to accumulate in all regions. By using this information in combination with knowledge about the mutation rate of coding regions, network construction and evaluation (whether coding region–based networks contain reticulations), and consistency and homoplasy index calculations, a logical decision can be made regarding the use of this approach.

In summary, by the implementation of multiple statistical approaches to maximize genetic signal and draw evolutionary inferences, a strong, multifaceted perspective of evolutionary history of *E. jubatus* has been developed. This history reflects a major influence of climate change and glacial vicariance, with demographic response contingent upon population size at the time. In addition, phylogenetic patterns indicate the direction of dispersal over evolutionary timescales and, paired with limited fossil data, present a hypothesis for the geographic center of origin of *E. jubatus* located in Asia. The results of this study can serve as a working hypothesis for future studies to develop a better understanding of the evolution of *E. jubatus*.

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Appendix I

Sample sizes (*n*) for *Eumetopias jubatus* categorized at 4 geographic scales: subspecies, genetically identifiable stock, region, and deme (rookery). Rookery numbers correspond to Fig. 1.

Subspecies	Stock	Region	Rookery	*n*
E. j. jubatus	Asian	Okhotsk	1. Iony Island	48
			2. Tuleny Island	50
			3. Yamsky Island	29
		Kuril Islands	4. Chernyye Brat'ya	11
			5. Srednego Island	13
			6. Raikoke Island	15
			7. Lovushki Island	13
			8. Antsiferova Island	17
		Kamchatka Peninsula	9. Zheleznaya Bay	8
			10. Kozlova Cape	52
	Western	Commander Islands	11. Medney Island	37
		Western Aleutian Islands	12. Attu Island	4
			13. Agatu Island	19
			14. Buldir Island	24
		Central Aleutian Islands	15. Kiska Island	13
			16. Tag Island	10
			17. Amchitka Island	2
			18. Ulak Island	6
			19. Adak Island	20
			20. Gramp Rocks	2
			21. Seguam Island	5
			22. Yunaska Island	11
		Eastern Aleutian Islands	23. Adugak Island	13
			24. Ogchul Island	2
			25. Bogoslof Island	2
			26. Akutan Island	24
			27. Akun Island	1
			28. Ugumak Island	11
			29. Amak Island	26
		Bering Sea	30. Walrus Island	16
		Western Gulf of Alaska	31. Clubbing Rocks	13
			32. Pinnacle Rocks	4
			33. Pinnacle Island	4
			34. Atkins Island	7
		Central Gulf of Alaska	35. Chowiet Island	19
			36. Chirikof Island	34
			37. Marmot Island	6
			38. Sugarloaf Island	36
			39. Chiswell Island	2
		Prince William Sound	40. Fish Island	8
			41. Seal Rocks	19
E. j. monteriensis	Eastern	Southeastern Alaska	42. White Sisters Island	33
			43. Hazy Island	79
			44. Forester Island	185
		British Columbia	45. North Danger Rocks	6
			46. Triangle Island	8
		Oregon	47. Rogue Reef	28
		Northern California	48. St. George Reef	26

Appendix II

Frequency of HVRI/*Cytb*/*ND1* haplotype linkages across the 3 genetically identifiable stocks. The 1st series of letters in the name refers to the hypervariable region 1 (HVRI) haplotype name, the following number refers to the cytochrome *b* (*Cytb*) haplotype name, and the number after the N in each name refers to the nicotinamide adenine dinucleotide dehydrogenase 1 (*ND1*) haplotype name. GenBank accession numbers for HVRI haplotypes: AY340876–AY340937, FJ948491–FJ948546. GenBank accession numbers for *Cytb* haplotypes: DQ144995–DQ145021, FJ948486–FJ948490. GenBank accession numbers for *ND1* haplotypes: GQ477068–GQ477078.

Gene linkages	Asian stock	Eastern stock	Western stock	Total
A1N6	6	1	27	34
A2N4		31		31
A3N1	2		1	3
A4N1	2			2
AAA27N1	6			6
AAAA1N1	6			6
AAAAAA1N6			3	3
AAAAAAA3N3		2		2
BB1N1	107		62	169
BB10N4		6		6
BB2N4	1	44	1	46
BB3N1	1	3	44	48
BB4N1	40		4	44
BB6N4		5		5
BB9N1	3			3
BBBB1N1	1			1
BBBBB3N3		1		1
BBBBBBB2N4		1		1
CC1N1	9	3	22	34
CC16N1	1			1
CCCCC3N3		1		1
CCCCCC3N3		4		4
CCCCCCC3N5		1		1
D3N5		1		1
DD1N1			9	9
DDD3N1			2	2
DDDD3N1	1		1	2
DDDDDD3N3		4		4
DDDDDDD1N1			1	1
E1N1	3	2	14	19
EE1N1			1	1
EEEE3N3	1			1
EEEEEEE3N5		1		1
FF1N1	5		4	9
FF10N4		2		2
FF4N1	2			2
FF6N4		4		4
FFF19N1			1	1
FFF3N1			1	1
FFFF1N2	5	1	3	9
FFFF23N2			1	1
FFFF36N2	1			1
FFFFFFF3N3		1		1
G1N7	3		8	11
GGG3N11			1	1
GGGG3N5		4		4
H3N3		62		62
H32N3		3		3
HH1N2			9	9
HHH1N1			1	1
HHHHHH35N1	2			2
I3N3		2		2
II1N2			1	1
III1N7	1		1	2
IIIII3N3		3		3
J3N3		1		1
JJJ3N1			2	2
JJJJJJ3N3	1			1
K3N5		26		26
KKK1N1	4		1	5
L3N3		7		7
LL3N3		8		8
LLL1N1	5			5
M3N3		6		6
MMMN11	10			10
MMM40N1	1			1
N3N3		33		33
NNNNNN3N3		1		1
O3N5		2		2
OOO1N2			2	2
P2N4		6		6
Q2N4		14		14
Q31N4		3		3
QQQ1N2	1			1
R3N4		1		1
RRRR3N4		1		1
S1N2	7	4	82	93
S20N2			1	1
S22N2			3	3
S23N2		1	20	21
SS3N3		2		2
SSSS2N4		1		1
SSSSS3N3	5			5
SSSSSS3N5		1		1
T1N2			2	2
T20N2			2	2
TTT4N1	1			1
TTTT1N2			1	1
U1N2	1		2	3
UUU27N1	4			4
UUUU3N11			1	1
VVVV3N3		10		10
VVVVV4N1	2			2
W1N2			8	8
WWW3N3	2			2
WWWW3N5		11		11
WWWWW1N1	2			2
X1N2	1			1
XXXX1N6			1	1
YY3N13		18		18
YYYY10N4		4		4
YYYY27N8	1			1
YYYYY1N1	1			1
Z1N17	4		1	5
Z3N1	6	2	31	39
ZZ3N3		3		3
ZZZ1N1	3		2	5
ZZZZZZ3N3		6		6
Total	271	365	385	1,021

Observations of Western Gray Whales by Ship-based Whalers in the 19th Century

Randall R. Reeves, Okapi Wildlife Associates, 27 Chandler Lane, Hudson, Quebec, Canada J0P 1H0 (rrreeves@okapis.ca)
Tim D. Smith, World Whaling History Project, 1774 Sterling Drive, Redding, California, USA 96003
Elizabeth A. Josephson, Integrated Statistics, 16 Sumner Street, Woods Hole, Massachusetts 02543, USA

Abstract

Animals belonging to the small, endangered population of western gray whales (*Echrichtius robustus*) are observed today primarily during the summer open-water season in feeding areas off the north-eastern coast of Sakhalin Island, Russia. The migration route(s) and wintering area(s) used by this population are largely unknown. Gray whales once had a fairly extensive distribution in the Sea of Okhotsk but little detailed information has been published on when and where they occurred. Open-boat, ship-based whalers from the United States and a few other countries conducted an intensive hunt for bowhead whales (*Balaena mysticetus*) and North Pacific right whales (*Eubalaena japonica*) in the Sea of Okhotsk from the 1840s to 1870s. According to entries in voyage logbooks, the American whalers regularly encountered (and sometimes hunted) gray whales in the far north-eastern corner of the Okhotsk Sea (Shelikhov Bay, Gizhiginskaya Bay and Penzhinskaya Gulf) between early May–late August. They also observed gray whales in summer along the northern coast of the sea (especially Tauskaya Bay), around the Shantar Islands, in Sakhalin Bay, off Cape Elizabeth at the northern tip of Sakhalin Island and along the west coast of the Kamchatka peninsula. No evidence was found in the logbooks studied of gray whales (and indeed of whaling effort) off north-eastern Sakhalin Island where most observations of gray whales occur in the present day.

Introduction

Recent and current interest in gray whales (*Eschrichtius robustus*) from the western Pacific (Korean-Okhotsk) population has centred on that population's endangered status and the ongoing threats to its survival and recovery. Specifically, there is concern about (a) the small number of whales in the population; (b) environmental degradation and disturbance from oil and gas development on the north-eastern Sakhalin Island shelf, the main area where the population is presently known to congregate in summer to feed; and (c) mortality of gray whales in Japanese waters, mainly in set nets.

The history of this population has been reviewed by Mizue (1951), Nishiwaki and Kasuya (1970), Brownell and Chun (1977), Omura (1988), Weller et al. (1999, 2002) and Kato and Kasuya (2002). In addition to those reviews, Henderson (1972, 1984, 1990) made reference to ship-based whaling on the western population during the 19th century, primarily by American and French whalers. In our recent studies of whaling history in the North Pacific, we have examined a sample of American voyage logbooks that contain substantial unpublished data on western gray whales. The present paper uses those data to

describe where and when western gray whales were observed by ship-based whalers during the 19th century.

The data confirm that in the past gray whales used various parts of the Okhotsk Sea, likely as feeding grounds and as routes to and from such grounds. Given the rapid proliferation of offshore oil and gas operations around the perimeter of the Okhotsk Sea as well as on the entire Sakhalin Shelf, understanding the historical (and thus both current and potential) summer range is essential.

Background

Offshore or ship-based whaling for gray whales along the Asian coast from southern China to Japan and in the Sea of Okhotsk has been less well documented than shore-based whaling there. Among the reasons for this difference is the death in June 1999 of David Henderson, who authored classic studies of the American pre-modern, ship-based fishery for *eastern* Pacific gray whales (1972, 1984) and was working on a similarly exhaustive study of the Okhotsk fishery for *western* Pacific gray whales (e.g. see Henderson 1984, p. 176, note 14; Kugler 1984, p. 157, note 6). Henderson (1972) provided only limited information on western gray whales although on his Map I, he offered an intriguing sketch of their distribution (Fig. 1). Henderson's 1984 book chapter (pp. 176-177) indicates that gray whales were not hunted by the American whalers in the Sea of Okhotsk until sometime in the 1840s and that catches of 6-7 whales per ship were being made by the 1850s. He judged that the total kill of gray whales in the Okhotsk Sea by the American fleet was probably similar to that in the Bering Sea and Arctic Ocean, i.e. a few hundreds (his estimate of total kill in the latter areas between 1845-1874, adjusted for hunting loss, was 539; Henderson 1984, p. 169). Some American whaling for gray whales continued in the Sea of Okhotsk until at least the mid-1880s (Henderson 1984, p. 177), by which time most of the remaining Arctic fleet was committed to the 'hazardous, though profitable, whaling in the Arctic [i.e. Bering, Chukchi and Beaufort seas]' (Clark 1887, p. 19). The Sea of Okhotsk was also a frequent destination of French whalers from the mid 1840s until perhaps the mid 1860s (Du Pasquier 1982, pp. 183, 192, 245-249; Kugler 1984, p. 152) and they probably took at least some gray whales although we have not found any direct evidence for this (Du Pasquier 1986, p. 274). At least three Russian whaleships (all originating from Finland) also visited the Okhotsk Sea in the 1850s (Clark 1887, pp. 206-207).

The Okhotsk Sea fishery for balaenids was most intensive from 1847-1867, with nearly 1,400 vessel-seasons, 90% of them from the United States and the rest from France, Bremen, Russia, and the Hawaiian Islands, and occasionally Great Britain, Norway, and Chile (Kugler 1984, p. 153). As an example of the intensity of this fishery, one ship's logbook reported that 65 other whaling vessels were in sight on 27 August 1854 in Shantar Bay (*Good Return*). In that same month, Lindholm (1863) counted 82 ships in the bay and on one day 363 whaleboats were in sight from his ship (*Storfursten Constantin*). Bowhead whales (*Balaena mysticetus*) and North Pacific right whales (*Eubalaena japonica*) were the principal targets and, according to Henderson's preliminary analyses (as reported by Kugler, *op cit.)*, more than 15,000 bowheads and

2,400 right whales were killed and processed by the Okhotsk whalers in those first 20 years. The fishery continued until the 1890s.

Henderson's only publication containing data on western Pacific gray whales (apart from the few references to Okhotsk whaling in his 1972 book and his 1984 book chapter) was a short article on American whaling in southern China in the 1860s (Henderson 1990). There he recounted two voyages to the 'Chinese gray whale ground' in the winter of 1868-69 – by the New Bedford ships *Cornelius Howland* and *Onward*. Although they failed to strike any, the crews of these vessels sighted gray whales near the Chinese mainland coast at c. 25-26ºN off the island of 'Hatan Ho Tan' (Haitan, Pingtan Dao, or Tao on modern maps, according to Henderson), in the middle of Taiwan (Formosa) Strait, and off the northern coast of Taiwan.

Materials and Methods

In addition to a search of the literature, we sampled whaling voyage logbooks from the Kendall Whaling Museum and Old Dartmouth Historical Society collections, both available at the New Bedford Whaling Museum library in New Bedford, Massachusetts. Okhotsk Sea logbooks were identified using library finding aids, *Whaling Logbooks and Journals* (Sherman et al. 1986), and *The History of the American Whale Fishery* (Starbuck 1878), as well as through references in logbooks to other vessels sighted or 'spoken' on the grounds. Data from the logbooks, including date, position, details concerning whale observations, and other vessels spoken, were entered into an Access database and plotted using ArcMap.

Frequently, the exact location could not be determined from the logbook and therefore it was necessary to estimate positions by interpolation and reference to landmarks. A particular problem encountered while working with this material was that place names used by the American whalers did not always correspond to the Russian names. For that reason, we compiled a gazetteer in the course of our logbook reading as a research tool. Sketch maps prepared by the whalers themselves were useful in that regard (Fig. 2). A composite map of the region was developed from a variety of sources (Fig. 3). When places are mentioned throughout the text of this paper, alternative names have been indicated in brackets.

The American whalemen used several different terms to refer to gray whales, including ripsacks (rip sacks), musseldiggers (mussel diggers), devil fish, scrags, scamperdowns, California grays, graybacks and California whales.[1] They called bowheads polar whales, steepletops, bowheads (bow heads) or often just whales (in most but not all instances, the species can be inferred from the context). Blue whales (*Balaenoptera musculus*) were consistently called sulphur bottoms (or sulfur bottoms). Right whales, humpback whales (*Megaptera novaeangliae*) and 'finback' whales (probably mainly fin whales, *B.*

[1] Henderson (1972, pp. 34-35; 1984, pp. 163-164) included mud digger, digger and hard head in the list of names used for the gray whale by American whalemen, but we did not encounter these terms in our limited sampling of logbooks.

physalus, though this name also may have been applied to sei whales, *B. borealis*) were referred to as such.

Results

Our sample of logbooks included 21 multiyear voyages that visited the Okhotsk Sea one or more times, for a total of 43 'vessel-seasons' in the Okhotsk. The ships were in the region for more than 5000 days, and daily positions have been determined or estimated for most of those days (Fig. 4). The sampled voyages spanned the period from 1847-1885 though the majority of them took place in the 1850s and 1860s. Logbooks of 14 voyages, including 24 vessel-seasons in the Okhotsk, contained references to sightings of gray whales. There was a total of 152 daily entries with observations of gray whales, including sightings, chases, strikes and captures (Fig. 5).

Occurrence

Citing early Russian literature, Yablokov and Bogoslovskaya (1984) described gray whales (and humpback whales) as having been "very common and even abundant in the coastal waters of the northern part of the Okhotsk Sea and off the western shores of the Kamchatka Peninsula." They surmised (as did Tomilin 1957, p. 314) that gray whales migrated into the Okhotsk Sea from the Sea of Japan via both Tatar Strait (Tatarskiy Proliv) and La Perouse Strait. Indeed, American logbook data imply that gray whales at least occurred in or near La Perouse Strait in mid-June (e.g. some were sighted and chased there by *Cicero*, 16 June 1859, c. 46ºN, 142ºE). Vladimirov (2004) questioned the feasibility of gray whales entering (or leaving) the Okhotsk Sea via Tatar Strait 'due to the small depths of the Amur Firth (2-3 m) … which must be a natural obstacle for migrating animals'. In contrast, Rice and Wolman (1971, p. 20), citing Mizue (1951), suggested that all gray whales passed through Tatar Strait 'as none was ever seen in La Perouse Strait'.[2]

Many voyages to the Okhotsk Sea originated in Hawaii and therefore the ships entered via the northern Kuriles (usually in the vicinity of Paramushir Island) and then worked northwards along the western shore of Kamchatka. According to Henderson (1972, p. 87, citing reports from *Fortune*, 6-8 June 1855, *Mary and Susan*, 19-30 August 1848 and *Montezuma*, 30 May and 29 September 1860), gray whales were observed mainly along the northern coast of the Sea of Okhotsk, and this is consistent with Yablokov and Bogoslovskaya (1984).

Gray whales were observed consistently by the American whalers in the southeastern portion of Shelikhov Bay (Zaliv Shelikhova) and in Penzhinskaya Gulf (Penzhinskaya

[2] From Mizue (1951, p. 79): "… it is reported by Mr. Tago that they reach Hokkaido or the western coast of Sakhalin in May or June and then through the Mamiya [Tatar] Channel go to the northern part of the sea of Okhotsk, where they seem to spend their summer. On their southwards migration they seem to take the same course as they come up north. It is not probable that grey whales pass through the Soya [La Perouse] Channel to the farther north, for fin and hump-back whales are captured there from the landstation in Hokkaido but not grey whales."

Guba) from early May (earliest record 6 May 1885; *Mary and Helen II*) to the end of August (approximately 43 observations in our sample; Fig. 5). They were seen in Gizhiginskaya Bay (North-east Gulf) between mid-May and late August (approx. 46 observations, including a report of 'thousands of devilfish but no bowheads' in the logbook of the *Benjamin Cummings* on 3 June 1869) and in the vicinity of Magadan along the north-central coast of the Sea of Okhotsk (i.e. in Tauskaya Gulf/Guba, generally called Tausk or Taousk Bay) from at least early June to early July and from mid-August to mid or late September (approx. 19 observations). Gray whales were seen occasionally just east of Okhotsk City in the north-western Sea of Okhotsk (*Lancaster*, 12 September 1860; *Oliver Crocker*, 29 August 1861). There is little evidence that they still occur in any of those northern areas (Maminov and Blokhin 2004) although it is unclear how much search effort has been expended there at the appropriate times.

Only a handful of references to gray whales in the vicinity of the Shantar Islands were found in the logbooks: 'a few rip sacks' northeast of Big Shantar Island on 5 June 1860 (*Oliver Crocker*), 'muscle diggers' somewhere in the Shantars on 7 September 1855 (*Nassau*) and 'Devilfish or Ripsack whales' in Taylor's Bay, off Ulbansky Bay, on 13 August 1885 (*Mary and Helen II*). Another sighting was recorded about midway between Ayan and the Shantar Islands on 14 June 1860 (*Lancaster*). Tomilin (1957, p. 314) cited Russian observations in Akademii and Ulbanskii bays. Also, in recent years a few observations have been reported in September in Tugurskiy and Ulbanskiy bays (Maminov and Blokhin 2004).

The American whalers observed gray whales, sometimes in sizeable concentrations (e,g., 20-30 seen in a day, references to "plenty" being seen), in Sakhalin Bay (Sakhalinskiy Zaliv) and off Cape Elizabeth (Mys Yelizavety) at the northern tip of Sakhalin Island (*Mary and Susan*, various entries between 18 August – 9 September 1848). A sighting of two gray whales in summer 2005 in Severnyy Bay (just south-west of Cape Elizabeth) (Tyurneva et al. 2006) demonstrates the continued use of that area by the extant population. Also, gray whales were seen in southern Sakhalin Bay in August 2000 (Maminov and Blokhin 2004).

Finally, American whalers sighted gray whales at least occasionally near the northern (Cape Huntsville, 58º05'N, 157º06'W; *Europa*, 17 May 1869), central (vicinity of Moroshechnoye, 55º51'N, 155º52'E; *Mary and Susan*, 13 July 1849) and southern coasts of western Kamchatka (51º16'N, 155º23'W; *Europa*, 14 September 1868). Although Blokhin (1996) reported that gray whales had not been seen along the western coast of Kamchatka in many years, one was reported in August 2000 at the mouth of the Bolshaya River (Vertyankin et al. 2004). In that regard, the logbook of *Mary and Helen II* refers to arrival at the Bolshaya mouth on 12 September 1885, the vessel having departed the Shantar Islands on 23 August bearing east "for 'Bolshaya River' for Right Whales". The 13 September logbook entry states: "I am bound back to the west end of the Sea north of the Shantar Islands for I am convinced there are no whales to be seen about this locality or where I have been expecting to find 'Ripsack Whales' off the mouth of the 'Bolshaya River'." Having found neither right nor gray whales off Kamchatka, the *Mary and Helen*

II relocated to Tauskaya Bay, with the top of the logbook page for 19-20 September declaring, "In 'Tausk Bay' among the 'Ripsack Whales'."

In recent years sightings of gray whales have become regular in Olga Bay (between Cape Seniavin and Cape Kozlov) and Vestnik Bay (just north of Cape Lopatke, c. 51º35'N) on the south-eastern coast of Kamchatka (Vertyankin et al. 2004) and at least some of the individuals seen there have been photographically matched to individuals observed off north-eastern Sakhalin (Yakovlev et al. 2007).

We found no evidence beyond that presented by Henderson (1990) that American whalers observed or took gray whales in Chinese waters where sightings and a few strandings and kills were reported in the 20th century (Wang 1984; 1993, 1999; Zhu 1998; Blokhin and Blokhin 2006). However, our logbook sample included little coverage of whaling in those waters.

Removals

Our reading of logbooks thus far has not revealed any major inconsistencies with Henderson's (1984) findings as summarised above. Gray whales clearly were secondary targets and they were pursued mainly at times when the preferred bowheads and right whales were unavailable. For example, in 1859 the ship *Oliver Crocker* arrived in Tauskaya Bay at the end of May, with its first sighting of 'mussel diggers' reported on 3 June. Within a few days the boats were engaged in the pursuit of bowheads in the bay. Three were bomb-lanced and/or harpooned, but lost, between 6-10 June. By 15 June the run of bowheads had ended, and after a few more days the hunt for gray whales began. Between 19-30 June the *Crocker*'s boats were lowered daily and no fewer than nine gray whales were taken and processed. In addition at least two were lost when the harpoon drew or the line was cut. Two of the processed whales had sunk initially and, in both instances, were only recovered two days later. Three other ships were spoken in the bay during the second half of June – *L.C. Richmond*, *Robert Morrison* and *Cambria* – but it is unclear whether any of them took gray whales (the *Richmond* was seen taking a bowhead on 13 June; the *Cambria* reportedly had taken three bowheads that season as of 30 June). On 1 July the *Crocker* sailed towards the Shantar Islands where bowheads were plentiful and hunting for them resumed on 11 July. There is no further mention of gray whales that year in the *Crocker* logbook. Also, in the next two years, even though the *Crocker* followed a broadly similar itinerary, there is nothing in the logbook to suggest another episode of intensive gray whaling. Two were taken in North-east Gulf on 3 August 1861, the only day during the 1861 season when the logbook indicates the boats were lowered for 'ripsacks'.

The ship *Europa* arrived in Gizhiginskaya Bay (North-east Gulf) early in the 1868 season, with its first bowhead sighting on 19 May. From then until 28 June, when the first bowhead was taken, only one more bowhead was seen by the crew (on 7 June), whereas gray whales (and 'finbacks') were seen often and the boats were lowered on at least three occasions with the explicit intention of hunting gray whales (none was taken by the *Europa* until 20 June). The logbook records that on 5 June 1868: "Lowered for Ripsacks

for the purpose of trying our new whaling guns, tried four shots and the irons would not enter the blubber." In 1869 the *Europa* followed the same itinerary but had more success finding and taking bowheads, and there was only one brief lull (11-12 June) when attempts were made to take both gray whales and a 'finback'. Later that season (26 July), the *Europa* 'picked up' and processed a dead gray whale found floating in Penzhinskaya Gulf between Ship Rock and Big Grampus Island and the log refers frequently to 'ripsacks' being observed (e.g. 17 August near Ship Rock, '…not seeing anything but Ripsacks') but with only one more desultory attempt made to hunt them (27 August).

In 1885 the *Mary and Helen II* reached the north-eastern part of the Okhotsk Sea by the end of April and gray whales were sighted on 6 May and again on 20 May, by which time no bowheads had yet been seen. In fact, only one brief sighting of a bowhead was made before mid-June. Even though gray whales were seen many more times, the boats were not lowered to chase them (except on 21 June and 11 July 'by mistake') until the brief and intense episode in Tauskaya Bay in mid-September mentioned above.

Before the present study is considered complete, we expect to produce a quantitative estimate of the American catch of western gray whales, adjusted appropriately to account for hunting loss. For the present, we note the following catch information: 9 (plus 2 struck/lost) by *Oliver Crocker* in 1859 and 2 in 1861 (see above); 1 by *Florida* (15 bbl) (Williams 1964, pp. 185) and 1 by *South Boston* in 1861 (Williams 1964, p. 186); 4 by *California* in 1863 (Henderson 1972, p. 87); 1 each by *Endeavour*, *Rainbow* and *Europa* in 1867 (*Europa* 1867); 1 by *Europa* (salvaged) in 1869; and 4 by *Mary and Helen II* in 1885.

The estimated total landed catch of western gray whales by modern whaling and Japanese net whaling between 1890-1966 was 1,800-2,000 (Kato and Kasuya 2002). No other catches are known to have taken place during that time or since 1966 although some unreported catches may have been made by catcher boats from the People's Republic of China or the Republic of Korea, neither of which belonged to the International Whaling Commission until 1980 and 1978, respectively. It is also possible that some catches were made by whalers from the Democratic People's Republic of Korea or from Taiwan.

Discussion

Occurrence

Mizue (1951) analysed catch dates and positions for 545 gray whales in the 'East Sea Area' of Korea. The catches all occurred between November and May with a strong peak in December (63%) and January (22%). The infrequency of catches in other months from September through March apparently was not related to effort because, as Mizue (p. 76) points out, the same area was an important whaling ground for fin whales and 'many catcher-boats work during the season, from September to March next year' and so the whalers 'would have certainly caught grey whales if they had seen them in the months of October, November, February and March'.

The speculation by Mizue (1951) that gray whales migrated northwards from Korea through the Mamiya Channel (Tatar Strait) in May or June and thence to summering grounds in the northern Sea of Okhotsk is not inconsistent with some of the American whalers' observations. It is unclear, however, whether Mizue was correct in his belief (shared by Andrews 1916, p. 210) that gray whales calved and mated in Korean waters. There is no reason to doubt that at least some of the whales migrated to as far south as 25ºN along the Chinese mainland and moved though Taiwan (Formosa) Strait (Henderson 1990). Also, it is important to consider that Mizue's reasoning that gray whale females with large foetuses taken in mid-December off Korea were 'immediately before birth' and that 'delivery is made among the islands at the southern extremity of the Korean Peninsula' was without the benefit of Rice's (1983) analysis showing a 'prenatal diapause' in eastern Pacific gray whales such that foetal growth 'virtually ceases' during the final month of pregnancy and birth occurs between early January and mid-February (median 27 January). It is therefore plausible that the strong peak in occurrence of female gray whales in Korean waters from early December to early January (Mizue 1951, his Table 5) represents primarily a movement of migrating animals towards a destination farther south for parturition.

Based on the American whalers' observations summarised in this paper, gray whales were consistently observed in specific portions of the Sea of Okhotsk during the middle decades of the 19th century. Although most of the observations reported in the logbooks occurred on grounds where bowhead whales were the primary targets, some observations were also made on right whale grounds (e.g. on the Okhotsk side of Paramushir Island/Mys Lopatka, 51°16'N, 155º23'W, 14 September 1868, *Europa* 1867-1868). No sightings were reported on the north-eastern Sakhalin Shelf where western gray whales are observed most often today. However, none of the logbooks read for this study contained evidence that the American whalers visited that area (Fig. 4). The ship positions of whaling voyages into the Okhotsk Sea between 1844-1852 indicate some effort off the far northern, east-central and southern shores of Sakhalin but almost none along the north-eastern coast on or near the present-day feeding areas (Josephson et al. 2008). Lindholm (1863), a whaleman with much experience in the southern part of the Okhotsk Sea (particularly around the Shantar Islands), reported that gray whales were 'found in large numbers close to Cape Elizabeth [northern end of Sakhalin Island] and in the northern section of the sea during the summer'.

It is important to emphasize that the spatial and seasonal coverage of the Sea of Okhotsk represented by the logbooks was dictated primarily if not solely by the whalers' interest in catching bowhead whales and right whales though it was also influenced by the logistical constraints of sailing conditions, ice coverage and day length. It is fair to question whether the relative concentration of sightings of gray whales in the far north-eastern reaches of the sea (Gizhiginskaya Bay and Penzhinskaya Gulf ; Fig. 5) reflects relative density or is instead the result of a strong bias in search effort. It was not possible to address this issue rigorously given the biased nature of the effort data (the whalers went where they hoped to find bowhead whales and right whales) and the uncertainty about how consistently observations of non-target or secondary-target species like the gray whale were reported in the logbooks.

Removals

As indicated earlier, Henderson (1984) suggested that commercial ship-based whalers in the Sea of Okhotsk took about as many gray whales between the 1840s-1880s as were taken over roughly the same period in the Bering Sea and Arctic Ocean. Our findings are consistent with Henderson's suggestion. It is clear from the logbooks we read that gray whales were of little interest to the whalemen during the early years of the Okhotsk fishery when bowheads and right whales were available in good numbers. In the 1840s and early 1850s, few masters bothered to lower the boats when gray whales were observed on or en route to the bowhead or right whale grounds. This seems to have begun changing by the mid 1850s when logbooks record gray whales being chased more often (e.g. *Gov. Troup*, 9 July 1854 near the Jamskiye Rocks [Yamske Islands]; *Cicero*, 16 June 1859 in La Perouse Strait).

Within a given voyage, particularly from the 1860s onwards, it was not unusual for the crew to pursue *eastern* gray whales in the Mexican lagoons or alongshore Baja California and California in the winter, and *western* gray whales in the Sea of Okhotsk in the summer. Kugler (1984, p. 153-4) referred to these as 'loop voyages', with the southern and northern components separated by visits to Hawaii and perhaps the Sea of Japan in the spring. Charles M. Scammon, for example, on the San Francisco ship *William C. Nye* during his last year as a whaling captain, sailed to the Okhotsk Sea for bowhead whaling in summer 1862 and then to Magdalena Bay for gray whaling in the following winter (Henderson 1972, pp. 86, 271).

The gray whale's reputation as a 'devilfish' is borne out by occasional statements in the logbooks. For example, when boats from the ship *Europa* (1866-1867) attacked a 'ripsack' in North-east Gulf on 19 August 1867, the bow boat 'got stove' after making the first strike, and then the other boats made the kill.

Conclusions

In the sample of logbooks examined, there was no evidence that American 19th century whalers visited the north-eastern coast of Sakhalin Island where gray whales have been studied intensively over the past decade. However, gray whales were observed regularly in certain other parts of the Sea of Okhotsk where the ship-based whalers hunted bowhead whales during the summer. They observed and hunted gray whales relatively often in the north-eastern corner of the sea, especially in Gizhiginskaya Bay (North-east Gulf) and Penzhinskaya Gulf. Gray whales were present in Gizhiginskaya Bay as early as mid-May when (or at least very soon after) the whalers arrived and gray whales continued to be observed there through the end of August. Good numbers also were observed in early June and as late as the third week of September in Tauskaya Bay Magadan coast) and in late summer (mid-August to mid-September) in Sakhalin Bay off the north-western coast of Sakhalin Island.

The historical distribution of gray whales in the Sea of Okhotsk appears to have been much more extensive than it is at present although increased search effort at appropriate times in areas of historical occurrence is needed confirm their absence from such areas. Although not definitive, the information on western gray whales obtained from American 19th century whaling logbooks is of potential value in the following ways:

- To inform the timing and spatial coverage of modern survey effort.
- To support, in principle if not also in planning as to time and location, a satellite tagging and tracking programme to learn more about the movements of western gray whales.
- To contribute to an accurate reconstruction of catch history for input to population models.
- To provide a basis for formulating hypotheses regarding stock structure.

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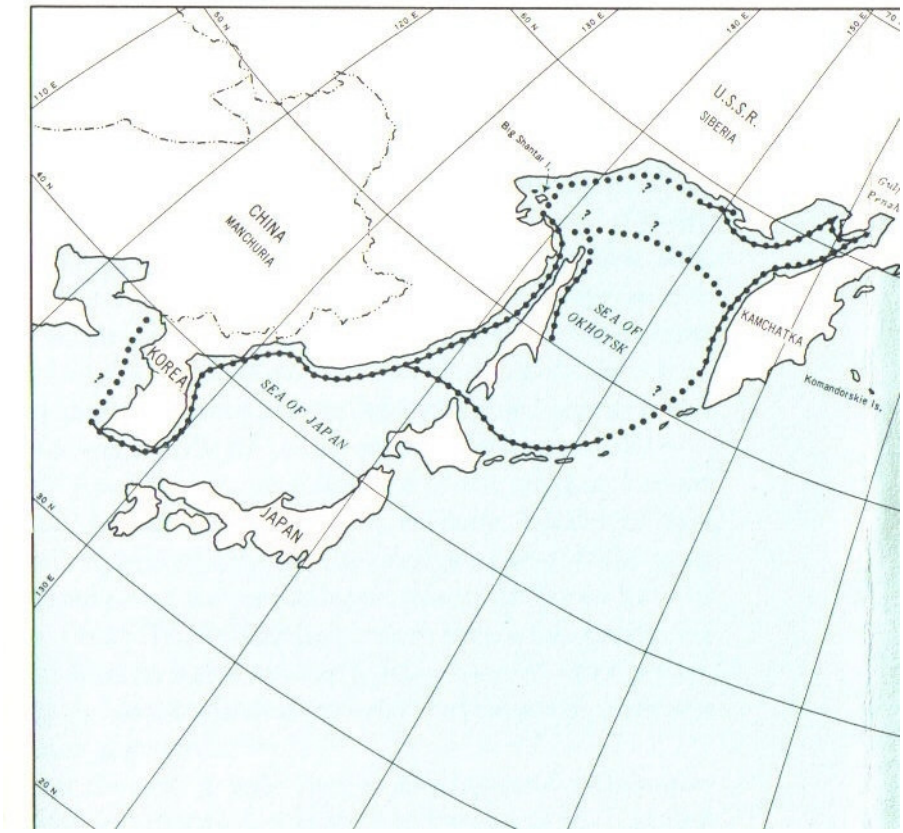

Figure 1. Excerpt from 'Distribution, Migration Routes, and Calving Grounds of Pacific Gray Whales' in Henderson (1972). Cited sources used by Henderson as the basis for this map include Mizue (1951), Tomilin (1957) and 'Scammon's and other historical records'.

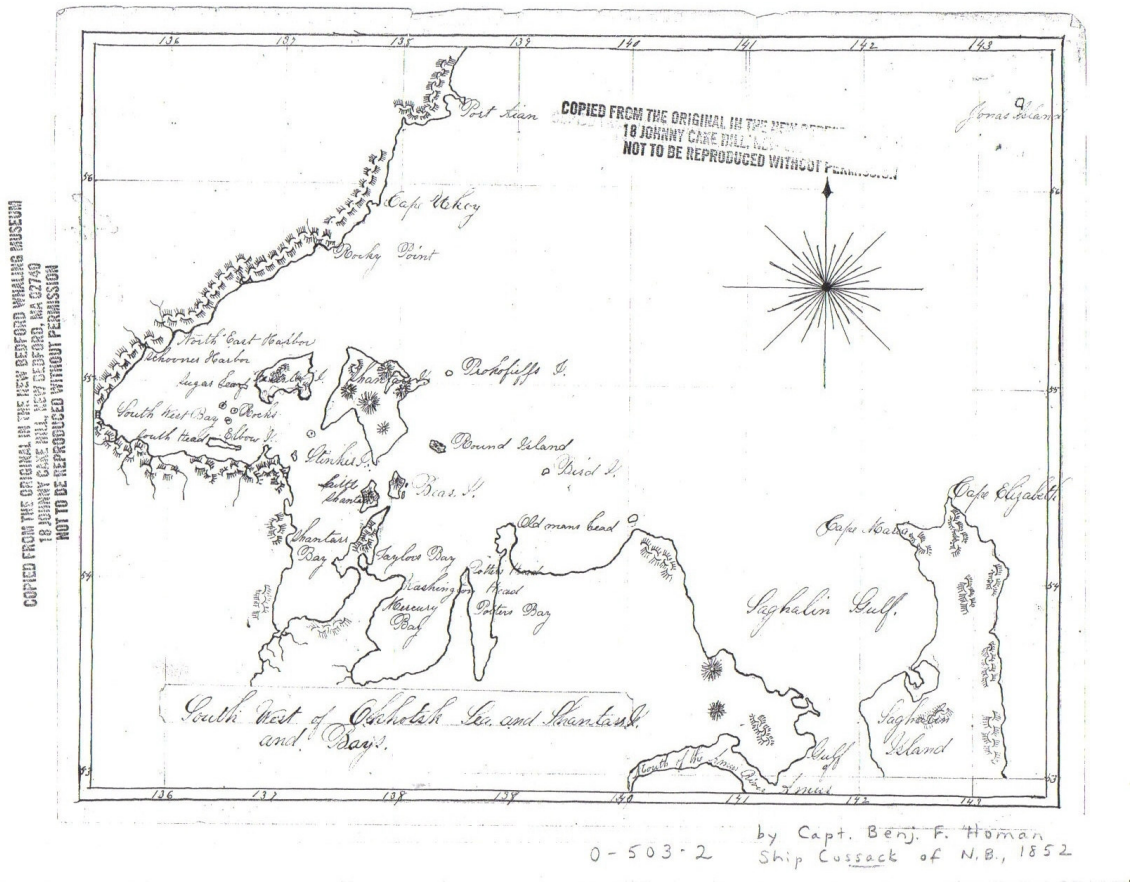

Figure 2. Sketch map from logbook of ship *Cossack* of New Bedford, 1852.

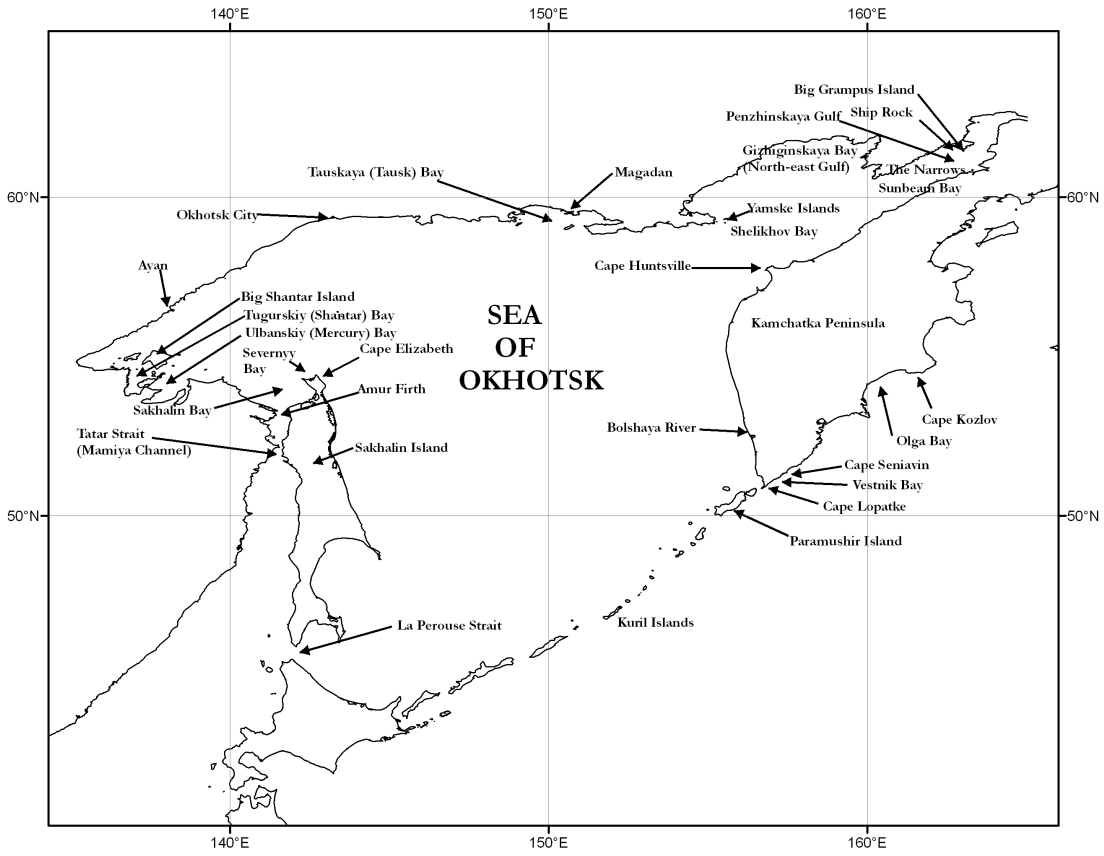

Figure 3. Places mentioned in text.

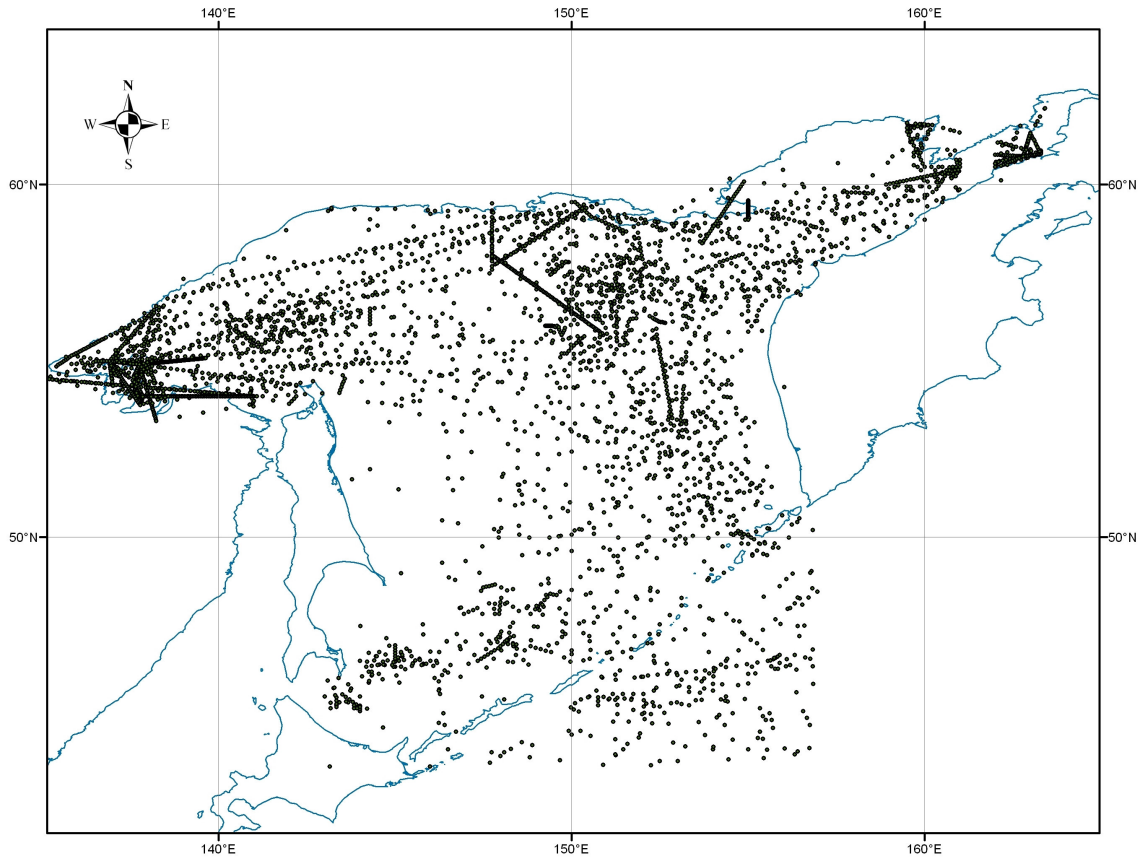

Figure 4. Approximate positions of whaling vessels in and immediately outside the Sea of Okhotsk based on logbook records of 21 voyages (43 vessel-seasons). Note the nearly complete absence of search effort along the north-eastern coast of Sakhalin Island.

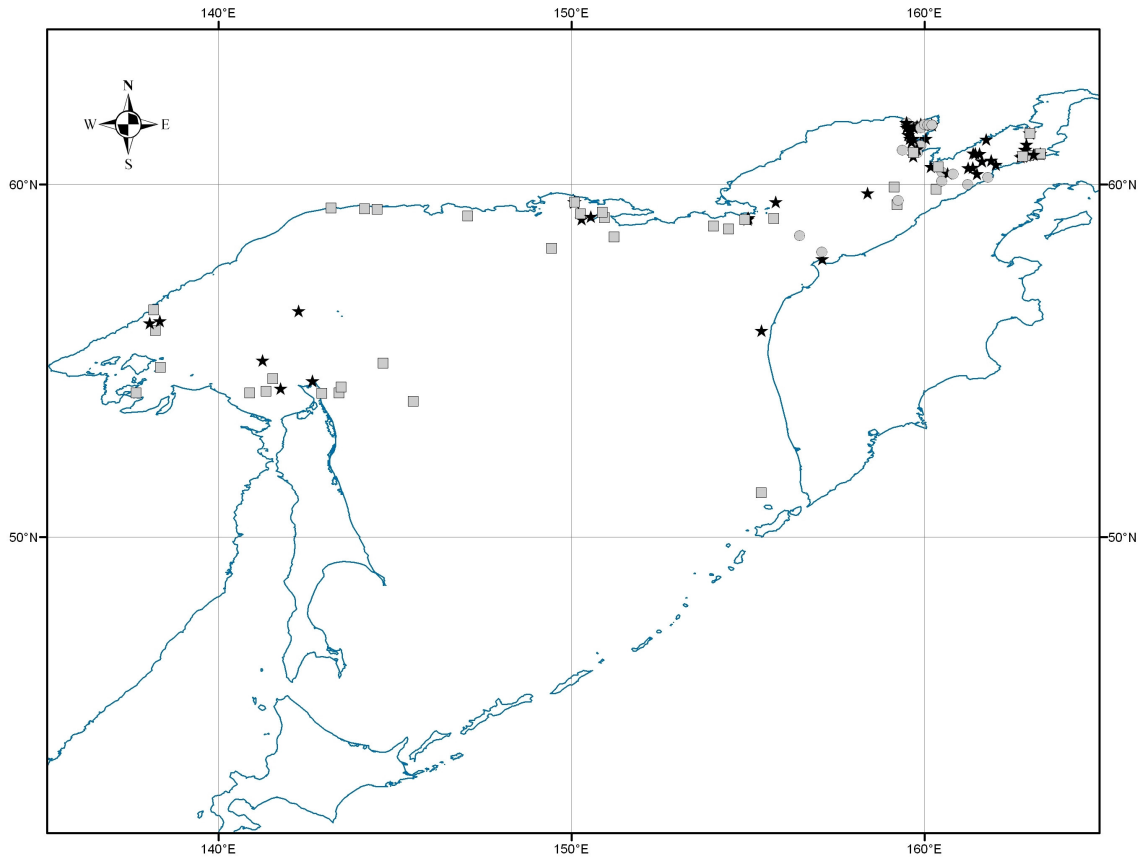

Figure 5. Approximate positions of 152 sightings (including kills) of gray whales in the Sea of Okhotsk by 19th century American whalers. Note that some symbols are overprinted in areas with many observations. Circles: April-May; stars: June-July; squares: August-September-October. Also note that many positions are based on extrapolation or interpolation from ship positions reported on days before or after that of the gray whale sighting. All data are from logbooks; see text.

LIFE HISTORY AND ECOLOGY OF THE GRAY WHALE (Eschrichtius robustus)

RICE AND WOLMAN

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THE LIFE HISTORY AND ECOLOGY OF THE GRAY WHALE (*ESCHRICHTIUS ROBUSTUS*)

By

DALE W. RICE

and

ALLEN A. WOLMAN

U. S. Fish and Wildlife Service
Bureau of Commercial Fisheries
Marine Mammal Biological Laboratory
Seattle, Washington

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FOREWORD

WHALES long remained among the world's least known mammals because their large size and oceanic habitat make them difficult to observe and collect. Individual whales cannot be observed repeatedly, therefore knowledge of most aspects of their life history must be deduced from data provided by examining large series of specimens. In the early decades of this century the expansion of the modern whaling industry with its efficient catcher boats and its mechanized shore stations and floating factory ships finally provided biologists the opportunity to undertake large-scale studies of whales. Concern for the future of whale stocks provided an incentive for government support of whale research. As a result, we have now learned more about the biology of the rorquals and the sperm whale than of most other species of wild mammals. Gray whale populations, however, had been depleted before this opportunity for research arose. Although field observations had provided a fairly detailed picture of the distribution, migration, and behavior of the gray whale, many important aspects of the species' biology—such as age and growth, reproduction, parasites, pathology, and population dynamics—remained virtually unknown.

Under the protection afforded by the 1946 International Convention for the Regulation of Whaling, the California gray whale stock has increased so much that a resumption of commercial exploitation has been considered. As the dearth of basic data on the biology of the species would handicap any efforts at rational regulation of the harvest, the Bureau of Commercial Fisheries in 1959 initiated a research program that included collecting small series of gray whales under Special Scientific Permits. Beginning in 1966, the number of animals taken annually was increased upon recommendation of the Scientific Committee of the International Whaling Commission, which has reviewed the work each year and provided much encouragement and advice. The data now available reveal the basic features of the ecology of the gray whale and provide a foundation for further studies on its population dynamics.

This study would not have been possible without the cooperation of the Del Monte Fishing Company and the Golden Gate Fishing Company of Richmond, California. John Caito and Charles Caito of Del Monte, and Robert Casebeer of Golden Gate placed the

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facilities and crews of their whaling stations and catcher boats at our disposal for collecting and examining specimens. Kenneth C. Balcomb III, James Ekberg, Bernard Lenheim, and Toshio Kasuya (Ocean Research Institute, University of Tokyo), assisted in the examination of whales at the whaling stations. Margaret Anderson, Lawrence Dickson, Susan D'Vincent, Ekberg, James Houk, Hiroshi Kajimura, Lenheim, Donald Ramsey, Jeffrey Rochin, James Rote, Catherine Short, and Robert Strawn manned the counting stations. Lenheim, Ramsey, and Ancel M. Johnson conducted the transect cruises of the catcher-boat *Allen Cody*. Balcomb, Kasuya, Thomas J. McIntyre, Masaharu Nishiwaki (Ocean Research Institute), Daniel Lluch B., and Joaquin Arvizu M. (both with the Instituto Nacional de Investigaciones Biologico Pesqueras, Mexico) assisted in the whale-marking cruises. Ford Wilke, Johnson, and Lenheim assisted in the aerial surveys. Francis H. Fay, Arctic Health Research Laboratory, U. S. Public Health Service, provided a sample of the stomach contents of a gray whale killed near St. Lawrence Island, Alaska. Earl L. Bousfield, National Museum of Canada, identified the amphipods, provided information on the habits of benthic invertebrates, and made suggestions concerning the feeding behavior of gray whales. The following individuals identified other stomach contents or parasites: Martin W. Johnson and Margaret D. Knight, Scripps Institution of Oceanography (crab larvae); Josephine F. L. Hart, British Columbia Provincial Museum (cumaceans); Frank Bernard (ascidians and holothurians) and Cyril Berkeley (polychaetes and salps), Pacific Biological Station, Fisheries Research Board of Canada; Yuk-maan Leung and John L. Mohr, University of Southern California (cyamids); Kenneth M. Neiland, Alaska Department of Fish and Game (acanthocephalans and campulid trematodes); Robert L. Rausch, Arctic Health Research Laboratory (cestodes and notocotylid trematodes); John T. Davey, Commonwealth Bureau of Helminthology (nematodes). Daniel F. Cowan, Michigan State University, examined a pathological liver specimen. The late Gordon C. Pike, Arctic Biological Station, Fisheries Research Board of Canada, made the baleen tracings and allowed us to see his unpublished manuscript on gray whales taken off British Columbia. Unless otherwise noted, individuals mentioned above are present or former employees of the Marine Mammal Biological Laboratory, Bureau of Commercial Fisheries.

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INTRODUCTION

In February each year, pod after pod of gray whales departs from the tropical mangrove-fringed lagoons bordering Bahia Magdalena, from Laguna Ojo de Liebre in the heart of the Vizcaino Desert, and from other lagoons on the west coast of Baja California. Swimming slowly but steadily, they move northward along the coast; four months later the same whales may be surfacing and blowing among the ice floes of the Chukchi Sea. This migration is the longest performed by any mammal.

The gray whale, *Eschrichtius robustus* (Lilljeborg, 1861), is unique in other ways. It is the sole member of the family Eschrichtiidae and the most primitive surviving baleen whale. In structure it is remarkably similar to the extinct cetotheres, which were ancestral to all living baleen whales. The gray whale became extinct in the North Atlantic only a few centuries ago and is now a relict species confined to neritic waters of the North Pacific Ocean and adjacent waters of the Arctic Ocean (Fig. 1).

Because gray whales swim slowly and congregate in near-shore waters, they were easy prey to whalers. By the turn of the century, the species was almost extinct. Since 1946, the eastern Pacific stock has increased under the legal protection afforded by the International Convention for the Regulation of Whaling to the point that commercial utilization may again be advocated.

Gray whales are the only large whales that can regularly be observed in large numbers from shore. Their annual passage along the coast of California is one of the world's outstanding wildlife spectacles. Public interest in gray whales is increasing, and they have become an important tourist attraction in southern California. More than a million people visit Cabrillo National Monument on Point Loma, San Diego, each year to watch the migrating whales, and several sport-fishing companies in San Diego and San Pedro profitably operate "whale watching" cruises (Rice, 1961).

The abundance and accessibility of gray whales in their calving lagoons and along the coast is also attracting a growing number of experimental biologists, and there is cause for concern that, especially on the calving grounds, repeated harassment of gray whales

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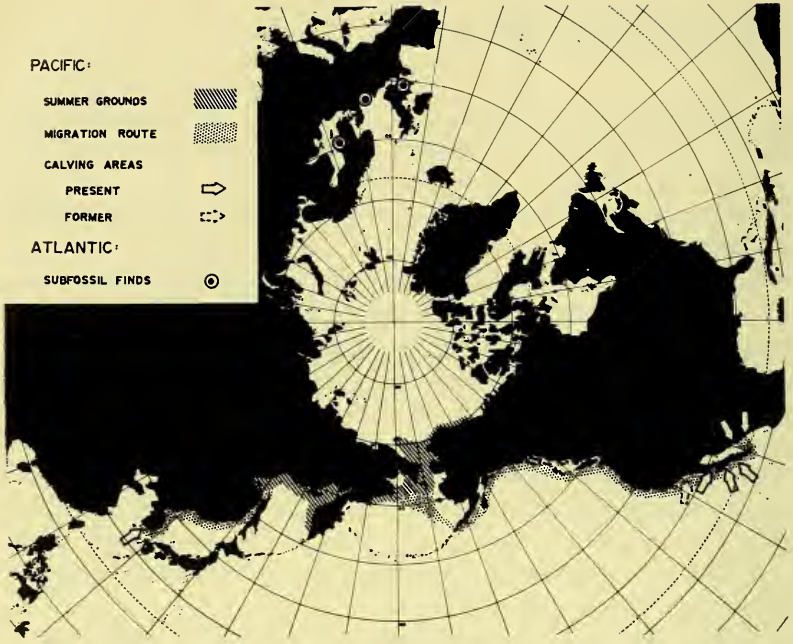

FIG. 1. Distribution of the gray whale. A few gray whales spend the summer in the migration area, especially along the coast of Washington and Oregon.

by investigators using small boats or aircraft in attempts to implant telemetering and tracking devices or drug darts may deleteriously affect reproduction (Schevill *et al.*, 1967; American Society of Mammalogists, 1967). Another threat to the survival of the gray whale is increasing industrial development and boat and ship traffic in the remaining calving lagoons (Marx, 1966). The species has long since been driven from San Diego Bay.

The gray whale is clearly an important species from the standpoint of basic scientific interest, esthetic appeal, and economic significance. If commercial exploitation is resumed it should be limited to the sustainable yield so that the scientific and esthetic values of the population may be preserved. A wise management program must be based on a sound knowledge of the biology of the species.

Beginning with Scammon's (1874) classic account, the gray whale has been the subject of many field observations (for example, Gilmore, 1960*a*, 1960*b*; Hubbs, 1959; Hubbs and Hubbs, 1967; Pike, 1962*a*). As a result, certain facets of its life history and ecology, such as distribution, migrations, and behavior, are better known than for other baleen whales.

Only five biologists have had the opportunity to examine series of gray whales. Andrews (1914) studied 23 specimens taken during southward migration and brought into the shore station at Ulsan, Korea, in January and February 1912. In his monograph he presented a historical review of earlier research on the species. Zenkovich (1934*a*, 1934*b*, 1937*a*, 1937*b*, 1937*c*) examined 104 gray whales aboard the Soviet floating factory *Aleut* during the summers of 1933 through 1936. Tomilin (1937) examined 54 specimens aboard the *Aleut* in August and September 1934. Unfortunately, neither Andrews, Zenkovich, nor Tomilin recorded reproductive information other than measurements of fetuses and condition of mammary glands. Pike (1962*a* and unpublished data) examined 10 northward migrating gray whales killed under a special scientific permit and brought into the shore station at Coal Harbour, British Columbia, during the first week of April 1953. Zimushko (1969*a*, 1969*b*) reported on 63 gray whales collected off the Chukotsky Peninsula in the summer and autumn of 1965 and 1966.

Few other original data based upon examination of dead gray whales have been published. Gilmore (1960*a*) and Eberhardt and Norris (1964) examined a number of dead calves at Laguna Ojo de Liebre, Baja California, and Maher (1960) reported on several whales killed by Eskimos at Barrow, Alaska.

Statistical data from commercial catches of gray whales in Baja California and in the Bering Sea were analyzed by Risting (1928). Unfortunately, his data are unreliable, because body lengths were estimated rather than measured (see Mackintosh and Wheeler, 1929, p. 273), and therefore the conclusions concerning fetal growth and size at sexual maturity are not valid. Mizue (1951) presented statistical data from gray whale catches in Korea.

The Bureau of Commercial Fisheries began a program of research on the species in 1952 under the leadership of Raymond M. Gilmore. During the first five years, the work consisted of field observations

and censuses designed primarily to determine the extent of the calving grounds and to document fluctuations in population size (Gilmore, 1960*a*, 1960*b*).

In 1958, responsibility for whale research was transferred to the Marine Mammal Biological Laboratory in Seattle, Washington, under the direction of the senior author. Beginning in 1959, small series of gray whales have been periodically collected to obtain basic data on all aspects of the life history and ecology of the species. Particular emphasis has been given to reproduction, growth, age, and population structure. As collections and observations had to be made incidentally to studies on rorquals and sperm whales, they have been mostly confined to the periods when the gray whales were on migration along the coast of California. This report presents the results of the study from 1959 through February 1970.

NOMENCLATURE

THERE has long been a controversy over the correct scientific name of the gray whale. *Eschrichtius robustus* (Lilljeborg, 1861) is used here for the extinct Atlantic and the living Pacific populations of gray whales following Cederlund (1939). As the data and conclusions of this author have been mostly ignored by subsequent workers, none of whom has contributed new evidence to refute his conclusions, it seems desirable to briefly review the nomenclature of the gray whale.

The generic name *Eschrichtius* Gray (1864) is now used by virtually all taxonomists. There are three available species-group names (Hershkovitz, 1966) that require consideration. These are, in order of priority: (1) *Balaena gibbosa* Erxleben (1777), based on the New England "scrag whale" described by Dudley (1725); (2) *Balaenoptera robusta* Lilljeborg (1861), based on subfossil skeletal remains from Gräsö, Sweden; and (3) *Agaphelus glaucus* Cope (1868), based on gray whales from the coast of California. Two questions must be resolved: (1) which of the first two names should be used for the Atlantic population, and (2) is the Pacific population taxonomically distinct from the Atlantic population?

The applicability of Erxleben's name *gibbosa* to the gray whale depends upon the identity of Dudley's "scrag whale." Dudley's (1725) brief description reads as follows: "The Scrag Whale is near a-kin to the Fin-back, but, instead of a Fin upon his Back, the Ridge of the Afterpart of his Back is scragged with half a Dozen Knobs or Nuckles; he is nearest the right Whale in Figure and for Quantity of Oil; his Bone is white, but won't split." The lack of a dorsal fin, knobs on the back, and white baleen are diagnostic of the gray whale. It seems improbable that Dudley's description of the scrag whale is inaccurate because all other large whales described by him are readily recognizable. On the other hand, there are minor discrepancies between Dudley's description of the scrag whale and the gray whale. For one thing, the oil yield is too high; Scammon (1874) stated that right whales yielded an average of 60 barrels, but that gray whales produced only 20 with a maximum of 60 or 70. For another, the number of knobs on the back is too few; gray

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whales have nine to 14 knobs behind the dorsal hump, although the posterior knobs are weakly defined. These discrepancies might seem minor were it not for the fact that no other account of early whaling gives any indication of the occurrence of *Eschrichtius* in the North Atlantic (True, 1904) and the fact that the term "scrag" or "scragg" was applied to different kinds of whales, particularly small, lean, right whales (Allen, 1916; Eschricht and Reinhardt, 1866). As the identity of Dudley's scrag whale can never be unequivocally determined, we agree with Cederlund (1939) and Schevill (1952) that Lilljeborg's specific name should be used for the Atlantic gray whales.

The question of the taxonomic relationship of the Pacific and Atlantic gray whale stocks has been investigated by van Deinse and Junge (1937) and Cederlund (1939), who compared the subfossil skeletal material from the Atlantic with skeletons and published data and photographs of Pacific gray whales. These authors found no consistent differences between the Atlantic and Pacific specimens and concluded that these populations were conspecific.

FIELD AND LABORATORY PROCEDURES

Collection of Specimens

A total of 316 gray whales was examined. These were collected by the whale catcher boats of the Del Monte and the Golden Gate Fishing Companies, Richmond, California, under special scientific permits issued to the Marine Mammal Biological Laboratory. The whales were taken along the coast of central California between Half Moon Bay (37°30′ N lat.) and Point Reyes (38°00′ N lat.).

The collections were scheduled to provide representative samples for the periods of the southward (December to January) and northward (February to April) migrations. The total sample included 180 southbound migrants (85 males, 95 females) and 136 northbound migrants (81 males, 55 females). Dates of collection, numbers of specimens (in parentheses), and persons who made the examinations and measurements are as follows: 23 to 26 February 1959 (two) Rice; 27 to 30 March 1962 (four) Rice; 14 to 25 March 1964 (20) Rice; 22 to 29 March 1966 (26) Rice, Wolman, Balcomb; 14 December 1966 to 19 January 1967 (95) Rice, Wolman, Ekberg, Kasuya; 21 February to 9 March 1967 (30) Wolman, Ekberg; 14 to 25 January 1968 (35) Rice, Wolman; 26 February to 11 March 1968 (24) Wolman, Lenheim; 2 to 11 April 1968 (seven) Rice, Wolman; 20 December 1968 to 9 January 1969 (50) Rice, Lenheim; 2 to 16 March 1969 (23) Wolman, Lenheim.

Whales were delivered to the shore stations of the Del Monte and Golden Gate Fishing Companies at Point San Pablo, Richmond, California, where the following data were recorded.

Measurements and Counts.—Twenty-two standard external body measurements of the first 177 whales collected were made with a steel tape graduated in centimeters. A preliminary analysis revealed that many of these measurements were redundant, imprecise, or useless. Consequently, only nine measurements were made on the last 139 specimens. These were: total length (straight line from tip of snout to notch of flukes); head length (from tip of snout to occipital condyles); tail length (from notch of flukes to anus); maximum girth of body

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(determined by measuring from the mid-dorsal line to the mid-ventral line on the side of the whale that was uppermost as the animal lay on the flensing deck and multiplying by two); span of flukes; breadth of flukes (from notch to nearest point on leading edge); anterior length of flipper; posterior length of flipper; and maximum width of flipper. Sixteen skulls and one complete skeleton were collected for cranial measurements. Throat grooves, baleen plates, and knobs on the dorsal ridge of the caudal peduncle were counted on most specimens.

Body Weights.—Weights of six whales were determined by summing the weight of the meat produced after it had been packaged in 50-pound (22.7 kilogram) bags and the weights of the blubber, viscera, and bones, which were determined by weighing each truckload of raw material on commercial truck scales. One near-term fetus was weighed in pieces.

Ectoparasites and Epizoites.—Abundance, position, and sizes of ectoparasites and epizoites on the body surface and baleen plates were recorded, and a series of each species was collected for identification.

Scars.—The nature and position of any scars and wounds were noted.

Blubber Thickness.—Thickness of the blubber was measured (to the nearest half centimeter) at a mid-lateral point on the body opposite the dorsal hump.

Mammary Glands.—Development of the mammary glands and presence or absence of secretory activity was noted. Maximum thickness of the glands, as determined by inspection, was measured to the nearest half centimeter. A small portion of mammary gland tissue was fixed in 10 per cent formalin or FAA (10 parts formalin, 30 parts isopropanol, 5 parts acetic acid, 55 parts water), sectioned at 10 microns, and stained with hematoxylin and eosin. The development of glandular tissue subsequently was determined by projecting a randomly selected section about one-quarter of a square centimeter onto a sheet of paper on which 100 dots were arranged in a regular 10 by 10 grid; the number of dots falling within glandular areas was used as an index of the proportion of glandular tissue.

Ovaries.—The ovaries of each female were collected and fixed in 10 per cent formalin. The preserved ovaries were weighed to the nearest hundredth of a kilogram and serially sectioned at half a centimeter on a mechanical meat slicer. Each corpus luteum and corpus albicans revealed through sectioning was measured, to the nearest millimeter, across its greatest diameter and across its maximum diameter at right angles to the greatest diameter; and the two measurements were averaged. The maximum diameter of the largest Graafian follicle also was measured to the nearest millimeter.

Uterus.—The diameter of each uterine horn at approximately the middle was measured to the nearest half a centimeter. A sample of the uterine wall was fixed in 10 per cent formalin or FAA, sectioned at 10 microns, and stained with hematoxylin and eosin for histological study. In specimens in which a corpus luteum or recently ovulated follicle was present in either ovary, but there was no obvious indication of pregnancy, the entire uterus was removed from the carcass, each uterine horn slit open along its entire length, and the

surface of the endometrium carefully searched. Embryos and small fetuses were preserved in 10 per cent formalin and their length (crown to tip of tail, with body straightened) and sex recorded. Standard body measurements were made on near-term fetuses and the sex was noted.

Testes.—Each testis was weighed to the nearest tenth of a kilogram at the whaling station. A small sample (1 to 2 cubic centimeters) of the largest testis of each whale was taken for microscopic examination from the middle of the gonad about halfway between the surface and center and fixed in FAA, 10 per cent formalin, or Bouin's solution. Specimens were sectioned at seven microns and stained with hematoxylin and eosin. Mean diameter of the seminiferous tubules was calculated from measurements with an ocular micrometer of the greatest diameter and maximum diameter at right angles to the greatest diameter of 20 tubules cut in cross section. The presence or absence of fluid in the epididymides and deferent ducts was noted.

Penis.—The length of the extruded penis from the base on the ventral surface to the tip and the circumference at the base were measured to the nearest centimeter. These measurements could not be made on some males, especially immature individuals, because the penis was not completely extruded.

Stomach Contents.—The quantity of any food remains in the stomach was estimated and a sample preserved for identification.

Endoparasites.—The stomach, intestine, liver, kidneys, lungs, peribullary sinuses, and blubber were examined for endoparasites. The intestine was slit open at three or more randomly selected points, and in the years 1967, 1968, and 1969 the rectum also was opened for inspection. The tips of the liver lobes were examined for evidence of cirrhosis and were sliced to reveal the bile ducts. The kidneys were slit to expose the main urinary duct.

Vertebral Epiphyses.—The degree of fusion of the epiphyses of the anterior thoracic vertebrae to their centra was determined by chopping into the ends of the vertebrae with a hatchet to a depth of several centimeters.

Ear Plugs.—An attempt was made to collect at least one ear plug from each whale. In a few animals, however, the plug was so soft that it could not be successfully removed. Ear plugs were preserved in 10 per cent formalin. They were bisected longitudinally and gently polished on a whetstone, so that the growth layers could be counted.

Baleen Plates.—Several of the longest baleen plates were collected from each whale. Variations in thickness of the plates were recorded graphically by means of an apparatus similar to that used by Ruud (1940).

Field Observations

Observations on living gray whales were made from coastal lookout points, chartered whale catcher boats, and light aircraft.

Coastal Stations.—During the southward migration in 1967–68, 1968–69, and 1969–70, coastal lookout stations were established to count migrating whales. One was on Point Loma at San Diego, California (32°40′ N lat.), 130 meters above sea level (Rice, 1961) and is the site where previous counts were made (Gilmore, 1960*a*, 1960*b*; Rice, 1961). This station was manned for 52 days (27 December to 16 February) in 1967–68 and for 57 days (20 December to 14 February) in 1968–69. The second station was 2 km. S Yankee Point, Monterey Co., California (36°29′ N lat.), 23 meters above sea level and about 100 meters back from the shoreline. This was near the site where a partial count of migrating gray whales was made in 1966–67 (Adams, 1968). We manned this station for 49 days (18 December to 4 February) in 1967–68, 60 days (10 December to 7 February) in 1968–69, and 64 days (8 December to 9 February) in 1969–70.

Observations were made continuously from 0700 to 1700 hours (essentially sunrise to sunset) each day. At each station, two observers each worked a 5-hour shift; morning and afternoon shifts were alternated between the two observers. The number of whales, time of passage, estimated distance from shore, and direction of travel were recorded for each group sighted. Wind direction and force, cloud cover, precipitation, and fog were logged throughout the day.

Vessels.—Between 25 January and 9 February 1968, we ran a series of transect cruises between Point Loma and a position west of Tanner and Cortez Banks. A similar transect was run off Yankee Point on 18 January 1968. While the vessel was underway, a constant watch for gray whales and other marine mammals was maintained on the bridge. All whales sighted were approached closely enough to ensure positive identification and the number of whales in each pod, the direction of travel, and the position and time of sighting recorded.

Observations on gray whales also were made during many cruises conducted for marking rorquals (Balaenopteridae) and sperm whales (*Physeter catodon*). The area covered included the waters along the coast from Point Reyes, California (38° N lat.), south to Isla Clarion off Colima, Mexico (18° N lat.). The cruises, totaling 15 months, were made mostly between December and April from 1962 to 1969. The calving grounds in Laguna Ojo de Liebre, Laguna Guerrero Negro, Laguna San Ignacio, and Bahia Magdalena, Baja California, were briefly visited. Gray whales were sighted on 304 occasions, and a total of 1045 individuals was recorded.

Aircraft.—On 25 and 26 March 1969, an aerial survey was made in both directions along the entire coast beween San Francisco, California (38° N lat.), and Cape Flattery, Washington (48° N lat.). Two aircraft (a Cessna 177 and a Cessna 185) were used, each with two observers in addition to the pilot. The flight path was 0.3 to 2.0 kilometers offshore at an average altitude of 230 meters and air speed of 200 kilometers per hour. When pods of whales were sighted they were often circled at a lower altitude. Data were recorded on a tape recorder. Sighting conditions were optimum, with calm seas and clear skies, throughout the period of the survey.

SEASONAL MIGRATORY CYCLE

GRAY whales now occur only in the North Pacific Ocean and adjacent waters of the Arctic Ocean. The species also existed in the North Atlantic until a few centuries ago. There are presently two geographically isolated stocks (Fig. 1): an eastern Pacific stock, which migrates between Baja California and the Bering and Chukchi seas, and a western Pacific stock, which migrates between South Korea and the Okhotsk Sea. These may be designated the California stock and the Korean stock, respectively, on the basis of their breeding grounds.

California Stock

SUMMER GROUNDS.—From late May through October, gray whales occupy the shallow waters of the northern and western Bering Sea, the Chukchi Sea, and the western Beaufort Sea. They are common along the Koryak coast of Siberia from Cape Navarin to Glubokoi Inlet (Berzin and Rovnin, 1966). Farther to the southwest they are rare; a few have been seen as far as Kronotskiy Bay on the Kamchatka Peninsula (Tomilin, 1957) and the Kommandorskiye Islands (Barabash-Nikiforov, 1938; Grebnitskii, 1902). In the Gulf of Anadyr, these whales are abundant along the southwest shore from Cape Navarin to Tymna Lagoon; they have not been seen in the northwestern part of the gulf from the Anadyr Estuary to Cape Kresta (Berzin and Rovnin, 1966). Gray whales are also common along the northeastern shore of the Gulf of Anadyr, from Cape Retkon to Cape Chaplino (Berzin and Rovnin, 1966), around St. Lawrence Island (Ichihara, 1958), around the shores of the Chukotskiy Peninsula as far northwest as Cape Serdtse Kamen' (Nikulin, 1946), in Kotzebue Sound (Wilke and Fiscus, 1961), and in the Chukchi Sea (north as far as 69° N lat.—Nasu, 1960). A few go westward along the coast as far as Tynkurginpil'gyn Lagoon (Berzin and Rovnin, 1966), and northwestward through the pack ice as far as Wrangel Island (Sleptsov, 1955).

Along the Arctic coast of Alaska they are found regularly from Cape Thompson (Pike, 1962*a*) east to Point Barrow, and a few have

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been reported by Eskimos along the shores of the Beaufort Sea as far east as Barter Island (Maher, 1960). To the southeast, there are few records of gray whales. One was found stranded at Scammon Bay, south of the Yukon Delta, in September (Fay, *in* Pike, 1962*a*). There is only one published record of gray whales from the Pribilof Islands (Gilmore, 1960*b*), but several were seen around St. George Island in the summers of 1965 and 1968 by C. H. Fiscus, A. M. Johnson, and V. B. Scheffer (personal communication). Gray whale remains have been found on St. Matthew Island (Pike, 1962*a*), and C. H. Fiscus (personal communication) saw four gray whales in Sarichef Strait between St. Matthew Island and Hall Island on 3 August 1960.

Not all gray whales migrate to the Arctic in the summer. A few remain scattered along the west coast of North America. Pike and MacAskie (1969) reported several near Langara, Queen Charlotte Islands, British Columbia, in late August and early September of 1959 and 1960, and a young male stranded near Ucluelet, Vancouver Island, on 16 August 1966. Some were seen near Lapush, Washington, in June and July 1961 by C. Munsen (personal communication) and in July 1967 by the junior author. A few were seen near Kalaloch, Washington, in July 1968, by A. M. Johnson (personal communication). Fiscus (personal communication) saw one near Cannon Beach, Oregon, in July 1969. Gilmore (1960*a*) reported that a few regularly spend the summer in the vicinity of St. George Reef and Pelican Bay in northern California and southern Oregon. Whalers working off San Francisco occasionally see gray whales during the summer. L. Newton (personal communication), captain of the catcher boat "Lynnann," saw a few near the Farallon Islands, California, throughout the summer of 1964; they remained until late September or early October. K. C. Balcomb saw a small gray whale in Bahia Magdalena, Baja California, on 11 June 1965, during one of our whale marking cruises aboard the catcher boat "Sioux City."

The northern boundary of the known summer range of the gray whale corresponds closely with the southern edge of the zone of close pack ice during the period 1 to 15 September (U. S. Navy Hydrographic Office, 1958). Close pack ice may limit their movements. Scammon (1874) and Sleptsov (1955) have reported seeing

gray whales in broken pack ice. Gray whales do not arrive at Point Hope or at Barrow, Alaska, until most of the ice has gone out, long after the bowhead whales have arrived. As few observers experienced in identifying whales enter the close pack ice in ships or fly over it in the summer, the extent to which gray whales penetrate the pack ice is unknown. In the western Bering Sea, gray whales are confined to coastal waters, their seaward range being delimited by the edge of the Continental Shelf. They have never been found in the deep waters of the southwestern Bering Sea. Their feeding habits (see section on food and feeding) apparently restrict them to shallow water. Although most of the eastern Bering Sea is shallow, the scarcity of gray whales there is believed to be the result of a low biomass of benthos, 55 grams per square meter, compared with 200 to 900 grams per square meter in the northwestern region (Berzin and Rovnin, 1966; Neiman, 1963).

Migrations.—Pike (1962*a*) summarized all published information on the migration route of the California population and presented significant new data. There are few observations on southward-migrating whales in the northern part of their range. From October through January, they probably move down the eastern side of the Bering Sea, go through Unimak Pass, and then follow the coast to Baja California. A few go around Cabo San Lucas and cross to the eastern side of the Gulf of California. From late February to June, the northward migration of males and females without calves, which is much better documented, follows the reverse route.

Our observations during whale marking cruises off California and Baja California show that the majority of gray whales migrate within a few kilometers of shore when passing points, headlands, and sectors of coastline where the Continental Shelf is narrow and there are no off-lying islands. Many tend to take the most direct route, however, when crossing bights and indentations of the coastline. For example, many southbound whales, after passing Point Conception (34°27′ N lat.), head southeast through the Channel Islands, passing as much as 200 kilometers offshore from the mainland of southern California (Rice, 1965). Some gray whales make a similar offshore passage from about Punta Baja (29°57′ N lat.)

to Isla Cedros (28°22′ N lat.), Baja California, thus avoiding the long journey around the shores of Bahia Sebastian Vizcaino. Quantitative data on offshore migration are presented in the chapter on populations.

The route taken by females with calves during the spring migration is unknown. During this study, the catcher-boat crews saw only one female with a calf—near Point Reyes on 15 March 1969. From 1959 through 1967, we collected no gray whales later than 30 March, and during that time we thought females with calves moved north later in the season. Therefore, in 1968 we hunted gray whales until 25 April, 14 days after the last whale was taken, and had one boat searching exclusively for females with calves from 2 to 25 April. Each year from 1956 through 1968, the regular sperm whaling season opened on 1 April and the baleen whaling season opened on 1 May (1956–59) or 16 April (1960–68). During these years, the whalers never saw a gray whale accompanied by a calf. Shore-based whalers working from San Simeon, California, in the 1880's likewise told Townsend (1887) that they never encountered females with calves.

On whale marking cruises in 1965, 1966, 1967, and 1969, we traveled north during late February, March, and early April, by which time most females with calves had already left the calving lagoons. We put in at many points along the coast between Cabo San Lucas (23° N lat.), Baja California, and San Francisco (38° N lat.), California, but never encountered a female accompanied by a calf, although we saw many northward-migrating gray whales. During the transect cruises, we saw two females with calves on 10 February 1968 (at 32°48′ N and 118°08′ W, heading west-northwest near San Clemente Island). During the aerial surveys between San Francisco, California, and Cape Flattery, Washington, on 25 and 26 March 1969, no females with calves were identified among 816 gray whales sighted. Morejohn (1968) reported a female with a calf at Moss Landing, northeast of Monterey, California, on 2 May 1967.

Gray whales observed on migration are usually swimming steadily and continuously in a constant direction on a course parallel to the shore. They surface regularly about every 3 to 5 minutes to blow three to five times. When out of sight of land,

they usually travel in a straight line. General observations indicate that the usual swimming speed is about 7 to 9 kilometers per hour (4 to 5 knots). Wyrick (1954) followed four separate gray whales migrating south past San Diego, California, for a total of more than 5 hours; their average speed was 8.5 kilometers per hour (4.6 knots). Cummings *et al.* (1968) tracked nine lone whales (some in daytime, others at night), over distances less than 1.7 kilometers and found the average speed to be 10.2 kilometers per hour (5.5 knots).

There was no consistent hourly variation in the number of gray whales migrating south past the counting stations, contrary to the opinion of Ramsey (1968). This lack of variation indicates that gray whales, on the average, maintain a constant speed throughout daylight hours.

There are few observations to show how fast gray whales travel at night. Unlike sperm whales, baleen whales are rarely, if ever, seen resting at the surface. Since they must rise to the surface regularly every few minutes to breathe, they must continue to swim at least slowly during hours of darkness. In polar regions during the summer when daylight is continuous, baleen whales appear to remain active continuously.

Cummings *et al.* (1968) used an array of hydrophones mounted on the sea bottom off San Diego to track migrating gray whales. They reported the following: "Gray whales were soniferous day and night. One hundred twenty-four signals were recorded from at least 61 whales between 1800 and 0600 h, compared with 107 signals recorded from at least 157 whales between 0600 and 1800 h. All whales seen or heard at night apparently were migrating southward, and there was no evidence of the popular notion that gray whales characteristically stopped migrating at night to rest or to sleep."

The average speed of gray whales along their entire migration route, calculated from dates of peak passage at various points along the coast, is about 185 kilometers per day, or 7.7 kilometers per hour, on the southward migration and half as fast on the northward migration (Pike, 1962*a*). If their average speed during the 10 hours of daylight is 8.5 kilometers per hour, they cover 85 kilometers; to travel the remaining 100 kilometers during the 14

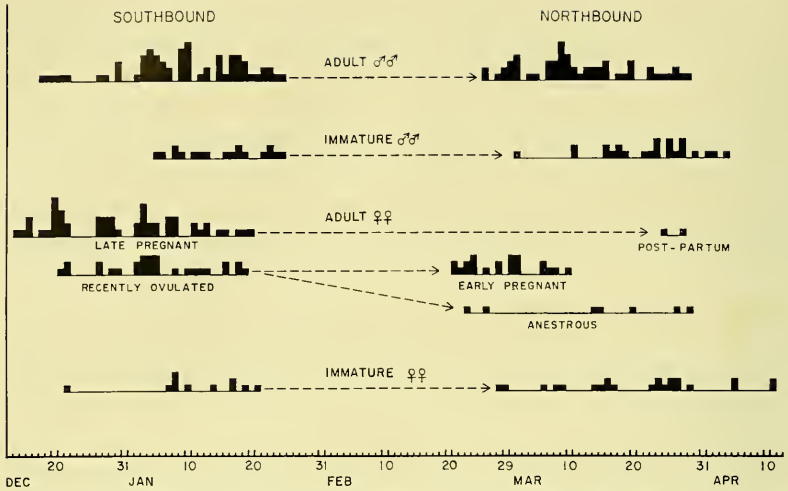

FIG. 2. Collection dates of gray whales, according to sex, age, and reproductive status. Each square represents one animal.

hours of darkness, they must average 7.1 kilometers per hour, or 92 per cent of their speed during daylight.

During migration, there is a partial temporal segregation of gray whales according to sex, age, and reproductive status. This is evident from Fig. 2 in which the collection date of each whale is plotted according to sex, maturity, and reproductive status. These data cannot be regarded as strictly representative, however, because the collecting effort was not the same throughout the season. It must be kept in mind also that the gunners doubtless tended to select the larger animals, even though we imposed no size limitations. This tends to bias the sample in favor of mature animals and females, especially those in late pregnancy. The mean and extreme dates of passage for each class (Table 1), however, should be fairly reliable.

In general, in both the southward and the northward migration, females migrate earlier than males and adults migrate earlier than sexually immature animals. The vanguard of the southward migration from mid-December to the first of January is composed predominantly of females carrying near-term fetuses. The late-pregnant females are followed by adult females that have recently

TABLE 1

MEAN PASSAGE DATES OF MIGRATING GRAY WHALES OFF CENTRAL CALIFORNIA (38° N LAT.) CLASSIFIED ACCORDING TO SEX, AGE, AND REPRODUCTIVE STATUS.

Category	Mean passage date		Days elapsed
	Southbound	Northbound	
Late pregnant (southbound); postpartum females (northbound)	31 December	26 March	85
Recently ovulated (southbound); early pregnant females (northbound)	5 January	28 February	54
Recently ovulated (southbound); metestrous and anestrous females (northbound)	5 January	14 March	68
Immature females	11 January	21 March	69
Adult males	9 January	12 March	62
Immature males	15 January	23 March	67

ovulated but have no macroscopically visible conceptus in the uterus; most of these females presumably weaned a calf a few months previously. The number of females in this class that were collected was fewer than expected. This probably resulted from gunner selection, although there also is a possibility that such females travel farther offshore. Next to pass are the immature females and, at about the same time, the adult males. Last to pass are the immature males.

During the northward migration, the first to pass are the newly pregnant females, which comprised the recently ovulated class of the preceding southward migration. Most of them pass within a limited period of about 15 days. We took them only between 21 February and 7 March in 1967, and between 26 February and 10 March in 1968. None was taken in 1969, when collecting did not commence until 2 March. The peak passage of adult males occurs more than 2 weeks later than that of the pregnant females. Adult males are followed by a few anestrous females that have failed to conceive. Immature whales of both sexes are the last to pass. Only two postpartum females were collected, both in late March. Neither was lactating; obviously their calves were stillborn or were lost shortly after birth.

Migrating gray whales travel singly or in pods of up to 16 individuals. In the course of the southward migration past Cali-

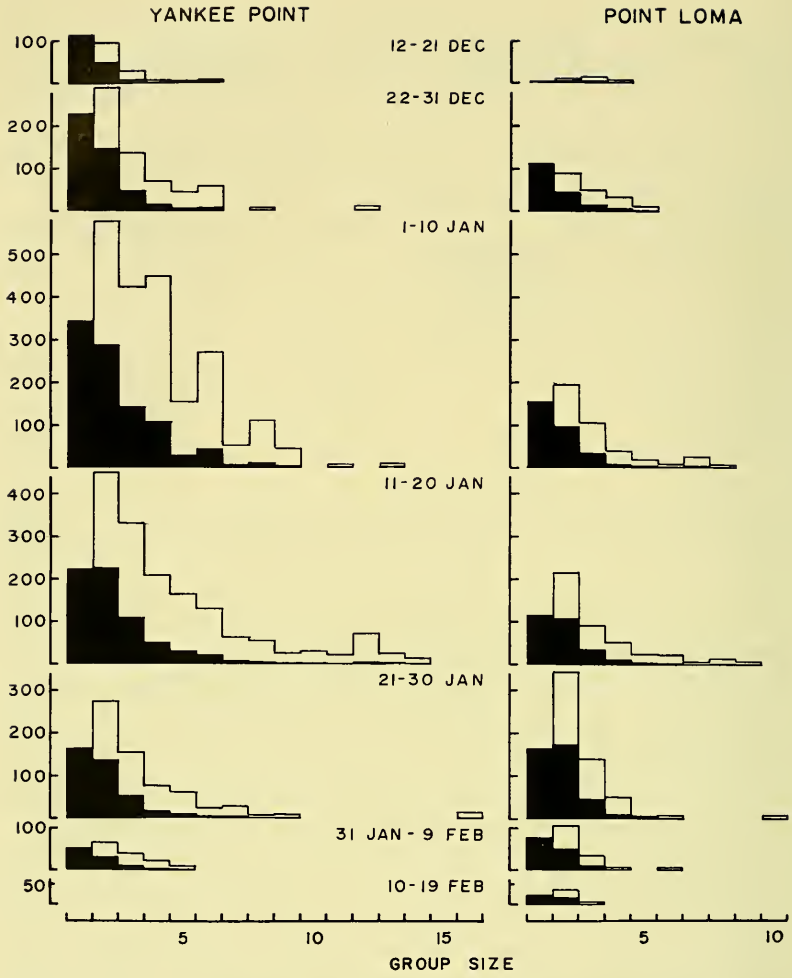

FIG. 3. Frequency distribution of group size of gray whales passing Yankee Point and Point Loma, by 10-day periods, during the southward migrations of 1967–68 and 1968–69. Solid bars indicate the number of groups, open bars the number of whales.

fornia, there are marked changes in the sizes of the groups (Fig. 3). During the early part of the migration, single whales (presumably mostly females carrying near-term fetuses) predominate, and almost no whales are in groups of more than six. During the

remainder of the migration, groups of two predominate. Most of the larger groups pass in the middle of the season, and towards the end of the season no groups contain more than five whales.

Winter Grounds.—In January and February most gray whales of the eastern Pacific population are in warm temperate or tropical waters on the west coast of Baja California and the southern Gulf of California. Our southernmost sighting was at Punta Mita, Bahia de Banderas, Jalisco (20°45′ N, 105°34′ W) on 17 February 1965. Gilmore (1960*a*) reported alleged sightings of gray whales at Isla Guadalupe and at Isla Clarion; we have seen none there nor anywhere else far off the coast of Mexico.

Most calves, as far as is known, are born in certain shallow lagoons. The six known calving areas, charted in detail by Gilmore (1960*a*), are as follows: *California and west coast of Baja California*—San Diego Bay (no longer occupied), Laguna Ojo de Liebre ("Scammon's Lagoon") and the adjacent Laguna Guerrero Negro, Laguna San Ignacio, and Bahia Magdalena and adjacent waters (including Bahia Almejas, Canal San Carlos, Estero Soledad, Estero Santo Domingo, Estero Las Animas); *eastern shore of Gulf of California*—open coast south of Yavaros, Sonora (see Gilmore *et al.*, 1967), and Bahia Reforma, Sinaloa.

Korean Stock

There is little information on the distribution of the Korean stock. No gray whales have been reported in recent years in either the Okhotsk Sea or the Sea of Japan, according to (personal communications) V. A. Arseniev and M. V. Ivashin of the All-Union Research Institute for Marine Fisheries and Oceanography, Moscow; H. Omura of the Whales Research Institute, Tokyo; and M. Nishiwaki of the Ocean Research Institute, Tokyo.

Summer Grounds.—Gray whales occupy, or at least formerly occupied, the northern Okhotsk Sea. They penetrated as far north as Penzhinskaya Bay (Krasheninnikov, 1755), and ranged southward as far as Akademii and Sakhalinskiy gulfs on the west (Sleptsov, 1955), and the mouth of the Kikhchik River on the east (Ditmar, 1890).

Migrations.—The migration route of the Korean stock of gray whales lay along the mainland coast of eastern Asia from Tatarskiy Strait to South Korea. Southbound whales passed Ulsan, South Korea, from late November to late January, and northbound whales passed there from the middle of March to the middle of May (Andrews, 1914). All the whales apparently passed through Tatarskiy Strait, as none was ever seen in La Perouse Strait between northern Hokkaido and southern Sakhalin (Mizue, 1951).

Winter Grounds.—The channels, inlets, and bays along the southern coast of South Korea are believed to have been the winter calving grounds of the western Pacific gray whales. According to Andrews (1914): "In November and December, when the females are taken, almost every individual will be found to be carrying young nearly ready for birth. As these would necessarily be delivered within two or three weeks after passing Ulsan, the birth must occur in the bays among the numerous islands at the extreme southern end of the peninsula. Indeed Captain H. G. Melsom, who has hunted gray whales for 15 years along the Korea coast, has often observed them in this vicinity, but because of the abundance of other and more valuable species, they are not killed at this time by the Japanese."

Atlantic Stocks

Subfossil gray whale bones have been found at five localities along the coast of northwestern Europe: Pentuan, Cornwall, and Torquay, Devonshire, England, on the English Channel; IJmuiden and Wieringermeer Polder in the Netherlands; and on the Island of Gräsö, Sweden, in the northern Baltic (van Deinse and Junge, 1937). The most recent bones are those from IJmuiden, which date from about A.D. 500. There are no historical records of gray whales in the eastern North Atlantic. The summer grounds of the eastern Atlantic gray whales probably were in the Baltic Sea, where *Ampelisca macrocephala* (the predominant food of the California stock in the Bering Sea) is abundant (Kanneworff, 1965). Their winter grounds were perhaps along the Atlantic or Mediterranean coasts of southwestern Europe or northwestern Africa.

Discussion and Conclusions

In their annual migrations between summer feeding grounds in Arctic waters and winter breeding grounds in subtropical waters, gray whales may travel more than 18,000 kilometers each year, a distance exceeding that traveled by any other baleen whale. This extensive migration, spanning 50 degrees of latitude, exposes them to a broad range of environmental conditions. Sea surface temperatures on the summer grounds range from about 8° centigrade down to 0° or slighly less in the pack ice. On the winter grounds, temperatures range from about 18° centigrade at the latitude of Laguna Ojo de Liebre to 22° off Cabo San Lucas. In midsummer most gray whales experience more than 22 hours of light each day, and those north of the Arctic Circle experience continuous daylight for several weeks. As the whales migrate southward, they are subjected to a rapidly decreasing photoperiod, which reaches a minimum of less than 8 hours in early December. Day length increases slowly during the remainder of the southward migration and while the whales are on the winter grounds, and then increases rapidly as the animals move north in the spring. The variable photoperiods to which the species is exposed may be an important proximate factor in regulating gonadal development.

There is no evidence to suggest that gray whales slow down at night while migrating southward. The length of their migration route, and their relatively slow swimming speed, makes it necessary for them to travel almost continuously at night as well as day.

The reasons for this long migration become apparent when the food habits of the gray whale are considered. In summer, the species requires areas of shallow water with an abundant benthos. In the North Pacific, large areas with such conditions are found only in parts of the Bering Sea and adjacent waters of the Arctic Ocean, and in the northern Okhotsk Sea. For almost half the year, the ice cover on these summer grounds cuts off the whales' major food supply and forces them to migrate.

Because they cannot feed much during the winter, it is necessary that they seek warmer waters to minimize energy requirements, particularly for the newborn calves. During the winter, the eastern North Pacific from California north is cold (less than 15° centigrade) and is subject to frequent storms with northwest winds that cause

heavy surf along the coast. The lagoons of Baja California are the nearest areas of warm, shallow, protected waters suitable for calving.

Females ready to bear a calf arrive on the winter grounds earlier and spend more time there than females that have recently mated. Apparently, calves must remain in warm protected waters until they have grown sufficiently to face the rigors of the long northward migration. The movements of females with calves after they leave the breeding lagoons are unknown. Unlike the other members of the population, they must travel farther offshore.

Pregnant females apparently are the first to arrive on the summer feeding grounds and spend more time there than lactating females. This is also true of fin whales, *Balaenoptera physalus* (Mackintosh, 1965), and humpback whales, *Megaptera novaeangliae* (Dawbin, 1966), and is no doubt related to the need of pregnant females to acquire more fat reserves (see discussion beyond of seasonal changes in nutritive condition).

FOOD AND FEEDING

Stomach Contents

SUMMER.—Few data are available on the stomach contents of gray whales killed on the summer grounds. Zenkovich (1934*a*, 1934*b*, 1937*c*) and Tomilin (1937) examined 104 and 54 stomachs, respectively, of whales taken in the Bering and Chukchi Seas from August to October. They did not publish quantitative data, but reported finding mostly gammaridean amphipods, of which were listed the following forms: Family Ampeliscidae—*Ampelisca macrocephala*; family Aoridae—*Lembos arcticus*; family Lysianassidae—*Anonyx nugax* and an unidentified species; family Haustoriidae—*Pontoporeia femorata*; family Eusiridae—*Eusirus* sp.; family Atylidae —*Atylus* sp.; family Gammaridae—unidentified species.

Ampelisca macrocephala predominated in the stomachs of whales killed in the Chukchi Sea and northern Bering Sea, whereas a species of Atylidae, apparently *Atylus carinatus*, predominated in those from along the coast between Natal'inskiy Bay and Cape Navarin. In addition to amphipods, several stomachs contained a few bottom-dwelling isopods, mysids (*Mysis oculata*), mollusks (*Buccinum* sp.), polychaetes (*Travisia forbesi*), and hydroids (Sertulariidae).

Pike (1962*a*) examined samples of the stomach contents of two gray whales killed by Eskimos off St. Lawrence Island in May and June. He found mostly the amphipods *Ampelisca macrocephala* and *A. eschrichti*, and a few *Anonyx nugax*; other items recorded were decapod crustaceans (including *Chionoecetes bairdi, Hyas coarcticus*, and *Liocyma fluctuosa*), cumaceans, polychaete (*Pectinaria* sp.) tubes, gastropods, and ascidians.

We examined a sample (collected by F. H. Fay) of the stomach contents of an immature female gray whale killed by Eskimos about 9 kilometers southwest of the village of Gambell, St. Lawrence Island, Alaska, in water about 30 meters deep. The sample of about 1 liter was a composite of random samples from several parts of the total contents of the stomach. More than 95 per cent of the sample consisted of gammaridean amphipods, ranging from less

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than 6 to more than 25 millimeters in length. A few other invertebrates were present. Following is a complete list of the species identified. Classification of amphipods at the level of family and genus follows Barnard (1969). The numbers of each species of amphipod identified are given in parentheses, but they do not necessarily represent the proportion of each species in the total sample.

Class Crustacea
- Order Amphipoda
  - Family Lysianassidae
    - *Anonyx* sp. (16)
    - *Hippomedon ?minusculus* (1)
    - *Hippomedon* cf. *abyssi* (4)
    - *Orchomene minuta* (12)
  - Family Phoxocephalidae
    - *Paraphoxus ?milleri* (3)
  - Family Ampeliscidae
    - *Ampelisca macrocephala* (*ca.* 85)
    - *Ampelisca* sp. (fragments)
  - Family Pleustidae
    - *Pleustes* sp. (2)
  - Family Oedicerotidae
    - *Acanthostepheia malmgreni* (6)
  - Family Atylidae
    - *Atylus bruggeni* (1)
  - Family Isaeidae
    - *Protomedeia grandimana* (1)
  - Family Ischyroceridae
    - *Ischyrocerus latipes* (1)
  - Family Podoceridae
    - *Dulichia* cf. *knipowitschi* (1)
- Order Cumacea
  - *Diastylis bidentata*

Class Polychaeta
- Unidentified tube

Class Holothuroidea
- Unidentified holothurian

Class Tunicata
- Order Ascidiacea
  - ? *Phallusia* sp.
- Order Thaliacea
  - ? Salps (attached to polychaete tube)

All of the organisms found in the stomachs of gray whales killed on the Arctic summer grounds are typically infaunal benthic species, that is, they burrow or live buried in the bottom sediments. *Ampelisca macrocephala*, the species most commonly eaten, is a large amphipod about 25 millimeters long. A study of its life history has been published by Kanneworff (1965). In the Bering and Chukchi Seas, *A. macrocephala* occurs mainly on sandy bottoms at depths of 5 to 300 meters (Gur'yanova, 1955).

Most of the amphipods in our sample were adult females, which are rarely found above the substratum during the day, although they form an appreciable part of the planktonic population at night; males alone tend to be pelagic during the day (E. L. Bousfield, personal communication).

In addition to food items, there was a considerable amount of fine gray sand or silt mixed with the stomach contents of the whale from St. Lawrence Island that we examined. Such extraneous material has also been recorded by other authors. Pike (1962*a*) found sand, silt, and bits of wood in the two samples he examined, and Zenkovich (1937*a*) found quantities of pebbles, as much as "2–3 pails," in many stomachs. Tomilin (1937) also reported finding silt, pebbles, and a large cobblestone, in addition to kelp leaves.

In northern California, Howell and Huey (1930) found a quantity of *Euphausia pacifica* in the baleen of a gray whale killed on 21 July 1926; they did not examine the stomach. This euphausiid is the chief food of rorquals in the waters off California.

The occasional infestation of gray whales with parasites that probably require fishes as intermediate hosts (see discussion of parasites in a later chapter) suggests that they sometimes eat fish.

During Migration.—Our data confirm the reports by other authors (Andrews, 1914; Pike, 1962*a*; Scammon, 1874) that the stomachs of migrating gray whales are almost invariably empty. Stomachs of all 180 southbound migrants and those of 134 of the 136 northbound migrants examined contained no traces of food, and the intestines contained only small amounts of a thick greenish fluid, apparently bile and mucosal secretions. One of the two specimens containing food was an anestrous female taken on 20 March 1964. Its stomach contained about 20 liters of the zoea stage larvae of the littoral crab *Pachycheles rudis* (Anomura,

Porcellanidae) and a few brachyuran zoeae, probably of the genus *Fabia* (Brachyura, Pinnotheridae). The other animal was an immature female taken on 11 April 1968. Its stomach contained about 50 liters of the zoea stage larvae of a pinnotherid crab, probably the same species found in the preceding specimen, and a few scattered porcellanid zoeae, which were in too poor condition to identify further.

Migrating whales sometimes have gravel and other miscellaneous items in their stomachs. We found almost a kilogram of gravel in the stomach of one southbound, recently-ovulated female; mixed with the gravel were numerous ascidian tunics, fragments of hydroid stems and polychaete worm tubes, a few gastropod opercula, one pelecypod shell, and two tiny fragments of waterlogged wood. A late pregnant female had several liters of hydroid stems and a few polychaete tubes in her stomach, but no gravel or sand. The stomachs of two immature males collected during the northward migration each contained about 10 kilograms of gravel. The stomach of an early pregnant female contained about 100 kilograms of gravel in which were a few polychaete tubes, hydroid stems, and a small bit of waterlogged wood. A northbound immature female contained about 50 kilograms of sand and silt. The stomachs of several other animals contained traces of sand and gravel. Andrews (1914) found pebbles in the stomachs of two southbound migrants taken off Korea. Gravel and sand are probably ingested accidentally while the whale is feeding.

Winter.—Scammon (1874) appears to have been the only person to examine the stomachs of animals taken in the calving lagoons. He examined "several" and found no food—only a small quantity of vegetable matter that was no doubt accidentally ingested.

According to Matthews (1932), Norwegian whalers found gray whales feeding on the "red crab," *Pleuroncodes planipes* (Anomura, Galatheidae), at Bahia Magdalena, Baja California, in 1926. He did not indicate whether this was ascertained by actual examination of stomachs. The red crab exists in both a benthic and pelagic phase (Boyd, 1967) and at times is extremely abundant off the western coast of central and southern Baja California. We found red crabs so abundant in Bahia Magdalena on the night of 6 February 1965 that they formed a continuous, tightly packed layer

on the surface, evidently attracted by the lights of our anchored vessel. On 1 March 1967, we passed through many dense shoals of these crabs, each a few meters wide and up to half a kilometer long or longer, just inside the 180-meter isobath about 45 km. SW Punta Abreojos. However, we never saw gray whales that appeared to be feeding on red crabs. *Pleuroncodes* apparently does not occur in Laguna Ojo de Liebre. According to Matthews (1932), Norwegian whalers noticed that the blubber oil obtained from "sei" whales (*Balaenoptera borealis* or *B. edeni*) on the Mexican coast was yellowish; he suggested that this was due to their feeding on *Pleuroncodes*. We have found that the blubber of gray whales is often yellow or orange during both the southward and northward migrations. A similar variation in blubber color was noted by Andrews (1914) in northbound Korean whales and by Zenkovich (1934*a*) in summer-taken specimens from the Bering Sea.

There is only one report on the stomach contents of gray whales on or near the wintering grounds in the western Pacific (Mizue, 1951). Two individuals killed in the northern waters of the Yellow Sea in May 1922 contained *Nephrops thomsoni*, a small benthic anomuran decapod similar to *Pleuroncodes*. These whales were taken unusually late in the spring and probably somewhat outside the normal range.

Seasonal Changes in Nutritive Condition

During southward migration, gray whales are fat, whereas during northward migration they are much thinner. Quantitative information on nutritive condition is provided by body weight, blubber thickness, and oil yield.

Body Weight.—We calculated and compared body weights of gray whales on southward and northward migrations, and attempted to estimate metabolic rate to determine if the difference between the two periods is sufficient to account for energy requirements in winter.

Weights and lengths of nine gray whales are given in Table 2. To calculate weights of other whales that could not be weighed, we used the formula $W = aLG^2$, where W = weight in kilograms, L = length in meters, and G = maximum girth in meters. The

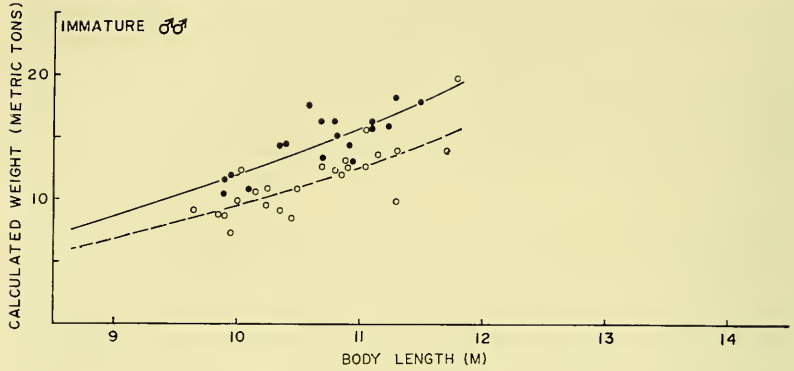

Fig. 4. Comparison of calculated weights of immature male gray whales during the southward and northward migrations. Solid circles and unbroken line indicate southbound migrants; open circles and broken line indicate northbound migrants.

value of *a* was derived from the seven gray whales of known weight, length, and girth (Table 2); this ranged from 32 to 44. The limited data suggest that *a* and body length are not correlated. This lack of correlation is not unexpected, as there is virtually no change

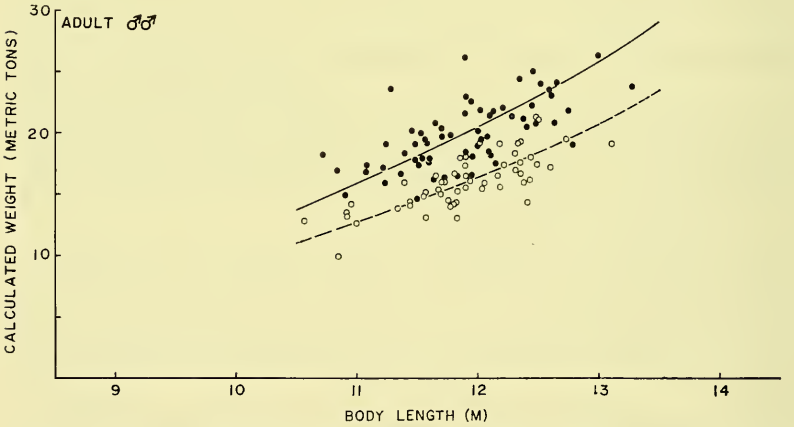

Fig. 5. Comparison of calculated weights of adult male gray whales during the southward and northward migrations. Solid circles and unbroken line represent southbound migrants; open circles and broken line represent northbound migrants.

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TABLE 2

WEIGHTS AND MEASUREMENTS OF NINE GRAY WHALES. UNLESS OTHERWISE NOTED SPECIMENS WERE COLLECTED IN PRESENT STUDY.

Sex	Age	Date	Body length (meters)	Girth (meters)	Weight[1]		Value of a^5
					Kilograms	Pounds	
♀	Fetus	20 January 1968	4.75	2.15	(409)	901	41
?[2]	Immature	10 January 1961	8.53	—	(6,632)	14,620	—
♂	Immature	30 March 1962	9.65	5.00	(8,808)	19,400	36
♂	Immature	28 March 1962	9.90	4.80	(8,876)	19,550	39
♂	Adult	29 March 1962	11.72	6.00	(15,686)	34,550	37
♂	Adult	27 March 1962	12.40	5.50	(16,594)	36,550	44
♀	Adult (pregnant)	23 February 1959	12.70	—	(16,360)	36,000	—
♀[3]	Adult (pregnant)	19 August 1936	13.35	8.48[4]	31,466	(69,380)	33
♀	Adult (pregnant)	14 December 1966	13.55	8.80	(33,846)	74,550	32

[1] Converted values in parentheses.
[2] Data from Gilmore (1961); originally recorded as 28 feet.
[3] Data from Zenkovich (1937*b*).
[4] Greatest height given as 270 centimeters; girth estimated as $\pi \times 2.70$ meters.
[5] See text for explanation.

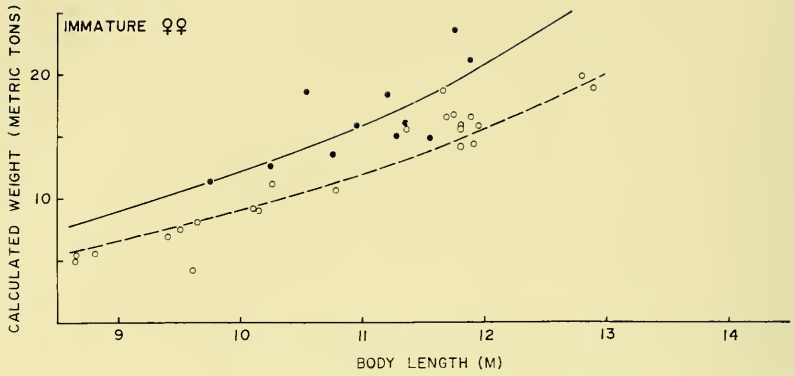

Fig. 6. Comparison of calculated weights of immature female gray whales during the southward and northward migrations. Solid circles and unbroken line indicate southbound migrants; open circles and broken line indicate northbound migrants.

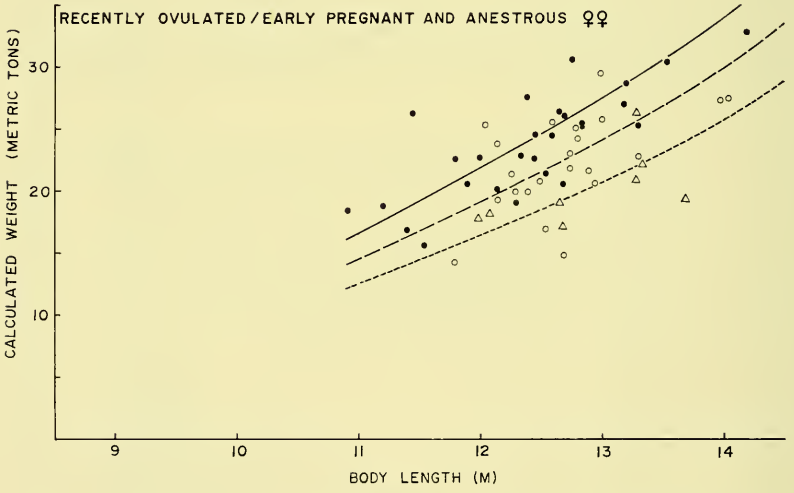

Fig. 7. Comparison of calculated weights of recently ovulated female gray whales during the southward migration and early pregnant and anestrous females during the northward migration. Symbols are as follows: solid circles and unbroken line, southbound migrants; open circles and long-dashed line, early pregnant northbound migrants; triangles and short-dashed line, anestrous northbound migrants.

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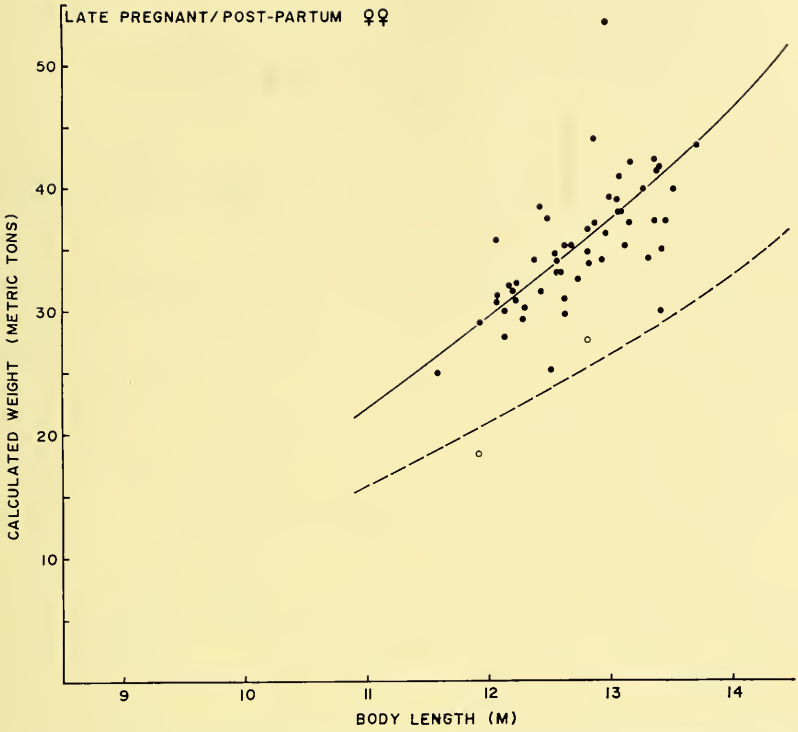

FIG. 8. Comparison of calculated weights of late pregnant female gray whales during the southward migration and postpartum females during the northward migration. Solid circles and unbroken line indicate southbound migrants; open circles and broken line indicate northbound migrants.

in body proportions with increasing length. We have used the mean value of 38. Estimates of percentage weight loss are independent of the value of a used.

The calculated weights of all whales (except for seven for which there were no comparable girth measurements) classified according to sex, age, and reproductive status, are plotted against body length in Figs. 4 to 8. Each class of southbound migrants is compared with the corresponding class of northbound migrants. Within each class, weight was closely correlated with length to the third power (in other words, there was no change in relative girth with increase in length), so we calculated mean weight-length curves for each

class with the equation $W = bL^3$. The value of b was calculated from the formula

$$b = \frac{\Sigma(G/L)^2}{N} a.$$

The mean absolute weights of whales of any given length during their southward and northward migrations may thus be compared. Their relative weights are simply a function of G^2.

The total weight loss of gray whales between the southward and northward migrations varied from 11 to 29 per cent and was correlated with elapsed time (Table 3). Weight loss per day varied from 0.21 to 0.37 per cent. Weight lost by postpartum females is, of course, not entirely attributable to metabolism. The fetus and fetal membranes and fluids probably account for about 2000 kilograms. The nutritive condition and energy requirements of pregnant and postpartum females are discussed beyond.

To determine if the observed weight loss is sufficient to account for energy requirements during the 54 to 85 days elapsing between the southward and northward migrations past San Francisco, it was necessary to estimate the metabolic rate. For simplicity, we have estimated the metabolic rate of a near-average gray whale weighing 20 metric tons on the basis of oxygen consumption and have assumed that the number of kilocalories per day per kilogram of body weight expended is the same for all whales regardless of body length. This assumption is open to question, but more data are required before more refined estimates of metabolic rate can be made.

No data are available on the lung volume of gray whales. As the relative size and shape of the lungs are similar to those of fin whales, we have used Scholander's (1940) measurements of 800, 1500, and 2000 liters for the lung capacity of three fin whales 15.2, 20.7, and 22.0 meters long, respectively, as a basis for estimating a value for the gray whale. His estimates of the body weights of these whales were too high, so we used Ash's (1952) formula to recalculate the weights as 20, 49, and 58 metric tons, respectively. The mean lung capacity in liters is thus equal to 3.5 per cent of the body weight in kilograms. A 20-ton whale would, therefore, have a lung capacity of 20,000 by 0.035, or 700 liters. The volume

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TABLE 3

WEIGHT LOSS OF GRAY WHALES BETWEEN SOUTHWARD MIGRATION (SM) AND NORTHWARD MIGRATION (NM).

Age, sex, and reproductive status	Number		Value of b[1] (mean ± SE)		Total weight loss (per cent)	Mean number of days elapsed	Mean weight loss per day (per cent)
	SM	NM	SM	NM			
Immature (males)	18	25	11.84 ± 0.26	9.47 ± 0.23	20.0	67	0.30
Adult (males)	63	54	11.83 ± 0.17	9.51 ± 0.11	19.6	62	0.32
Immature (females)	11	23	12.09 ± 0.57	9.03 ± 0.29	25.3	69	0.37
Adult (females)							
Recently ovulated (SM); early pregnant (NM)	27	22	12.43 ± 0.30	11.01 ± 0.42	11.4	54	0.21
Recently ovulated (SM); anestrous (NM)	27	8	12.43 ± 0.30	9.44 ± 0.40	24.1	68	0.35
Late pregnant (SM); postpartum (NM)	54	2	16.80 ± 0.27	11.95 ± 1.25	28.9	85	0.34

[1] See text for explanation.

of tidal air may be estimated at 80 per cent, as Irving *et al.* (1941) found in *Tursiops truncatus,* giving an estimate of 560 liters per breath. Oxygen utilization may be estimated at 10 per cent of tidal volume, based on *Tursiops* (Irving *et al.,* 1941), giving an estimate of 56 liters of oxygen per breath. As a gray whale breathes about once a minute, it uses an estimated 80,640 liters of oxygen per day, or 0.17 cubic centimeters per gram per hour. Since 1.99 liters of oxygen are required to oxidize 1 gram of fat (Bishop, 1950), 80,640 liters is sufficient to oxidize 41 kilograms or 0.20 per cent of the animal's body weight per day.

Oxidation of 1 gram of fat produces 9.54 kilocalories (Bishop, 1950), so the whale will produce about 3.8 by 10^5 kilocalories per day or 19 kilocalories per kilogram per day. This estimate of the metabolic rate is lower, on the basis of kilocalories per kilogram of body weight, than that of smaller mammals, but lies above Benedict's (1938) "mouse-to-elephant" curve. His curve gives a value of 70 times $20{,}000^{0.75}$, or about 1.2 times 10^5 kilocalories per day for a 20-ton animal. It should be noted, however, that our estimate cannot be considered a basal rate, because it is based on the respiration rate of an actively swimming animal. In some other mammals, the energy expended over a 24-hour period ranges between 1.3 and 4.0 times the basal rate, and for animals performing a moderate amount of work the average is approximately three times the basal rate (Brody, 1945). On this basis, the metabolic rates of large whales do not appear to be far above the "mouse-to-elephant" curve (see Kanwisher and Sundnes, 1966).

Blubber Thickness.—The thickness of the blubber has long been about the only measurement that has been used as an indicator of the nutritive condition of large whales (Slijper, 1954). Blubber thickness of gray whales was not correlated with body length, so we have used absolute measurements in our analysis. All sex and age classes of gray whales showed a slight decrease in blubber thickness between the southward and northward migration (Table 4), but this decrease was not statistically significant ($P > .05$) for any class.

Blubber thickness is less sensitive than girth as an indicator of the nutritive condition of gray whales. The reduction of girth reduces body surface area, and thus tends to make the blubber

TABLE 4

COMPARISONS OF BLUBBER THICKNESS OF GRAY WHALES DURING MIGRATION PERIODS.

Age, sex, and reproductive status	Number	Blubber thickness (cm)	
		Mean ± SE	Range
Immature males			
Southward	17	12.8 ± 0.3	10.5–15.0
Northward	25	12.6 ± 0.3	9.5–16.0
Adult males			
Southward	66	13.5 ± 0.2	9.5–17.5
Northward	44	12.8 ± 0.2	10.5–16.0
Immature females			
Southward	11	14.4 ± 0.4	12.5–16.5
Northward	23	12.8 ± 0.4	8.0–17.0
Adult females			
Southward (recently ovulated)	27	15.7 ± 0.4	10.5–20.0
Northward (early pregnant)	22	15.2 ± 0.4	10.0–18.5
Northward (anestrous)	8	13.3 ± 1.1	9.5–19.0
Southward (late pregnant)	53	15.7 ± 0.2	12.5–19.0
Northward (postpartum)	2	14.5	10.0–19.0

thicker. It was apparent to us while examining the viscera of southbound and northbound migrants that weight loss is due more to utilization of body fat than to utilization of blubber.

OIL YIELD.—The oil yield of the carcass is probably the most reliable indicator of nutritive condition, but such data are not available for individual gray whales. The mean estimated body weight and mean yields of oil, meal, and meat from southbound whales were two and one-half to three times those of northbound animals (Table 5). The southbound sample consisted mostly of adult females carrying near-term fetuses; the northbound sample consisted mostly of males, and included many immature animals. The cubic mean length of the southbound whales was 12.62 meters, whereas that of the northbound animals was 11.23 meters. Quantities of each product were also affected by the relative amount of meat salvaged from each carcass. The remainder of each carcass was rendered for oil and meal. The difference between calculated body weight and total weight of oil, meal, and meat may be attributed to water loss during rendering of the oil and drying of the meal. Inasmuch as the samples are heterogeneous as regards

TABLE 5

MEAN WEIGHTS OF OIL, MEAL, AND MEAT PRODUCED FROM GRAY WHALES TAKEN IN SOUTHWARD AND NORTHWARD MIGRATIONS. MEAN CALCULATED BODY WEIGHT OF 26 SOUTHBOUND WHALES WAS 31,662 KILOGRAMS AND THAT OF THE 26 NORTHBOUND WHALES WAS 12,861 KILOGRAMS.

	Southward migration		Northward migration	
Products	Kilograms	Per cent	Kilograms	Per cent
Oil	7,559	39.6	2,496	38.1
Meal	6,834	35.8	2,520	38.5
Meat	4,689	24.6	1,533	23.4
Total	19,082	100.0	6,549	100.0

sex, age, and reproductive status, they are not directly comparable, but they do show the great difference in body weight between southbound and northbound migrants. The ratio of oil to meal also indicates a moderate decrease in relative oil yield between the southward and northward migrations.

Discussion and Conclusions

The predominance of gammaridean amphipods, especially *Ampelisca macrocephala*, among stomach contents indicates that gray whales, unlike other baleen whales, are primarily, if not exclusively, bottom feeders. The poor representation of polychaete worms and mollusks, which are usually dominant in the infauna, suggests that gray whales are selective feeders. Perhaps they stir up the bottom sediments with their snouts, then filter the turbid water immediately above the bottom from which the heavier mollusks have settled out. The worms presumably retreat deep into their tubes and burrows, whereas the amphipods, freely swimming, are trapped in the baleen plates. The occurrence of sand, silt, and gravel in the stomachs provides further evidence that gray whales feed on the bottom. In the Chukchi Sea, several observers (Pike, 1962*a*; Scammon, 1874; Wilke and Fiscus, 1961) have reported seeing gray whales, presumably feeding, surfacing with muddy snouts. Greater wear of the baleen on the right side suggests that gray whales swim on their right side while feeding (Kasuya and Rice, 1970). Fin whales (Gunther, 1949), Bryde's whales, *Balaenoptera edeni* (Rice, field notes), and humpback whales (Andrews, 1909)

swim on their sides when feeding near the surface. Swimming on their side permits whales to turn more easily in the horizontal plane.

While migrating, gray whales apparently rarely attempt to feed, at least along the southern sector of their migration route. What little evidence is available also indicates that gray whales seldom, if ever, feed while on the winter grounds. A calculated weight loss of 0.21 to 0.37 per cent of body weight per day between the southward and northward migration past San Francisco exceeds the hypothetical value of 0.20 per cent per day based upon their estimated metabolic requirements. Thus, there is no reason to assume that gray whales must feed while on the winter grounds. This conclusion may not apply to females with calves, however, as we have no data for them.

AGE AND GROWTH

Age Determination

No gray whales of known age have been studied. Age must be deduced from indirect evidence and by analogy with other species of baleen whales. Jonsgård (1969) reviewed methods of determining the ages of cetaceans. Three criteria appeared promising for determination of age in gray whales. These are the number of growth layers in the ear plugs, corpora albicantia in the ovaries, and growth zones in the baleen plates.

Ear Plugs.—In balaenopterid whales, the number of growth layers in the ear plug is generally considered to be the most useful indicator of age (Purves, 1955; Laws and Purves, 1956). Each layer consists of one light and one dark lamina. There has been controversy, however, over the correlation between number of growth layers and absolute age. Data on ear plugs collected from fin whales marked more than 25 years previously, and several independent lines of indirect evidence, support the hypothesis that only about one growth layer is formed each year, at least in sexually mature fin whales (Ohsumi, 1964*a*). Ichihara (1966) provided evidence suggesting that in immature fin whales the rate of accumulation of ear plug laminae is irregular, varying from one to two annually, with a mean of one and one-half. Roe (1967*a*, 1967*b*), however, on the basis of histological examination of the ear plugs of fin whales collected in all months of the year, concluded that one growth layer is produced each year in both immature and adult whales of both sexes. He found that the light laminae are formed in summer and the dark laminae in winter. He also noted that the ear plugs of immature whales usually have minor laminae similar to but much thinner than the normal laminae; their significance is obscure, but he concluded that they should not be included in lamina counts for age determination.

Ear plugs of gray whales (Figs. 9–11) are soft, especially in the smaller animals, and difficult to remove without distortion or breakage. Some of the plugs have a fibrous, columnar, or amorphous

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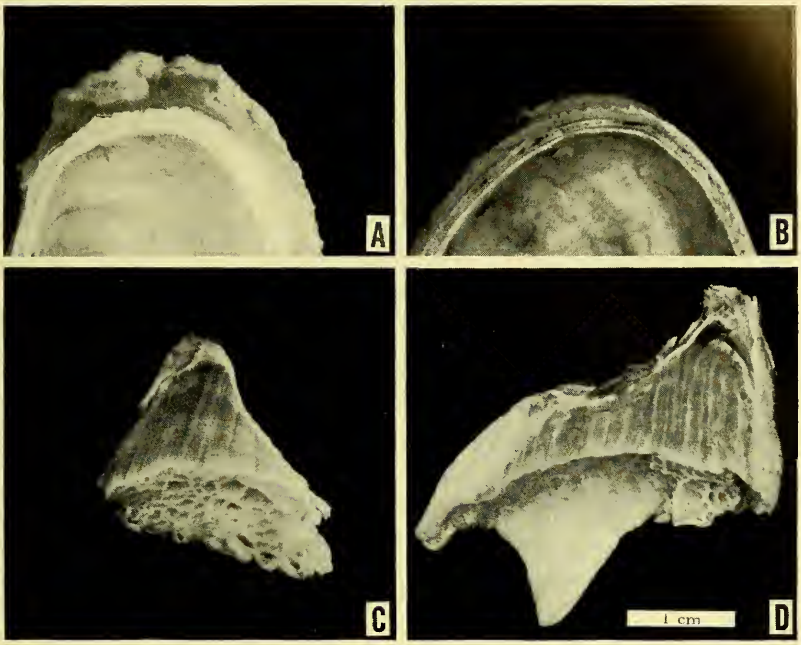

FIG. 9. Ear plugs of immature gray whales bisected longitudinally. A, 9.8-meter male, estimated age one year (attached to the "glove finger" of the tympanic membrane); B, 8.6-meter female, estimated age one year (attached to "glove finger"); C, 10.1-meter male with three growth layers; D, 11.3-meter female with six growth layers. All plugs are to same scale.

structure in which no laminae can be discerned. In the remaining plugs, laminae are vaguely to moderately well defined. Readable ear plugs were obtained from only 100 (60 per cent) of 166 males and 68 (45 per cent) of 150 females. On the better plugs, repeated counts of the laminae were consistent to within plus or minus 10 per cent of the total count. Males more often show regular laminae than do females, presumably because the annual physiological rhythm of females is modified by their longer and more irregular reproductive cycle.

The ear plug laminae are broad and poorly defined in immature whales but narrow and more sharply defined in adults. In many plugs from mature gray whales, the laminae are clear in the basal portion but indistinct or absent in the distal portion. This dif-

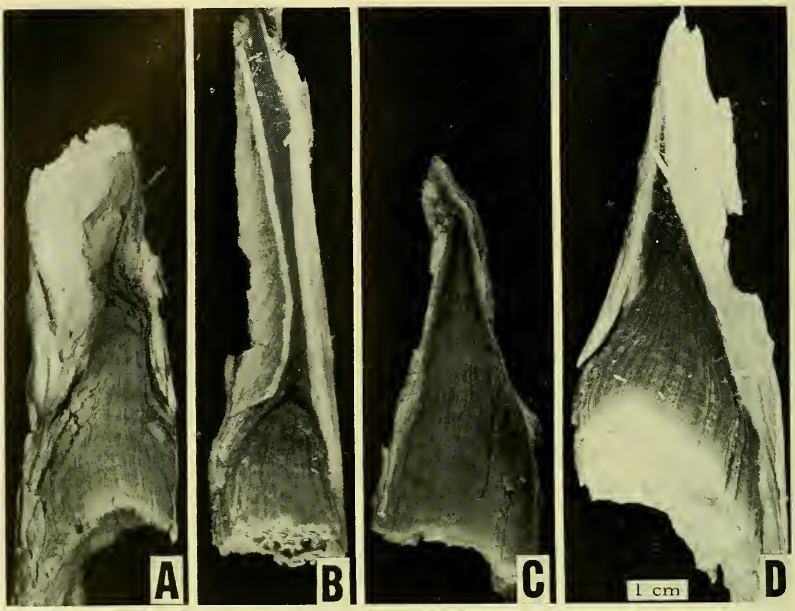

FIG. 10. Ear plugs of adult gray whales bisected longitudinally. A, 11.7-meter male with 11 growth layers; B, 11.4-meter female with 14 growth layers; C, 12.8-meter female with 18 growth layers; D, 12.3-meter male with 21 growth layers. All plugs are to same scale.

ference in the two regions suggests that the laminae laid down during immaturity may disappear as the plug grows. Another possible explanation—that some animals do not begin to produce clear laminae until they attain sexual maturity—appears unlikely, because the proportion of readable plugs was higher in immature than in mature whales (65 compared to 59 per cent in males and 56 compared to 42 per cent in females).

We found no ear plugs in several near-term fetuses that we dissected, and found no individuals with only one growth layer in the ear plugs. The smallest animals collected, 8.63 to 10.34 meters long, had two growth layers. We assumed that most of these animals were yearlings, and that the first layer forms during the nursing period and the second in late summer after weaning. As a working hypothesis, we assumed that each subsequent growth layer represented one year of growth in both immature and mature whales

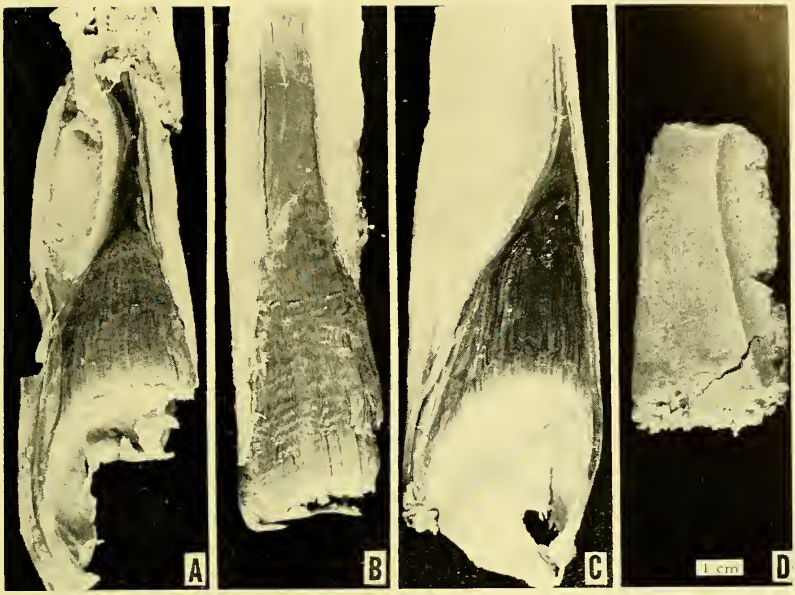

FIG. 11. Ear plugs of adult gray whales. A, 11.7-meter male with 23 growth layers; B, 12.5-meter female with 24 growth layers; C, 12.5-meter male with 40 growth layers; D, 11.7-meter male with amorphous plug showing no growth layers. All plugs are to same scale.

This interpretation is consistent with our estimate of the rate of accumulation of corpora albicantia in the ovaries (see discussion of reproductive cycle beyond). As it appears that two layers are formed the first year, the age of a whale in years should be one less than the number of growth layers in its ear plug. If, as suggested above, the earlier layers disappear in older animals, the count of growth layers provides only a minimum estimate of age.

OVARIES.—As the ovulation rate appears to be regular at about 0.50 per year, and the corpora albicantia remain permanently visible in the ovaries, the number of corpora in the ovaries provides a reliable estimate of the number of years elapsed since a female attained puberty. The mean age at puberty appears to be about 8 years (see below). Therefore, the age of a recently ovulated or early pregnant female is about twice the number of corpora (including

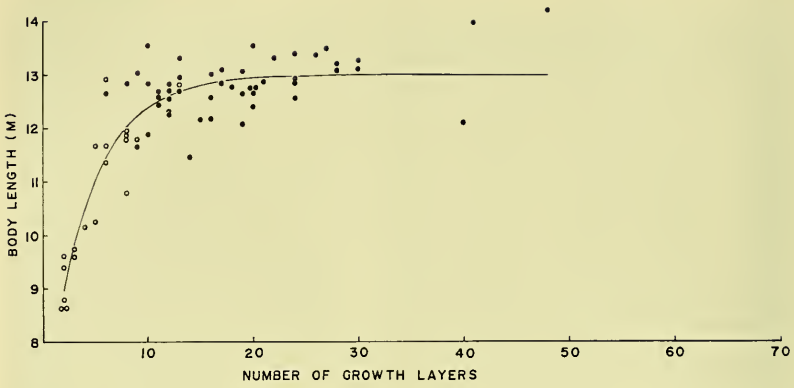

FIG. 12. Body length in relation to number of growth layers in ear plugs of female gray whales (open circles, immature females; solid circles, adult females; line, von Bertalanffy growth curve).

the corpus luteum) in her ovaries plus 6 years, and that of a late pregnant or postpartum female twice the number of corpora plus 7 years.

BALEEN PLATES.—Ruud (1940, 1945) found that the growth of baleen plates of blue (*Balaenoptera musculus*), sei (*B. borealis*), and fin whales is characterized by seasonal changes in thickness and that the pattern of variation in thickness can be used to estimate the age of the whales (see van Utrecht-Cock, 1965). Because of constant wear, there is rarely more than 5 or 6 years of growth present in a baleen plate. Thus this method is useful only for young whales.

Baleen plates of most gray whales show moderately well-defined "steps," or growth zones, each of which presumably represents one year of growth. None of the baleen plates we examined showed more than four growth zones, regardless of the age of the whale as estimated from the ear plugs. The number of growth zones in the baleen plates of most whales was less than the number of growth layers in the ear plug, and in no specimen was it greater. It thus appears that wear on the baleen plates of the gray whale is more rapid than in other baleen whales, probably because of greater abrasion resulting from bottom-feeding habits.

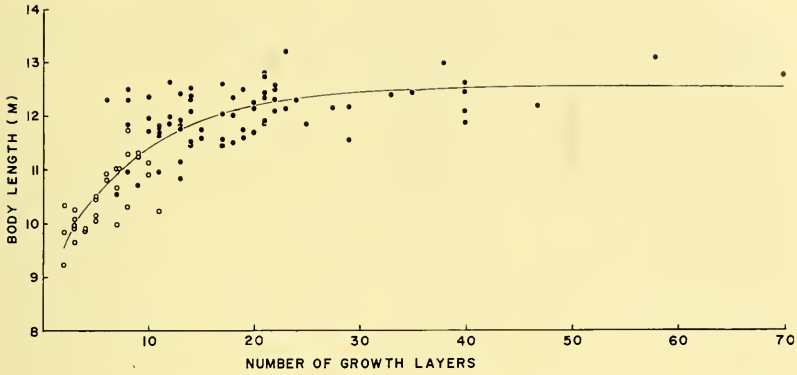

FIG. 13. Body length in relation to number of growth layers in ear plugs of male gray whales (open circles, immature males; solid circles, adult males; line, von Bertalanffy growth curve).

Growth

The external morphology and osteology of the gray whale have been described in detail by Andrews (1914), Zenkovich (1934*a*), and Tomilin (1957). Further data on growth in length, ontogenetic changes in body proportions, and sexual dimorphism were obtained in this study.

LENGTH.—Body lengths of males and females one year old and older have been plotted against the number of growth layers in the ear plugs in Figs. 12 and 13. Growth curves for each sex were calculated by using the von Bertalanffy equation (von Bertalanffy, 1938; Beverton and Holt, 1957) as follows: $l_t = L_\infty [1 - e^{-K(t-t_0)}]$, where l = body length in meters, L_∞ = asymptotic body length, K = rate at which length approaches the asymptote, and t = time in years. The results are given below (mean and standard deviation).

Females		Males	
L_∞	$= 12.97 \pm 0.11$	L_∞	$= 12.43 \pm 0.12$
K	$= 0.246 \pm 0.035$	K	$= 0.141 \pm 0.021$
t_0	$= -2.842 \pm 0.772$	t_0	$= -8.346 \pm 1.721$

It should be emphasized that because of the small sample sizes and the difficulty of reading ear plugs these curves are not com-

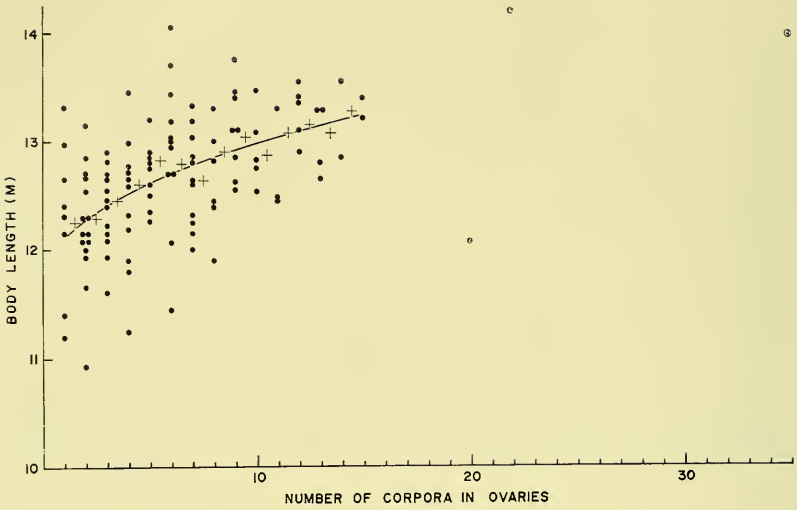

Fig. 14. Body length in relation to number of corpora albicantia and corpora lutea in ovaries of adult female gray whales. Crosses are running means of two; growth curve fitted by eye to mean values.

pletely reliable. The samples of the younger age groups are biased in favor of the larger individuals. Furthermore, possible disappearance of some ear plug laminae in older animals may have resulted in the estimated mean length at any given age being greater than the true mean.

In Fig. 14, the body length of adult females has been plotted against the number of corpora in the ovaries and a curve fitted by eye to the running means of two. This curve is probably a more accurate representation of the growth characteristics of adult females than the von Bertalanffy curve.

From a mean length at birth in January of about 4.9 meters, calves grow to a mean length of about 8.5 meters at weaning in August and to 9.3 meters by the following winter. With this first annual increment of 90 per cent of neonatal size, the females attain 66 per cent of their ultimate body length and the males 72 per cent. The growth rate drops to 7 per cent during the second year and continues to decline in subsequent years, but growth continues until at least about 30 years of age.

TABLE 6

BODY PROPORTIONS (EXPRESSED AS PERCENTAGE OF TOTAL BODY LENGTH) OF NEAR-TERM FETUSES AND POSTNATAL GRAY WHALES. SEE TEXT FOR DESCRIPTION OF MEASUREMENTS.

	Females				Males			
	Fetuses		Postnatals		Fetuses		Postnatals	
Measurement	*N*	Mean ± SD	*N*	Mean ± SD	*N*	Mean ± SD	*N*	Mean ± SD
Head length	17	22.4 ± 1.1	136	23.2 ± 1.0	25	22.5 ± 1.3	155	23.3 ± 0.9
Tail length	25	28.4 ± 2.4	147	30.3 ± 1.6	30	28.2 ± 2.6	167	29.7 ± 1.3
Fluke span	25	22.8 ± 1.8	120	24.3 ± 1.8	30	22.6 ± 1.8	138	24.9 ± 1.6
Fluke breadth	25	7.6 ± 0.6	141	7.3 ± 0.5	30	7.3 ± 0.6	152	7.3 ± 0.6
Flipper length	25	19.6 ± 1.0	147	17.3 ± 1.1	29	19.9 ± 0.8	166	17.8 ± 1.2
Flipper width	25	6.8 ± 0.5	144	6.5 ± 0.5	29	7.0 ± 0.4	166	6.7 ± 0.6

PROPORTIONS.—We have analyzed the following six body measurements to determine if body proportions change with age: (1) head length, (2) tail length, (3) span of flukes, (4) breadth of flukes, (5) length of flippers, and (6) width of flippers.

A comparison of these measurements (expressed as a percentage of body length) of near-term fetuses with those of postnatal whales (Table 6) shows that mean tail length increases from 28.2 to 29.7 per cent in males ($P < .05$) and from 28.4 to 30.3 per cent in females ($P < .001$). Relative flipper length decreases from 19.9 to 17.8 per cent ($P < .001$) in males and from 19.6 to 17.3 per cent ($P < .001$) in females. Fluke span increases from 22.6 to 24.9 per cent ($P < .005$) in males and from 22.8 to 24.3 per cent ($P < .01$) in females. Examination of near-term fetuses suggests that the apparent increase in relative fluke span does not represent differential growth, but instead is simply the result of postnatal abduction of the flukes in the horizontal plane from the adducted and folded position *in utero*. There are no significant age differences in relative head length, fluke breadth, or flipper width.

The magnitude of changes in body proportions of gray whales from one year of age to physical maturity also was examined. All postnatal animals of each sex were grouped into one-meter length classes. The mean and standard deviation of each measurement for each length class were calculated and the mean expressed as a percentage of total body length (Table 7). Only specimens for which

all six measurements were available were included. For each series of measurements, we calculated the allometric equation $Y = bX^d$, where X = body length and Y = measurement being compared with X. The constant of allometry, *d*, does not differ significantly ($P > .05$) from unity for any of the series of measurements for either sex, indicating that body proportions change little after one year of age.

Sexual Dimorphism.—There was no significant difference between the sexes in body length of near-term fetuses. As noted above, females grow more rapidly after birth and average larger than males at any given age, as is true for all other species of baleen whales.

The data in Tables 6 and 7 reveal small but statistically significant postnatal differences between the sexes in some body proportions. Thus, males have longer flippers ($P < .01$) and shorter tails ($P < .01$) than females. There is no sexual dimorphism in number of throat grooves, baleen plates, or crenulations on the dorsal ridge of the caudal peduncle.

Puberty and Sexual Maturity

As ordinarily used by cetologists, puberty refers to the age at which gametes are first produced, and sexual maturity is the age at which the animal reaches its full reproductive power. For purposes of this study, any animal that had attained puberty is referred to as an adult.

Puberty in the female is indicated by the presence of a corpus luteum or at least one corpus albicans in the ovaries. Females are considered to be sexually mature at the onset of the first pregnancy. Evidence of sexual maturity thus is pregnancy, lactation, or the presence of mature but involuted mammary glands and a parous type uterus. In the female gray whale, attainment of puberty and sexual maturity usually coincide, but in five of 15 nulliparous and primiparous females, the presence of a corpus albicans (in one case, three corpora), in addition to a corpus luteum or recently ovulated follicle, indicated that they had attained puberty but had not conceived at least a year before their most recent estrous cycle.

Males are considered to be sexually mature when first capable of successfully impregnating females. It is impossible to make a distinction between puberty and sexual maturity in the male on

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TABLE 7

MEASUREMENTS (IN METERS) AND RELATIVE SIZE (AS PERCENTAGE OF BODY LENGTH) OF VARIOUS BODY PARTS OF GRAY WHALES.

Class range of body length	N	Mean body length	Head length		Tail length		Fluke span		Fluke breadth		Flipper length		Flipper width	
			Mean ± SD	Per cent	Mean ± SD	Per cent	Mean ± SD	Per cent	Mean ± SD	Per cent	Mean ± SD	Per cent	Mean ± SD	Per cent
Females														
Near-term fetuses	17	4.69	1.05 ± 0.09	22	1.33 ± 0.14	28	1.08 ± 0.12	23	0.36 ± 0.04	7.7	0.92 ± 0.08	20	0.32 ± 0.03	6.8
8.01– 9.00	3	8.69	1.92 ± 0.03	22	2.77 ± 0.02	32	2.12 ± 0.11	24	0.65 ± 0.02	7.5	1.46 ± 0.07	17	0.54 ± 0.03	6.2
9.01–10.00	5	9.58	2.21 ± 0.13	23	3.05 ± 0.15	32	2.38 ± 0.16	25	0.70 ± 0.06	7.3	1.67 ± 0.13	17	0.63 ± 0.03	6.6
10.01–11.00	8	10.49	2.43 ± 0.19	23	3.26 ± 0.15	31	2.46 ± 0.27	23	0.76 ± 0.06	7.2	1.80 ± 0.19	17	0.68 ± 0.04	6.5
11.01–12.00	23	11.68	2.75 ± 0.10	24	3.64 ± 0.10	31	2.90 ± 0.13	25	0.88 ± 0.04	7.5	1.99 ± 0.11	17	0.76 ± 0.05	6.5
12.01–13.00	42	12.52	2.90 ± 0.10	23	3.78 ± 0.23	30	3.07 ± 0.22	25	0.91 ± 0.05	7.3	2.16 ± 0.14	17	0.81 ± 0.04	6.5
13.01–14.00	22	13.33	3.05 ± 0.11	23	3.96 ± 0.15	30	3.16 ± 0.24	24	0.93 ± 0.06	7.0	2.35 ± 0.23	18	0.87 ± 0.05	6.5
14.01–15.00	1	14.20	3.20	23	4.20	30	3.24	23	0.95	6.7	2.60	18	0.94	6.6
Males														
Near-term fetuses	24	4.56	1.02 ± 0.07	22	1.29 ± 0.13	28	1.02 ± 0.11	22	0.34 ± 0.03	7.5	0.92 ± 0.07	20	0.32 ± 0.02	7.0
9.01–10.00	9	9.81	2.26 ± 0.08	23	3.06 ± 0.12	31	2.48 ± 0.10	25	0.71 ± 0.05	7.2	1.71 ± 0.10	17	0.65 ± 0.03	6.6
10.01–11.00	27	10.62	2.51 ± 0.13	24	3.20 ± 0.19	30	2.68 ± 0.21	25	0.76 ± 0.04	7.2	1.91 ± 0.13	18	0.71 ± 0.05	6.7
11.01–12.00	56	11.62	2.73 ± 0.12	23	3.42 ± 0.15	29	2.87 ± 0.22	25	0.84 ± 0.06	7.2	2.05 ± 0.16	18	0.77 ± 0.05	6.6
12.01–13.00	33	12.36	2.23 ± 0.09	23	3.66 ± 0.14	30	3.05 ± 0.16	25	0.89 ± 0.03	7.2	2.18 ± 0.15	18	0.84 ± 0.04	6.8
13.01–14.00	3	13.21	2.90 ± 0.21	22	3.91 ± 0.07	30	3.27 ± 0.13	25	0.91 ± 0.05	6.9	2.33 ± 0.10	18	0.86 ± 0.04	6.6

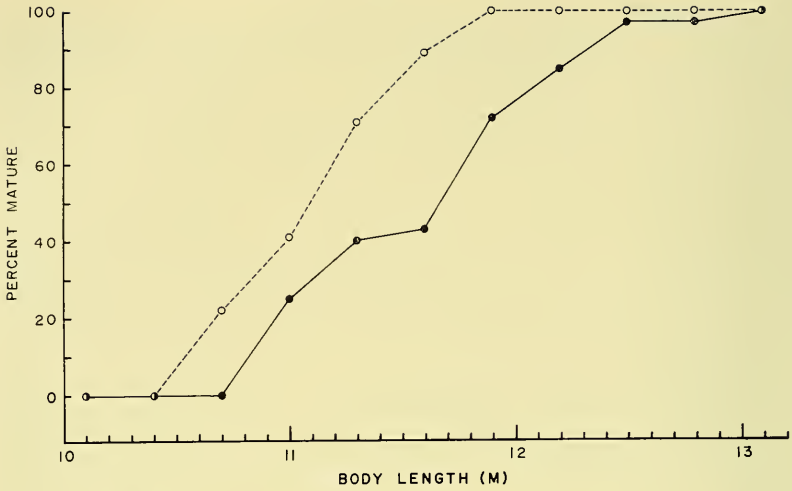

FIG. 15. Percentage of adult gray whales according to body length (grouped by 0.3-meter length classes). Open circles and broken lines represent males; solid circles and unbroken lines represent females.

the basis of our data. We determined the attainment of puberty by histological examination of the testes and regarded as adult all males whose testes showed evidence of spermatogenesis.

Fig. 15 shows that 50 per cent of the females have attained puberty by the time they reach a length of about 11.7 meters. The two smallest females that had reached puberty were 10.92 meters and 11.20 meters long; both were nulliparous and had recently ovulated for the first time. The smallest parous female was 11.24 meters long, whereas the largest immature female was 12.92 meters in length.

Fifty per cent of the males had attained puberty at a length of 11.1 meters (Fig. 15). The smallest male showing spermatogenic activity was 10.56 meters long, and the largest immature male was 11.75 meters long.

The age at puberty was estimated by plotting the percentage of animals that had attained puberty against the number of growth layers in the ear plug (Fig. 16). The mean number of growth layers at puberty was nine, giving an estimated age of 8 years. In both males and females, the fewest growth layers found in the ear plug

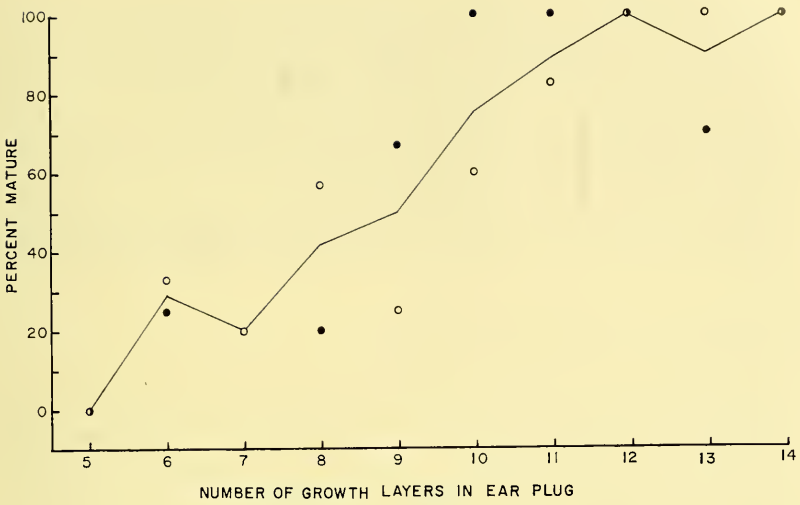

FIG. 16. Percentage of adult gray whales in relation to number of growth layers in ear plugs. Open circles represent males and solid circles represent females; line connects running means of three for both sexes combined.

of an adult animal was six, whereas the highest number in an immature animal was 11 (excepting one female with 13). On this basis, age at puberty is estimated to range from 5 to at least 11 years. Because of the difficulty of counting growth layers in ear plugs of immature animals, these figures may not be entirely reliable.

Physical Maturity

We collected few physically mature animals, as determined by the complete fusion of the vertebral epiphyses with the centra. Only two of the females examined fell in this class. They were 13.98 and 14.20 meters long. The smaller had 35 corpora in the ovaries and about 41 growth layers in the ear plugs, whereas the larger had 22 corpora and 43 laminae in the ear plugs. Physically immature females had 20 or fewer corpora and as many as 40 growth layers. Except for one individual with unreadable ear plugs that was 14.05 meters long, physically immature females were 13.75 meters or less in length.

Five males were regarded as physically mature. They ranged from 12.75 to 13.30 meters in length. The smallest had only 21 growth layers in the ear plug, whereas the others had 38 to 70 (the plugs of one were unreadable). Physically immature males did not exceed a length of 12.80 meters, except for one with 23 growth layers that was 13.23 meters long.

The largest reliably measured gray whales on record are males 14.3 meters long and a female 15.0 meters in length (Zenkovich, 1937*a*).

Discussion and Conclusions

Growth layers in the ear plugs have limited use for age determination in the gray whale because of uncertainty in counting them and because not all individuals have readable plugs. They provide a minimum estimate of age because laminae produced early in life may disappear in older whales. The number of corpora in the ovaries appears to be a more reliable method for age determination in adult females. Growth zones in the baleen plates are of little use for age determination because of the rapid wear of the plates.

Gray whales grow rapidly during their first year. Rapid initial growth is essential in large aquatic mammals that depend primarily on size for thermoregulation and protection from predators.

Between late fetal life and one year of age, relative length of the flipper decreases slightly and relative length of the tail increases slightly. There are no appreciable changes in body proportions from one year to physical maturity. The latter conclusion is contrary to the findings for blue whales and fin whales (Mackintosh and Wheeler, 1929; Ohsumi, 1960), sei whales (Matthews, 1938), humpback whales (Matthews, 1937), right whales, *Balaena glacialis* (Omura *et al.*, 1969), and bowhead whales, *Balaena mysticetus* (Eschricht and Reinhardt, 1866). In most of these species, as body length increases the head becomes relatively longer, the tail relatively shorter, and the flippers and flukes relatively shorter and narrower.

Sexual maturity is attained in both sexes at a mean age of 8 years (range, 5 to 11), at a mean length of 11.1 meters in males and 11.7 meters in females. This estimate of age at sexual maturity is

in general agreement with estimates for fin whales (Nishiwaki *et al.*, 1958) and humpback whales (Chittleborough, 1959) that were based on counts of growth layers in the ear plugs. Physical maturity is attained at a mean length of about 13.0 meters in males and 14.1 meters in females, at a mean age of about 40 years. As in other baleen whales, females are larger than males. Sexual dimorphism in body proportions is slight, but males have slightly larger flippers and shorter tails than females.

FEMALE REPRODUCTIVE CYCLE

Reproduction in cetaceans has been reviewed by Harrison (1969), Rice (1967), and Slijper (1956, 1963). Our collection of 116 adult females included animals in four stages of the reproductive cycle (sample sizes in parentheses): southbound females that had recently ovulated (28); northbound females in early pregnancy (22); southbound females in late pregnancy (56, including one recently aborted individual); and northbound postpartum females (two, neither of which was lactating, apparently having lost their calves). In addition, eight northbound metestrous and anestrous females, which had failed to conceive, were included in the sample. Some anestrous females would also be expected on the southward migration, but none was collected in this study.

Where appropriate, the data on the 15 females undergoing their first reproductive cycle were analyzed separately from the data on the 101 females that had previously experienced one or more cycles. We defined a female as *nulliparous* if she has never given birth (or aborted) and was not visibly pregnant (although she may contain a macroscopically undetectable conceptus), as *primiparous* if she was in her first pregnancy or had given birth (or aborted) only once, and as *multiparous* if she had given birth (or aborted) at least twice or had given birth (or aborted) only once and was currently pregnant; *parous* refers to any female that had conceived at least once (North Pacific Fur Seal Commission, 1963). Nulliparous females and primiparous females in early pregnancy were recognized by the condition of the mammary glands and uterus as described below. Females in late pregnancy and postpartum females with a single corpus luteum and no corpora albicantia were obviously primiparous, and those with at least one corpus albicans in addition to the corpus luteum were regarded as multiparous.

Ovarian Cycle

The ovaries of the gray whale are morphologically similar to those of the fin whale (Laws, 1961; Mackintosh and Wheeler, 1929; Ommanney, 1932), and the humpback whale (Dempsey and Wislocki,

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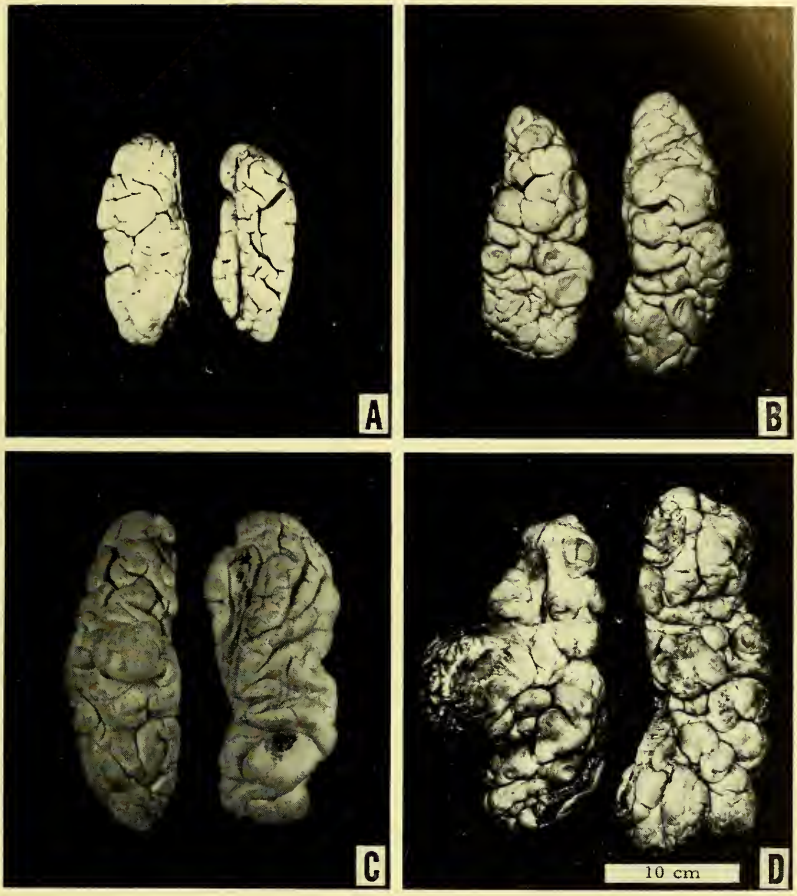

FIG. 17. Ovaries of gray whales showing various stages of ovarian cycle. A, 8.6-meter immature female with no large Graafian follicles; B, 11.2-meter immature female with enlarged Graafian follicles; C, southbound female with recently ruptured Graafian follicle in right ovary and corpus luteum of ovulation in left ovary; D, southbound, recently ovulated female with developing corpus luteum in left ovary. All ovaries are to same scale.

1941). They are elongate, flattened, and oval, with the anterior end slightly larger than the posterior end. Some are exceptionally long and narrow, being almost strap-shaped. The larger Graafian follicles and corpora albicantia protrude from the surface. Ovaries

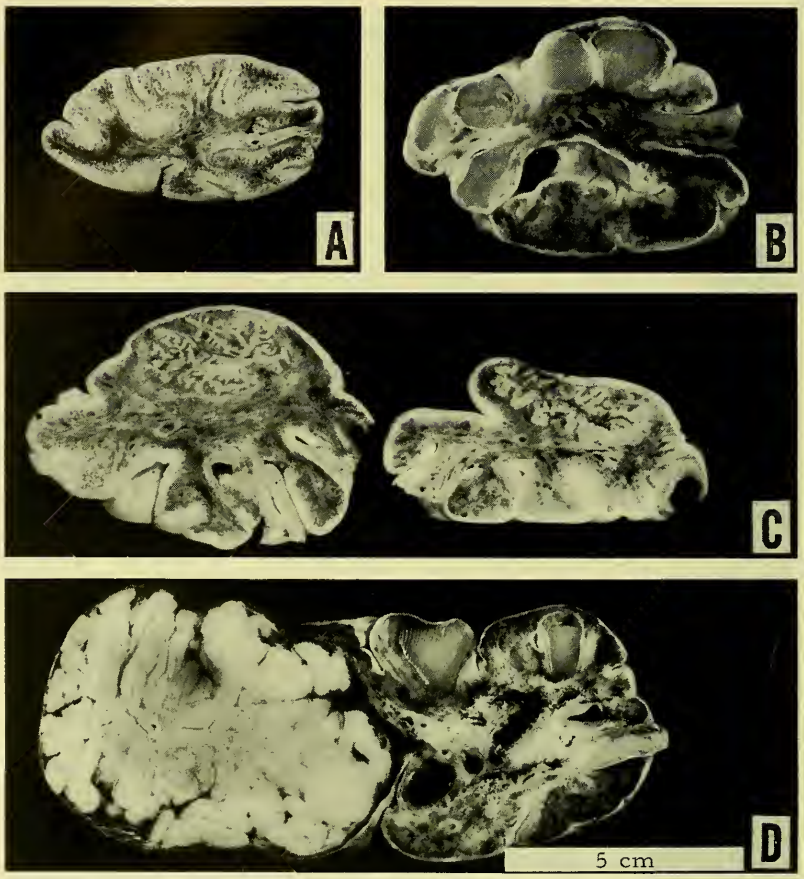

Fig. 18. Transverse sections of ovaries shown in Fig. 17. Sections shown in C and D transect the most recent corpora. All sections are to same scale.

representative of various stages of the reproductive cycle are shown in Figs. 17 to 20.

Ovary Weights.—There is no marked or consistent difference in weight between left and right ovaries. The mean weight of both ovaries of sexually immature females is plotted against body length in Fig. 21. In the smaller individuals, ovary weights range from 70 to 250 grams, with a mean of 136. At a body length of 11.2 to 11.4 meters, corresponding to an estimated age of about 5 years,

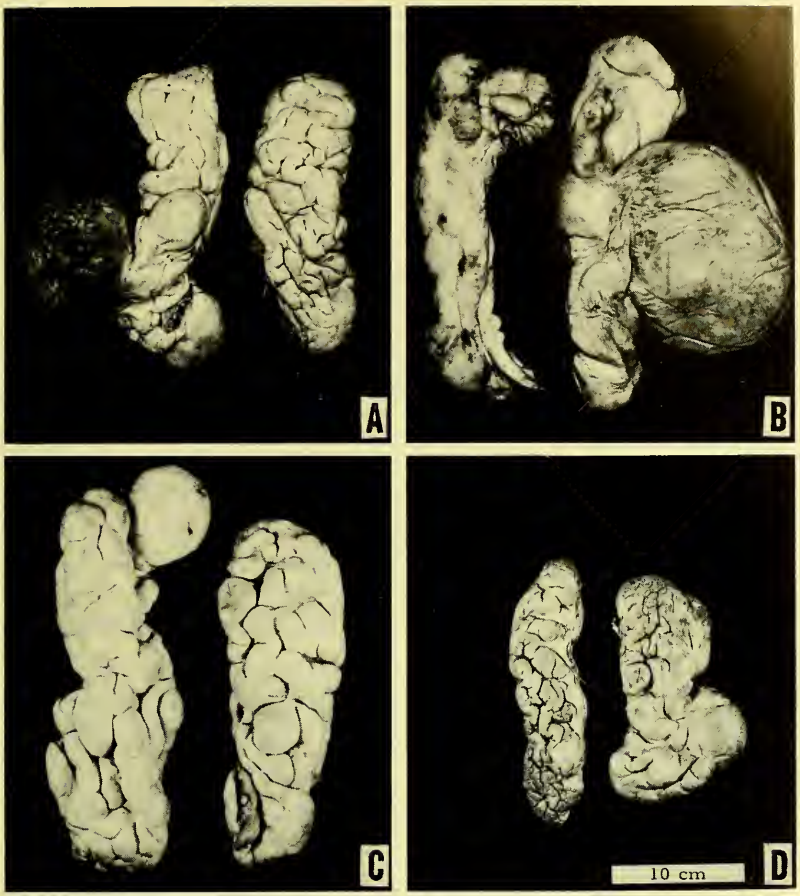

FIG. 19. Ovaries of gray whales showing various stages of the ovarian cycle. A, northbound, early pregnant female (90-millimeter fetus) with corpus luteum in left ovary; B, southbound late pregnant female (4.86-meter fetus) with corpus luteum in right ovary; C, northbound postpartum female (that had lost her calf) with regressing corpus luteum in left ovary; D, northbound anestrous female with large corpus albicans derived from the most recent corpus luteum in right ovary. All ovaries are to same scale.

ovarian weight increases abruptly to 250 to 550 grams (mean, 312), approximating that of younger sexually mature females.

The weight of the ovaries of sexually mature females is greatly increased when a corpus luteum is present. As most mature females

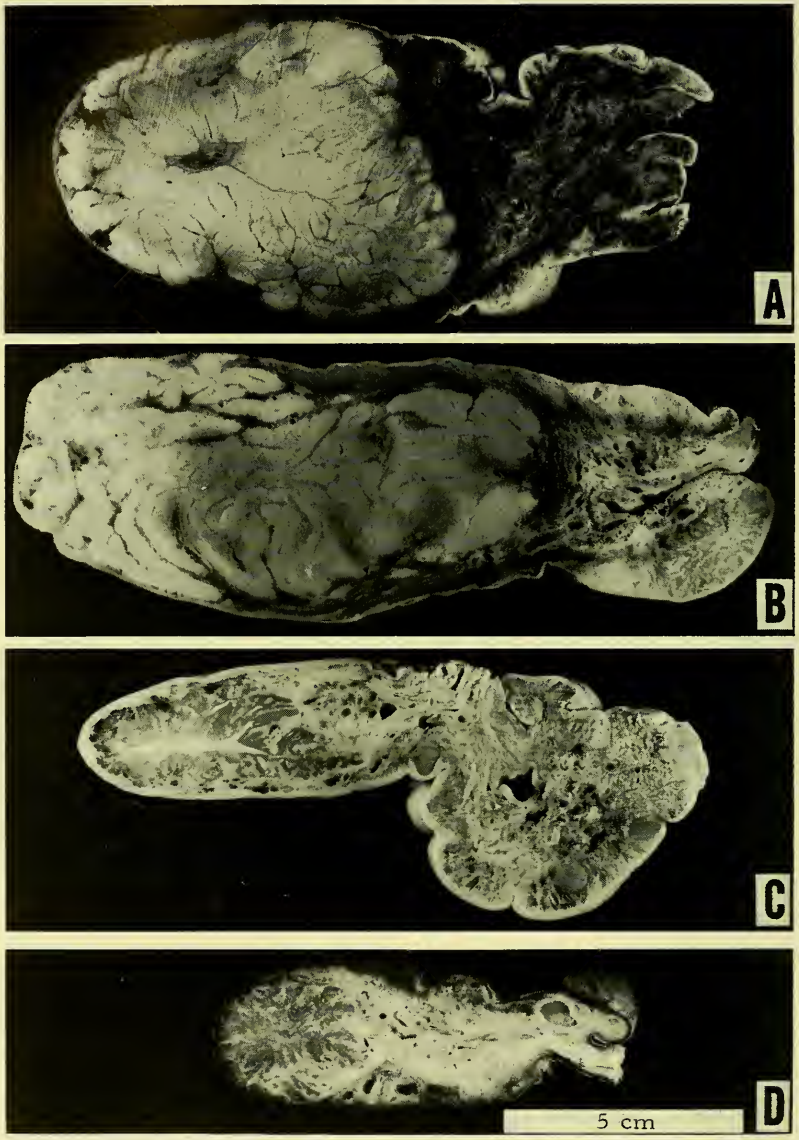

FIG. 20. Transverse sections through the most recent corpus in each pair of ovaries shown in Fig. 19. All sections are to same scale.

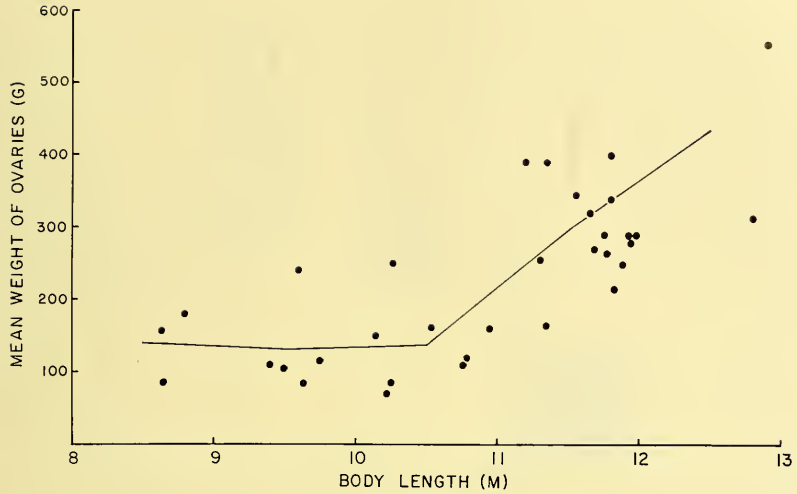

FIG. 21. Ovary weights of immature female gray whales plotted against body length. Line connects mean weights at one-meter length intervals.

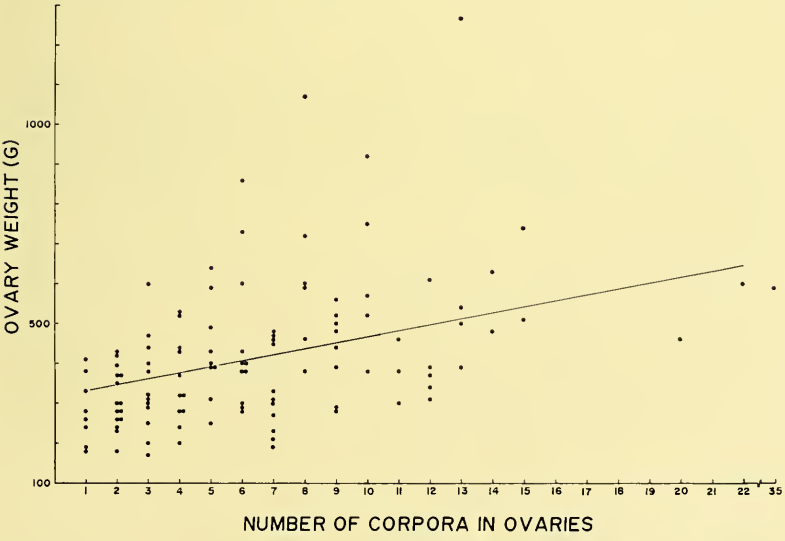

FIG. 22. Ovary weights of adult female gray whales plotted against number of corpora in ovaries.

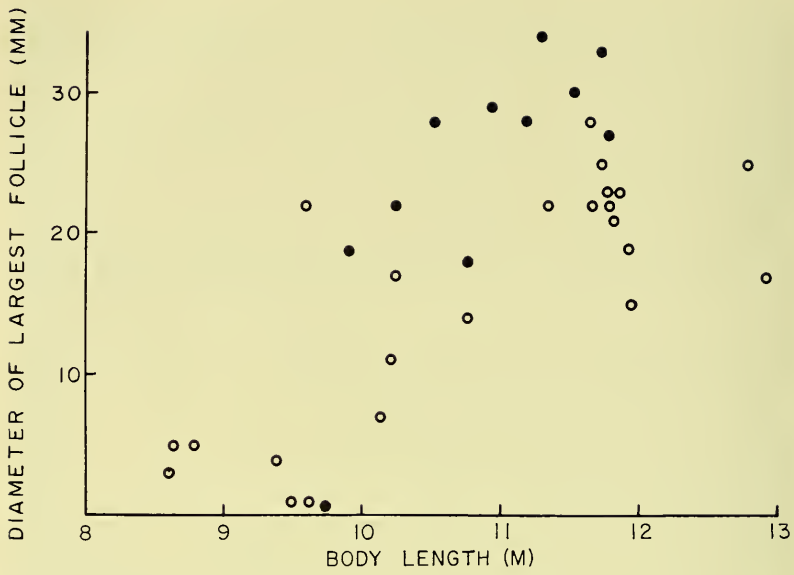

FIG. 23. Diameter of largest Graafian follicle versus body length of immature female gray whales. Solid circles indicate southbound migrants; open circles indicate northbound migrants.

had a corpus luteum in one ovary, we have used only the weight of the other ovary in making comparisons. For females without a corpus luteum, we have used the mean weight of the two ovaries. In Fig. 22, these weights are plotted against the number of corpora in both ovaries.

The weights of mature ovaries without a corpus luteum vary from 170 to 1270 grams. The regression of ovary weight on number of corpora is $Y = 316 + 15X$, where Y = ovary weight in grams and X = number of corpora. As the slope of this line differs significantly from zero ($P < .001$), ovarian weight apparently increases with age from a mean of 331 grams at puberty to 646 grams at an age of 50 years.

FOLLICLES.—None of the follicles in the ovaries of immature females up to 9.6 meters long exceeded 7 millimeters in diameter; in all immature females longer than 10.2 meters, the largest follicle

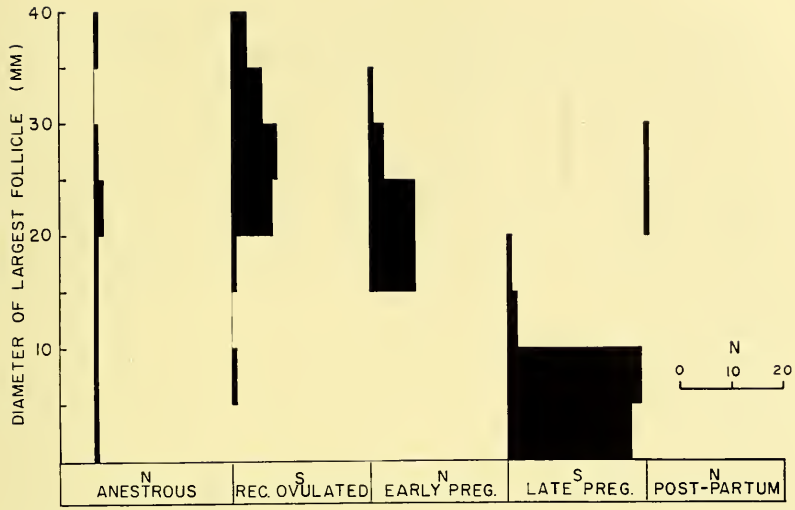

FIG. 24. Frequency distribution of diameter of largest Graafian follicle in ovaries of adult female gray whales in different phases of the reproductive cycle (N, northbound migrants; S, southbound migrants).

in either ovary exceeded 14 millimeters (Fig. 23). In the latter animals the largest follicles ranged from 18 to 34 millimeters (mean, 27) in southbound animals and from 14 to 28 millimeters (mean, 21) in northbound animals. These data suggest that females first begin to undergo a seasonal cycle of follicle-stimulating hormone secretion when they reach a length of between 9.6 and 10.2 meters at an estimated age of 2 or 3 years. Laws (1961) found a seasonal follicular cycle in immature fin whales. It should be noted that the follicles in these older immature females are significantly larger than those of late pregnant or postpartum females and slightly larger than those of northbound anestrous females. It is probable that the southbound immature females with follicles about 30 millimeters in diameter or larger (see below) are destined to ovulate for the first time later in the same season.

The size of the largest follicle in either ovary of adult females differs markedly in various phases of the reproductive cycle (Fig. 24). All southbound females not carrying near-term fetuses had recently ovulated. The largest follicle in these specimens ranged

from 18 to 40 millimeters (mean, 28) in diameter (except for one nulliparous animal in which maximum follicle diameter was only 6 millimeters). Assuming that the largest follicle had ovulated, the biggest remaining follicle in these females would have been the second largest follicle just before ovulation. It thus appears that in gray whales the follicle exceeds 30 millimeters and may reach 40 before rupturing. Chittleborough (1954) found that the follicles of humpback whales exceed 30 millimeters before ovulation.

In the northbound early-pregnant females, the diameter of the largest follicles average less than two months earlier, ranging from 16 to 33 millimeters, with a mean of 22.

In strong contrast to females that had recently ovulated, southbound pregnant females carrying near-term fetuses had no greatly enlarged follicles. The largest follicle varied from 3 to 16 millimeters, with a mean of only 6. A female taken on 8 January that had apparently aborted recently likewise had no follicles larger than 6 millimeters. Such follicles are significantly smaller than those of anestrous females. The small size of follicles in late-pregnant females suggests that the progesterone secreted by the corpus luteum suppresses follicular maturation. Chittleborough (1954) found that the follicles of humpback whales in late pregnancy were smaller than those in anestrous animals. No such marked reduction has been found in blue whales and fin whales examined mostly during midpregnancy (Laws, 1961; Mackintosh and Wheeler, 1929; Nishiwaki and Oye, 1951).

In the two northbound females examined that were nonlactating and postpartum, the largest follicles were 24 and 29 millimeters in diameter. Their size suggests a resumption of follicular maturation after regression of the corpus luteum.

Northbound females that were neither pregnant nor postpartum had follicles ranging from 1 to 37 millimeters (mean, 18) in diameter. In three of these females that had recently ovulated, the largest follicles ranged from 14 to 37 millimeters, with a mean of 24. These approximate maximum follicle sizes of southbound females that had recently ovulated and were presumably pregnant. These three females probably should be regarded as being in metestrus. Five anestrous females that had not ovulated recently had follicles with maximum diameters of 1 to 25 millimeters, with a mean of 14.

This size range is probably closest to that of follicles of fully anestrous females.

Nine pairs of ovaries contained one to several thin-walled, fluid-filled cysts up to about 8 centimeters in diameter. Presumably, these are cystic follicles.

Frequency of Ovulation.—Nonpregnant adult females regularly ovulate in late November and early December (see discussion of gestation period and fetal growth beyond), while still north of central California on the southward migration. All of the adult females collected in southward migration that were not carrying near-term fetuses had recently ovulated, as revealed by the presence of recently ruptured follicles or developing copora lutea. The mean number of recent ovulations in these females was 1.14 for nulliparous animals and 1.10 for parous animals (Table 8). It is possible that some of these whales would have ovulated again later if their most recent ovulation did not result in conception.

The mean number of recent ovulations in northbound females (excluding postpartum animals) was 1.33 in the nulliparous and the primiparous pregnant females and 0.85 in the parous nonpregnant and the multiparous pregnant females. The diameter of the largest corpus albicans in the ovaries of each metestrous and anestrous female suggests, however, that some of these may have been fairly recently formed corpora whose recent origin was no longer apparent. These corpora ranged from 24 to 39 millimeters in diameter, with a mean and standard error of 32.3 ± 3.0, whereas the largest corpus albicans in each early pregnant female ranged from 18 to 42 millimeters, with a mean and standard error of 27.4 ± 1.6. The latter presumably were the corpora lutea of the previous pregnancy that had regressed after the end of lactation several months earlier.

The mean ovulation rate estimated for females during their regular biennial breeding season was 1.20 for nulliparous females, 0.96 for parous females, and 1.00 for all females (Table 8). For reasons stated above, these estimates may be slightly low.

Each of two females taken on 16 and 18 January had both recently ruptured follicles and a corpus luteum of ovulation. This observation suggests that about 40 days intervene between successive ovulations during one breeding season.

TABLE 8
NUMBER OF RECENT OVULATIONS IN ADULT FEMALE GRAY WHALES, EXCLUDING LATE PREGNANT AND POSTPARTUM FEMALES.

Direction of migration and reproductive status	Number of whales	Number of recent ovulations[1]				Total recent ovulations	Ovulation rate
		0	1	2	3		
Southbound							
Nulliparous	7	0	6	1	0	8	1.14
Parous	21	0	20	0	1	23	1.10
Total	28	0	26	1	1	31	1.11
Northbound							
Nulliparous or primiparous							
Nonpregnant	1	0	0	1	0	2	2.00
Pregnant	2	0	2	0	0	2	1.00
Subtotal	3	0	2	1	0	4	1.33
Parous or multiparous							
Nonpregnant	7	5	2	0	0	2	0.29
Pregnant	20	0	19	1	0	21	1.05
Subtotal	27	5	21	1	0	23	0.85
Combined northbound sample							
Nonpregnant	8	5	2	1	0	4	0.50
Pregnant	22	0	21	1	0	23	1.05
Total	30	5	23	2	0	27	0.90
All specimens							
Nulliparous or primiparous	10	0	8	2	0	12	1.20
Parous or multiparous	48	5	41	1	1	46	0.96
Grand total	58	5	49	3	1	58	1.00

[1] Figures in body of table indicate the number of whales that had the number of recent ovulations shown at the top of each column.

The only evidence for multiple (simultaneous) ovulation was one female with two recently ruptured follicles of the same size.

The nature of the estrous cycle in baleen whales has been the subject of controversy, because few specimens taken during the breeding season have been available for study, and conclusions have had to be drawn mostly from indirect evidence. Harvey (1963) reviewed the relevant literature and concluded that balaenopterid whales are monestrous. Chittleborough (1965), however, presented direct evidence that female humpback whales, although they usually conceive after ovulating only once, may undergo two or three estrous

cycles if pregnancy does not intervene. Gambell's (1968) data strongly suggest a similar condition in sei whales. Potential polyestry would be of considerable selective advantage in a species that can produce no more than one offspring every 2 years, that does not form permanent pair bonds, and that may be so widely dispersed that a male might not be available when the female first comes into estrus.

As southbound female gray whales carrying near-term fetuses had no enlarged follicles, it may be concluded that there is usually no postpartum estrus in this species. However, postpartum estrus sometimes occurs in other whale species. A postpartum estrus resulting in pregnancy almost invariably occurs in the minke whale, *Balaenoptera acutorostrata* (Jonsgård, 1951; Omura and Sakiura, 1956). Postpartum estrus in a high proportion of Southern Hemisphere humpback whales also is indicated by the fact that eight (44 per cent) of 19 lactating animals examined in one study were simultaneously pregnant (Chittleborough, 1958). Likewise, 15 (12 per cent) of 129 lactating Southern Hemisphere fin whales also were pregnant (Laws, 1961). According to Gambell (1968) an estimated 11 per cent of female Southern Hemisphere sei whales experienced postpartum estrus.

The two nonlactating postpartum females examined had not recently ovulated, but the fact that they had follicles (24 and 29 millimeters) much larger than any late pregnant female and larger than the average for anestrous females indicates a resumption of follicular maturation after the corpus luteum starts to regress and progesterone secretion is reduced. It is possible that such follicles may develop sufficiently to undergo ovulation. Chittleborough (1958) has shown that humpback whales usually recommence estrous cycles immediately after stillbirth or early loss of the calf. Ovulation following stillbirth or loss of a calf would be so infrequent that it would not significantly affect the mean ovulation rate.

The possibility of postlactation ovulation, or ovulation by any nonpregnant females during the summer, remains to be considered. The southbound females that had recently ovulated, most of which presumably had ceased lactating about 5 months previously, gave no evidence of having ovulated more than once since that time.

In each, the largest corpus albicans was 22 to 38 millimeters in diameter (mean, 29); this was no doubt the regressing corpus luteum of lactation. Only data from females collected on the summer grounds can provide direct evidence on this point. There is evidence that a considerable proportion of Southern Hemisphere fin whales experience a postlactation ovulation (Laws, 1961), and about 12.5 per cent of the female Southern Hemisphere sei whales ovulate in the summer (Gambell, 1968). These summer ovulations almost never result in pregnancy. In humpback whales, which lactate for approximately 10½ months, an estrous cycle usually commences immediately following the end of lactation; this cycle corresponds with the normal winter breeding season and usually results in pregnancy (Chittleborough, 1958).

The two oldest females studied, with 19 and 34 corpora albicantia, were pregnant, so there is no indication of cessation of breeding in old females.

In summary, female gray whales normally experience one estrous cycle every 2 years, although rarely they may ovulate twice or perhaps three times during one breeding season. The mean ovulation rate for parous females is 0.96 per breeding season. A female that fails to conceive during one breeding season probably undergoes an estrous cycle again the following year. As the pregnancy rate is 0.46 (see below), the mean ovulation rate per year of parous females is 0.52 ($[1.00 - 0.46] \times 0.96$).

Corpora Lutea.—Our material included three ovaries with recently ruptured Graafian follicles that provided data on early development of the corpus luteum. In one case the rupture site was still open (Figs. 17 and 18), and in the other two the rupture sites were still obvious as dark spots, although no actual openings were visible. These follicles, 24, 25, and 25 millimeters in diameter, were smaller than mature unruptured follicles. Loss of fluid presumably causes the follicle to collapse immediately after rupture. There is a marked infolding of the walls and a proliferation of luteal tissue from the membrana granulosa. The luteal tissue fills almost the entire antrum. One corpus contained a small amount of liquor folliculi in the central cavity. Subsequent development of the corpus luteum depends upon whether or not pregnancy ensues.

It is difficult to distinguish corpora lutea of ovulation from corpora lutea of pregnancy, because failure to find a visible conceptus in the uterus is not proof that an animal has not conceived. Only in the four females that had recently undergone more than one estrous cycle was it certain that corpora lutea of ovulation were present (Figs. 17 and 18). In these animals the penultimate corpora were 13, 15, 21, and 25 millimeters in diameter. Because of their small size, they did not greatly protrude from the surface of the ovaries. In cross section, the corpora were somewhat irregular or stellate in outline. The layer of luteal tissue was thin and greatly plicated, and no cavity remained. The luteal tissue was pale yellow, as in corpora lutea of pregnancy, in the larger two of the four corpora and more orange-yellow in the two smaller corpora.

Three northbound females had corpora lutea 22, 81, and 102 millimeters in diameter but showed no macroscopic evidence of pregnancy. The two larger corpora in this series were indistinguishable from corpora lutea of pregnancy.

The above data indicate that corpora lutea of ovulation do not attain a size greater than about 25 millimeters and rapidly regress if the female comes into estrus again after a brief diestrous period. The fate of the corpus luteum when the female does not become pregnant or undergo another estrous cycle requires further study.

Corpora lutea of pregnancy in the gray whale (Figs. 17 and 20) are similar to those of the fin whale (Laws, 1961) and humpback whale (Chittleborough, 1954). They protrude from the body of the ovary, from which they are separated by a constricted neck.

In most of the southbound females that had recently ovulated but were not yet visibly pregnant, the corpora lutea ranged from 37 to 87 millimeters (mean, 56; standard deviation, 16). Females with small fetuses collected two months later during northward migration had corpora lutea ranging from 61 to 100 millimeters in diameter (mean, 82; standard deviation, 11). In these animals, the size of the corpus luteum was correlated with the length of the fetus. The female carrying the smallest fetus (25 millimeters long) had a corpus luteum only 63 millimeters in diameter. In females with fetuses 120 to 140 millimeters in length (estimated age 87 to 89 days), the average diameter of the corpus luteum was 84 millimeters, which is not significantly different from that in late pregnant females.

Chittleborough (1954) has shown that it takes nearly three months for the corpus luteum of the humpback whale to reach maximum size. In southbound female gray whales with near-term fetuses, the corpora lutea varied from 61 to 115 millimeters in diameter (mean, 87; standard deviation, 12). No data were obtained on the condition of the corpora lutea in lactating females.

Twenty-one per cent of the corpora lutea of pregnancy contained central vesicles filled with liquor folliculi. Thus, in this species the presence or absence of a central vesicle is of no use in distinguishing corpora lutea of ovulation from those of pregnancy. Laws (1961) has refuted the contention of some authors (for example, Robins, 1954) that the absence of a central vesicle is diagnostic of corpora lutea of ovulation in balaenopterid whales. The largest vesicle in our animals was 54 millimeters in diameter. A few were irregularly shaped or eccentrically located. Some corpora lutea had gel-filled cavities up to 24 millimeters in diameter located around their periphery or at the base (Fig. 20). Although these structures resemble large, flattened follicles, their close association with the corpus luteum suggests that they are part of it.

Only one whale, a primiparous late pregnant female, had an accessory corpus luteum (in the opposite ovary from the primary corpus luteum). It was 14 millimeters in diameter and lacked a stigma, suggesting that it must have developed from an unruptured follicle.

Corpora Albicantia.—The corpora albicantia (Fig. 20F) of gray whales are morphologically similar to those of balaenopterid whales, and the sequence of changes during regression is essentially the same as described by Laws (1961) and van Lennep (1950) for the fin whale.

The earliest stages of regression were seen in the two postpartum females that had recently lost their calves (Figs. 19, 20). The corpora lutea in these individuals were 53 and 60 millimeters in diameter. The connective tissue septa characteristic of corpora albicantia were already obvious, and the color of the luteal tissue was more orange than is typical of the corpus luteum of pregnancy.

As the corpus albicans continues to shrink, it recedes below the surface of the ovary. The color changes to brown as collagen

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TABLE 9

DIAMETER (mm) OF CORPORA ALBICANTIA IN OVARIES OF GRAY WHALES AT DIFFERENT STAGES OF THE REPRODUCTIVE CYCLE. SEE TEXT FOR EXPLANATION OF SIZE CLASS.

Size class of corpora albicantia	Recently ovulated			Early pregnant			Late pregnant			Postpartum		
	N	Mean ± SE	Range	*N*	Mean ± SE	Range	*N*	Mean ± SE	Range	*N*	Mean	Range
1	20	29.1 ± 0.9	22–38	20	27.4 ± 1.6	18–42	50	24.8 ± 0.7	17–35	2	26.5	26–27
2	18	22.0 ± 0.8	14–31	20	21.8 ± 0.7	17–30	43	20.5 ± 0.5	14–29	2	24.5	24–25
3	16	19.7 ± 0.7	14–26	16	20.4 ± 0.7	17–28	38	19.3 ± 0.6	12–29	1	23	
4	14	19.4 ± 0.7	16–26	15	18.4 ± 0.9	12–23	31	18.7 ± 0.6	10–28	1	22	
5	12	17.7 ± 0.9	12–23	11	18.0 ± 0.9	14–22	27	17.9 ± 0.5	14–24	1	20	
6	11	16.5 ± 0.8	12–21	6	17.5 ± 1.3	13–21	25	16.8 ± 0.5	12–24	1	18	
7	8	17.1 ± 0.6	15–20	3	18.0 ± 1.5	15–20	22	15.6 ± 0.6	11–23	1	16	
8	6	16.2 ± 0.5	15–18	3	17.7 ± 1.9	14–20	19	15.3 ± 0.7	10–23	1	16	
9	5	15.4 ± 0.8	13–17	33	17.0 ± 1.5	14–19	12	15.2 ± 0.6	13–20	1	15	
10	5	15.0 ± 0.9	12–17	2	17.5	16–19	9	14.9 ± 1.0	13–19			
11	4	15.0 ± 0.6	14–16	2	16.0	13–19	7	14.1 ± 1.3	8–19			
12	4	14.2 ± 0.6	13–16	2	15.5	12–19	3	16.0 ± 1.5	14–19			
13	3	13.7 ± 0.9	12–15	1	18		3	15.7 ± 1.7	14–19			
14	2	14.0	13–15	1	18		2	13.5	12–14			
15	1	15		1	18		1	13				
16	1	15		1	18		1	13				
17	1	15		1	18		1	12				
18	1	14		1	18		1	12				
19	1	14		1	18		1	10				
20	1	14		1	18							
21	1	12		1	17							
22–34				1	17–6							

replaces the luteal cells, and the proportion of connective tissue increases. Some of the smaller corpora albicantia consist almost entirely of unpigmented connective tissue.

The corpora albicantia persist throughout life in the ovaries of fin whales (Laws, 1961) and this probably applies to all large balaenopterids. This also occurs in sperm whales (Best, 1967), but not in at least some of the smaller odontocetes, such as the pilot whale, *Globicephala melaena* (Harrison, 1949; Sergeant, 1962).

The corpora persist as permanently recognizable structures in the ovaries of gray whales. The corpora albicantia of each female (excluding nulliparous and primiparous ones) were classified according to relative size in the following manner: class 1, the largest corpus in each whale; class 2, the second largest, and so on. The mean, standard error, and range for each of these classes in females in each phase of the reproductive cycle are presented in Table 9. It is apparent from the size distribution that after an initial phase of rapid regression, there is little further decrease in size of the corpora albicantia. Few were less than 12 millimeters in diameter.

In the discussion of time and frequency of ovulation, it was concluded that females usually ovulate only once every 2 years. If this is true, and the corpora albicantia persist for life, the rate of accumulation of corpora albicantia would be close to 0.5 per year. We examined two other lines of evidence bearing on this question: the size frequency distribution of the corpora albicantia and the correlation between number of corpora albicantia and number of growth layers in the ear plug.

The means, standard errors, and ranges of the diameters of the corpora lutea and two largest corpora albicantia of females in each stage of the reproductive cycle are shown in Fig. 25. We assumed that each female ovulates only once every 2 years, and adjusted the horizontal time scale accordingly. The smooth line shows the presumed rate of regression in size of the corpus albicans during the first 4 years. If the smaller corpora albicantia (Table 9) were similarly plotted, the line would gradually approach the horizontal at about 14 millimeters beyond 20 years. It is apparent from Fig. 25 that a presumed accumulation rate of one corpus albicans every 2 years is consistent with the observed size-frequency distribution of

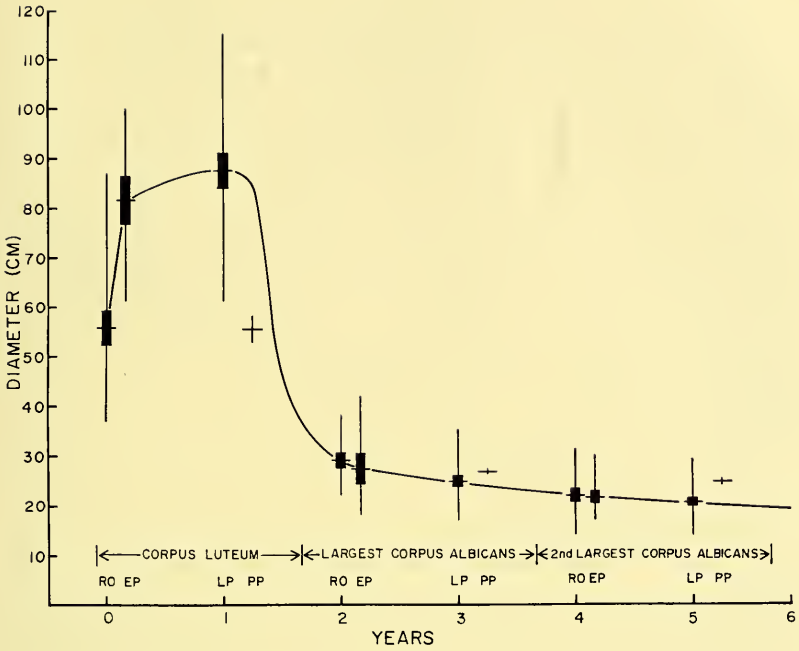

FIG. 25. Diameter of corpus luteum and two largest corpora albicantia in ovaries of gray whales in different stages of the reproductive cycle. The horizontal scale represents the age of each corpus, assuming one ovulation every two years. RO, recently ovulated females; EP, early pregnant females; LP, late pregnant females; PP, postpartum females. The two postpartum females had lost their calves, thus their corpora lutea were smaller than in lactating animals. Horizontal dashes, mean; vertical bars, two standard errors on either side of mean; vertical lines, range. Curve fitted by eye to mean diameters of corpora.

corpora. If the ovulation rate were significantly greater, the size-frequency data would not show such a regular decline. The data on ovulation further indicate that the rate cannot be less than about 0.5 per year.

The relationship between number of corpora albicantia and the number of growth layers in the ear plug is presented in Fig. 26. The solid line ($Y = 0.5X - 3.5$) represents the expected correlation between number of corpora and number of growth layers under the assumptions that two growth layers are formed the first year

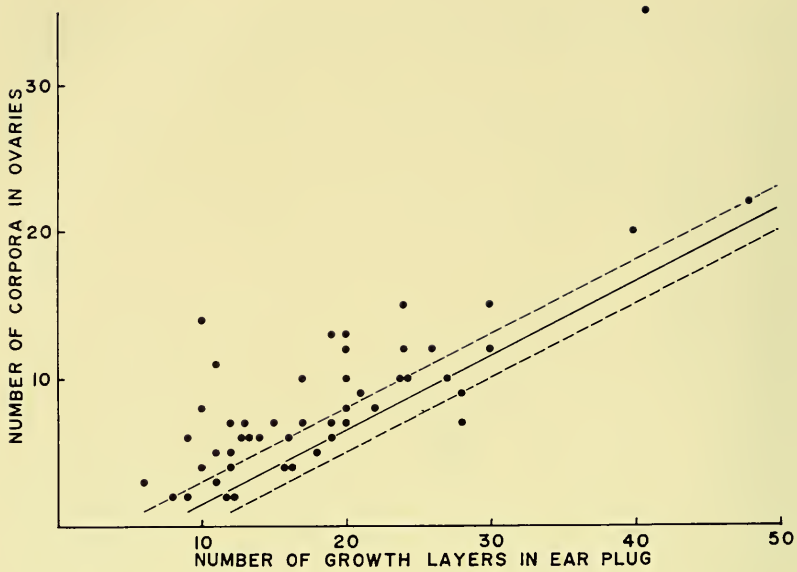

Fig. 26. Number of corpora in the ovaries versus the number of growth layers in the ear plugs of adult female gray whales. The hypothetical correlation is represented by the unbroken line (mean) and the broken lines (range).

and one each year thereafter, and that one corpus is formed every 2 years beginning at 8 years of age (mean age at sexual maturity). The two broken lines ($Y = 0.5X - 2.0$ and $Y = 0.5X - 5.0$) represent the lower and upper limits, respectively, of variation expected because of the variation in the age at sexual maturity of from 5 to 11 years. Deviations from the hypothetical mean number of growth layers are markedly skewed. The mode falls on the lower limit (–3); 41 per cent of the specimens fall within the expected limits (–3 to +3). Only one whale falls above the expected limits (+7); 57 per cent fall below the lower limit (–3 to –37), with 33 per cent falling between –3 and –7. These data are thus consistent with the conclusions that corpora accumulate at a rate of 0.5 per year and growth layers in the ear plug accumulate at a rate of one per year, although the earlier layers may not be discernible.

The only corpora albicantia that are unquestionably derived from corpora lutea of ovulation are those in nulliparous and

primiparous females. These corpora do not differ in size or other respects from those representing corpora lutea of pregnancy. In three recently ovulated nulliparous females, the largest corpora albicantia were 23, 30, and 34 millimeters in diameter, and in two primiparous females in early pregnancy they were 13 and 29 millimeters in diameter. All except the smallest of these were within the size range of the largest corpora albicantia in multiparous females in corresponding phases of the reproductive cycle (Table 9).

In addition to normal corpora albicantia, the ovaries of 13 females each contained one to three small orange bodies 4 to 9 millimeters in diameter and which were either compressed and elongate, or stellate, in cross section. The total number of these structures in the 13 animals was 17, which was 2 per cent of the corpora albicantia present in all the females. They are similar to the corpora atretica described by Laws (1961) for the fin whale and presumably originate by atresia of follicles that have not ovulated. This assumption is supported by the finding of a few unruptured follicles with a partial lining of yellow-orange colored tissue. These corpora apparently do not represent ovulations and they were not included in counts of corpora albicantia.

Functional Symmetry and Polarity of Ovaries.—Of the total of 756 corpora, 418 (55.3 per cent) were in the left ovary and 338 (44.7 per cent) in the right ovary. The probability of this ratio occurring in a random distribution is less than .05, suggesting that the observed dominance of the left ovary may be real. Laws (1961) found a slight but statistically insignificant dominance of the right ovary in fin and blue whales. In many odontocetes, most ovulations occur in the left ovary (Ohsumi, 1964*b*).

The position of each of 179 corpora in the anterior, second, third, or posterior quarter (measured linearly) of 52 mature ovaries was recorded. There was a significant ($P < .005$) preponderance of corpora toward the anterior pole. The numbers of corpora in each quarter, from anterior to posterior, were: 61 (34 per cent), 48 (27 per cent), 45 (25 per cent), and 25 (14 per cent). A preponderance of ovulations from the anterior pole of the ovary was also found in fin and sei whales (Laws, 1957) and in the sperm whale (Best, 1968), but not in the pilot whale (Harrison, 1949; Sergeant, 1962) or false killer whale, *Pseudorca crassidens* (Comrie and Adam, 1938).

Pregnancy

Pregnancy Rate.—The pregnancy rate is difficult to determine directly because of bias introduced into the sample by the temporal and spatial differences in migration patterns between females in different phases of the reproductive cycle and by gunner selection for the larger animals. In the series of 84 southbound migrants examined, the ratio of late pregnant females to other mature females was two to one, whereas the actual ratio in the population must be less than one to one. The sample of northbound adult females consisted of 22 early pregnant females and eight anestrous females, but only two postpartum females. As it is logical to assume that the number of postpartum females in the spring population should be nearly equal to the number of pregnant females, the sample was obviously biased.

Because the proportion of late pregnant and postpartum females in the samples was biased, these animals were excluded from calculations of the pregnancy rate and appropriate corrections made to determine the overall pregnancy rate in the adult female segment of the population.

The pregnancy rate of females that had already undergone at least one pregnancy will be considered first. During the southward migration, all females that were not carrying near-term fetuses had a developing corpus luteum. If we assume that all of them had conceived, their pregnancy rate would be 1.00. As a few may not have conceived, this figure may be a slight overestimate. During northward migration, 20 of 27 females (exclusive of postpartum females) were pregnant, giving a pregnancy rate of 0.74. Two of the females that were not visibly pregnant each had a corpus luteum that we assumed to be a corpus luteum of ovulation. Although it is possible that they had recently conceived and were carrying a conceptus too small to detect, we think this is unlikely so late in the season. Considering both the northbound and southbound migrants, 41 of the 48 were pregnant or could reasonably be assumed to have already conceived. This gives a pregnancy rate of 0.85 per breeding season.

Considering females that had not undergone a previous pregnancy, all seven taken on the southward migration had recently

ovulated. Each of five animals had a single corpus luteum 19 to 62 millimeters in diameter and were assumed to have already conceived. One with a recently ruptured follicle and a corpus luteum of ovulation (25 millimeters in diameter) possibly had done so. The last had what appeared to be a corpus luteum of ovulation (27 millimeters in diameter) and Graafian follicles up to 35 millimeters in diameter, so it might have ovulated again later and then conceived. Of the three northbound animals examined, two were pregnant. The third had two fairly recent corpora lutea (22 and 13 millimeters in diameter) and was probably not pregnant. Thus, of 10 females that had not previously been pregnant, seven were pregnant, two were not pregnant but probably would have conceived later, and one probably would not have conceived that season. These data indicate a probable pregnancy rate of 0.90 per breeding season, but further data are needed to determine whether newly mature females are as fertile as older individuals.

The combined pregnancy rate for nulliparous and parous females, exclusive of late pregnant and postpartum animals, is 0.86. To determine the overall pregnancy rate for all adult females in the population, we made a correction for the biased representation of late pregnant and postpartum females in the sample. If the pregnancy rate remains constant from year to year, or if the sample was taken over a period of several years, the overall pregnancy rate may be calculated as 0.86/1.86, or 0.46 per year.

Zenkovich (1937*a*) examined a large series of gray whales taken in the Bering Sea between August and October from 1933 to 1936. Assuming that all females 12.0 meters or more in length were sexually mature, there were 57 mature females in his sample. Of these, only 16 were pregnant, giving a calculated pregnancy rate of only 0.28. G. C. Pike (unpublished data) reported that only one of three adult females he examined off British Columbia in April was pregnant.

Of the seven northbound adult females (exclusive of postpartum individuals) that were not pregnant, only three had recently ovulated, indicating that missed pregnancies may result from either failure to ovulate or failure to conceive following ovulation.

Breeding Season.—Almost all of the adult females (except those carrying near-term fetuses) taken during southward migration

TABLE 10

BODY LENGTH OF GRAY WHALE EMBRYOS AND EARLY FETUSES (CROWN-RUMP LENGTH OF EMBRYOS IN PARENTHESES).

Date of collection	Length (mm)	
	Males	Females
21 February	80	90
22 February	120	
23 February	59 (40), 85	
24 February	110	90, 110
26 February		80
28 February	85	90
1 March	75, 120	140
2 March	39 (16)	25 (10), 105
6 March		120, 120
7 March		110
8 March		135
10 March		120

probably had already conceived, although none was visibly pregnant. The mean conception date calculated from the fetal growth curve (see below) is 5 December. We calculated the duration of the breeding season by estimating the ages of the 22 embryos and early fetuses collected. The estimated ages were based on certain assumptions about early fetal growth discussed below. The calculated conception dates fall between 27 November and 13 December, except for one on 22 December and one on 5 January. The female that conceived about 22 December was multiparous and showed evidence of two recent ovulations, indicating that she had failed to conceive following her first ovulation that season. The female that conceived about 5 January was primiparous; Laws (1961) found that newly mature female fin whales conceive, on the average, later than multiparous females.

The duration of the breeding season also was estimated on the basis of length measurements for 16 fetuses collected in late summer by Zenkovich (1937*a*). The estimated conception dates of 12 (75 per cent) of these fetuses fall between 23 November and 14 December, and all fall between 13 November and 10 January. Individual variations in growth rate will give a spurious spread to the calculated range, so that the actual breeding season is doubtless even shorter than these data indicate. For the same reason, the

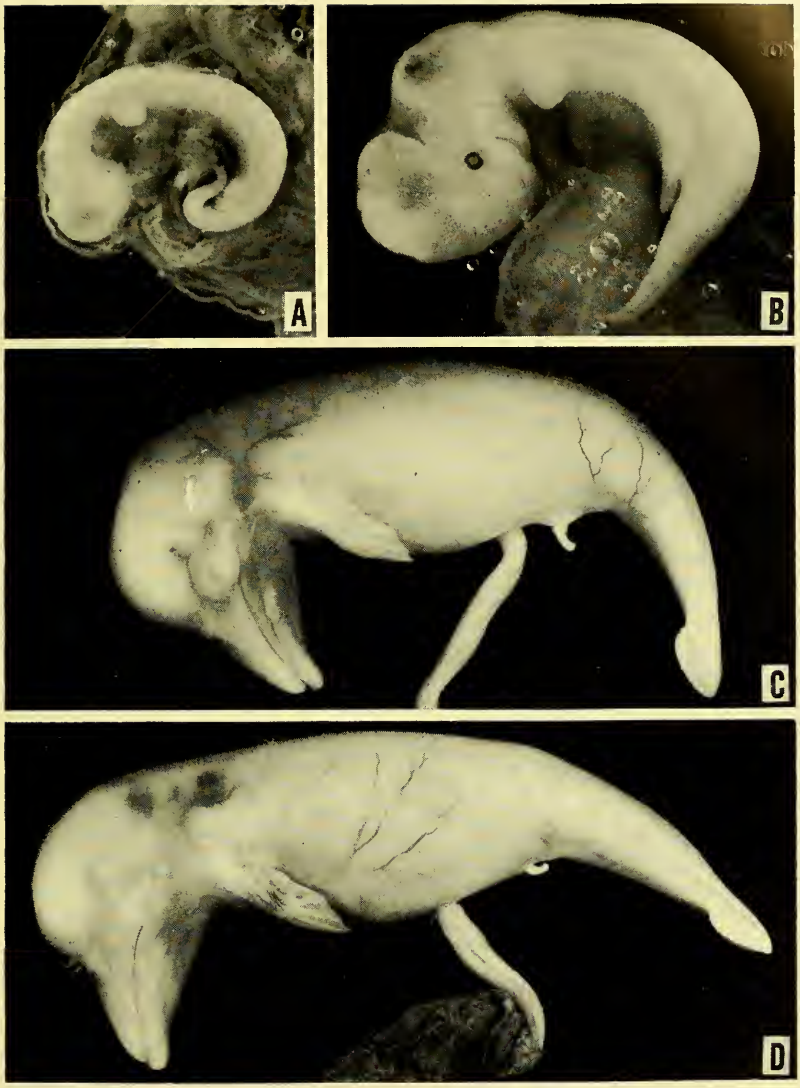

FIG. 27. Embryos and early fetuses of gray whales. A, 25-millimeter (10 millimeters crown-rump) female embryo, estimated age 55 days; B, 39-millimeter (16 millimeters crown-rump) male embryo, estimated age 70 days (note hind limb buds); C, 120-millimeter male fetus, estimated age 87 days (note size and position of penis); D, 110-millimeter female fetus, estimated age 86 days (note size and position of clitoris).

data from near-term fetuses are even less useful for calculating conception dates.

Gestation Period and Fetal Growth.—Available measurements of fetuses are limited to the periods of early and late pregnancy.

A total of 22 embryos and early fetuses was collected between 21 February and 10 March (Table 10, Fig. 27). Body length, measured from the crown to the tip of the straightened tail varied between 25 and 140 millimeters (mean, 96; standard error, 6).

Additional data on fetal sizes in the gray whale are contained in a number of reports. Scammon (1874) examined five embryos taken on the California coast, but gave no measurements or dates. Andrews (1914) reported fetuses 180 and 250 millimeters long taken on 13 and 14 March 1912, on the coast of Korea. Pike (unpublished data) found a 250-millimeter fetus the first week of April from the coast of Vancouver Island, British Columbia. Zenkovich (1937*a*) published data for 16 fetuses collected in the Bering Sea between 8 August and 24 September. Their lengths ranged from 1.70 to 2.64 meters, with a mean and standard error of 2.05 ± 0.06. Townsend (1887) examined four fetuses taken in December 1885 at San Simeon, California, and stated: "Their average length was about 12 feet [3.66 meters]; the longest . . . 17 feet [5.18 meters] long." Andrews (1914) inconsistently reported one fetus taken at Ulsan, Korea, on 8 January 1912, as 4.35 and 4.76 meters long.

We measured 55 near-term fetuses (30 males, 25 females) collected during a 38-day period from 14 December to 20 January. The length varied between 3.60 and 5.31 meters, with a mean and standard error of 4.62 ± 0.05 (Table 11, Fig. 28). The average length of females (4.65 ± 0.06 meters) was slightly greater than that of males (4.60 ± 0.08), but the difference was not statistically significant ($P > .10$). If these measurements are grouped by shorter time periods, they show no change in mean length from mid-December until late January. This suggests that the timing of migration of a pregnant female depends upon how advanced her pregnancy is.

The statistics for Norwegian factory ship operations near the calving grounds on the west coast of Baja California from 1924 to 1927 (published in part by Risting, 1928) list 20 fetuses taken from 29 December to 16 February with estimated (not actually

TABLE 11

BODY LENGTH OF NEAR-TERM FETUSES OF GRAY WHALES.

Date of collection	Length (meters)	
	Males	Females
14 December	4.86	
15 December		4.58
16 December	4.53, 4.65, 4.67	
18 December		4.50
19 December	4.15	
20 December	4.07, 4.54, 4.84	4.55, 4.78, 5.12
21 December	3.85, 4.62, 4.63	5.08
22 December	4.62, 4.79	
27 December	4.22, 4.89	3.60
28 December	4.52, 4.81	4.32
29 December	4.70	5.12, 5.12
30 December		5.24
2 January	4.72	4.58
3 January	4.77, 5.31	4.42, 4.44, 4.93
4 January		4.54, 4.92
5 January	4.72	4.24
7 January	4.52, 5.24	4.43
8 January		4.11, 4.73
11 January		4.33, 5.11
12 January	4.59	
13 January	4.41, 4.48	
15 January	4.26	
16 January	4.53	
18 January		4.80
19 January	4.39	
20 January		4.75

measured) lengths ranging from 6 to 18 Norwegian feet (1.90 to 4.71 meters).

Measurements of six recently born calves found dead at Laguna Ojo de Liebre, Baja California, in late January and early February, are given by Eberhardt and Norris (1964). These ranged from 3.95 to 5.40 meters (mean, 4.68; standard error, 0.245). Gilmore (1960*a*) also listed measurements of seven recently born calves found in the same lagoon. The total lengths given for these calves (3.54 to 4.51 meters, mean, 4.05) are well below those presented by Eberhardt and Norris and even average less than our December fetuses. Therefore, we can only conclude that Gilmore made his measurements differently or that the published figures are in error.

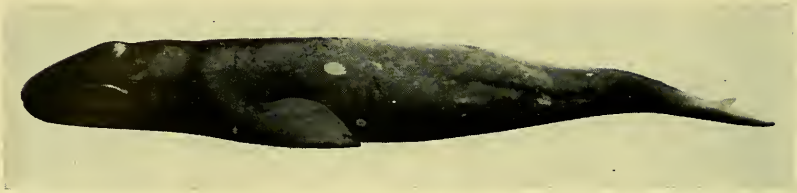

Fig. 28. Near-term gray whale fetus 4.54 meters long. Note color pattern of whitish rings and blotches (the other marks are postmortem abrasions).

Only three of the series of measurements presently available are large enough to provide statistically reliable data for use in constructing a fetal growth curve for the gray whale. These include our series of early embryos and fetuses, Zenkovich's series taken in late summer, and our series of near-term fetuses. The means for these three sets of measurements have been plotted in Fig. 29. It is apparent that the points do not fall on a straight line. Laws (1959) found that in balaenopterid whales, excepting the earliest

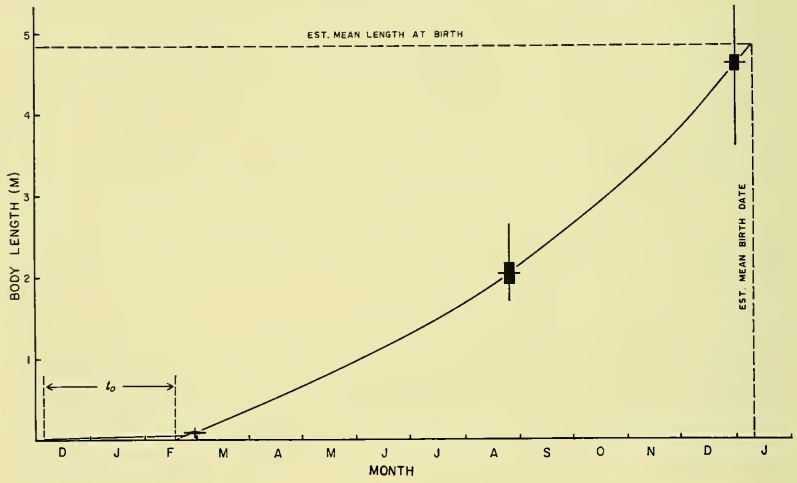

Fig. 29. Estimated prenatal growth curve based on measurements of 22 embryos and early fetuses collected in February and March, Zenkovich's (1937*a*) 16 mid-term fetuses collected in August and September, and 55 near-term fetuses collected in December and January. Horizontal dashes indicate means; vertical bars represent two standard errors on either side of mean, and vertical lines represent the range. For estimation of t_0 see text.

part of pregnancy, the length of the fetus increases linearly during the first half of pregnancy and logarithmically during the last half. A similar curve fits the present data (Fig. 29). From the slope of the lower portion of this curve, we estimated the "specific fetal growth velocity," or a of Huggett and Widdas (1951), as 0.95.

To determine the total gestation period, it is necessary to estimate the length of the gestation period before the beginning of the linear growth phase, termed t_0 by Huggett and Widdas (1951). J. G. Sinclair, who is studying the anatomy of two early fetuses (25 and 39 millimeters long from crown to tip of tail, and 10 and 16 millimeters in crown-rump length), has, on the basis of their stage of development, estimated their ages at about 55 and 70 days. According to Sinclair, the rapid linear growth phase starts when ossification begins, at a crown-rump length of about 35 millimeters; this is equivalent to a length of about 55 from crown to tip of tail. Judging from the estimated ages of the two early embryos, this length would be reached at an age of at least 80 days, or perhaps slightly more. An estimate of t_0 will therefore be $80 - (5.5 \times 0.95)$, or about 75 days. The growth curve, extrapolated backwards, intercepts the abscissa on 18 February (Fig. 29). Adding to this the estimate of t_0, the calculated mean conception date falls on 5 December.

If the growth curve is projected forward, it intercepts the mean length of the six newborn calves observed by Eberhardt and Norris (1964) on 2 January, only 2 days later than the mean date of passage of pregnant females past San Francisco. Considering the speed of migration, it would take the whales at least 9 to 12 days to travel from San Francisco to the major calving grounds at Laguna Ojo de Liebre, Laguna San Ignacio, and Bahia Magdalena. Therefore, the mean birth date would be about 10 January, when the projected growth curve reaches 4.90 meters. This estimate of length at birth falls within one standard error of the mean of newly born calves, so the agreement is close.

Based upon the calculated mean dates of conception and parturition, the mean length of the gestation period is estimated to be slightly more than 13 months, or about 400 days.

Applying Laws (1959) method of estimating t_0 for baleen whales to the data of this study yields values of only 31 days for t_0 and

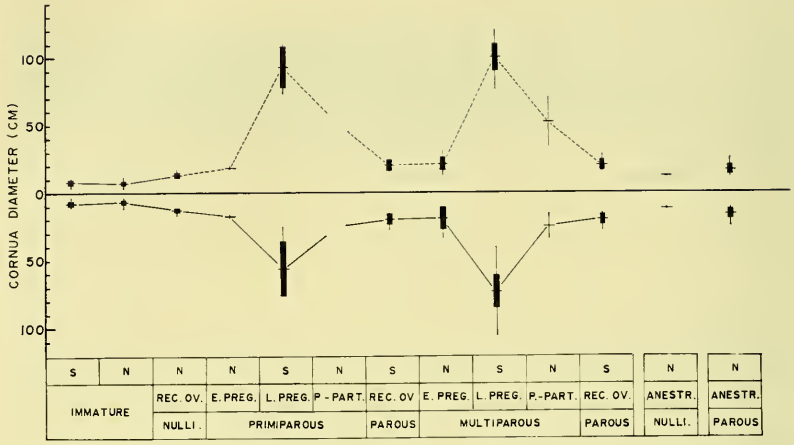

FIG. 30. Diameter of the uterine cornua of gray whales in different stages of the reproductive cycle. For pregnant and postpartum females, measurements of the horn in which implantation occurred are plotted above the base line and those for the other horn below. Symbols are as follows: horizontal dashes, mean; vertical bars, one standard deviation on either side of the mean; vertical lines, range; S, southbound migrants; N, northbound migrants.

no more than one year for total gestation period, which are not consistent with the actual data. The discrepancy results from the way in which Laws interpreted data for several species of terrestrial mammals given by Huggett and Widdas (1951) in estimating the length of t_0 for three species of odontocetes in which fetal growth is linear until the end of pregnancy. His estimates showed an *inverse* relationship between t_0 and length of gestation period (and also a). Huggett and Widdas' data show, however, that "t_0 *increases as gestation times lengthen* but forms a decreasing fraction of total gestation time" (italics added). There are no data to justify Laws' conclusions; his error appears to be the result of using imprecise, arbitrary percentage values for t_0. Laws then estimated the length of t_0 in the humpback whale as 38 days on the basis of published fetal length data and Chittleborough's (1954, 1958) data on the mating and calving seasons. Chittleborough's data suggest, however, a peak conception date in late July, not early August as stated by Laws, so Laws' estimate of t_0 is doubtless too short. Since his four estimates of t_0, for three species of odontocetes and one

mysticete, showed an apparently consistent inverse relationship between t_0 and a, he extrapolated these results to other species of baleen whales. This resulted in his inexplicable and anomalous conclusion that the larger species of balaenopterid whales have shorter gestation periods than the smaller ones. Any logical extrapolation of the data presented by Huggett and Widdas would result in an estimate of at least 50 or 60 days for the duration of t_0 in larger cetaceans. In any event, it is dangerous to extrapolate from small terrestrial mammals to large cetaceans.

We suspect that when more direct evidence is available on early embryonic growth, most large mysticetes will be found to have a gestation period of about a year or somewhat longer. It is certainly approximately 13 months in the gray whale, and probably more than a year in the humpback whale. A gestation period longer than one year would not preclude an occasional pregnancy resulting from a postpartum ovulation, as has been reported in fin whales (Laws, 1961) and humpback whales (Chittleborough, 1958), but it does indicate that such pregnancies cannot occur regularly if a marked seasonality of breeding is to be maintained.

Calving Season.—The mean calving date, as indicated above, is estimated to be about 10 January. The duration of the calving season should be generally similar to that of the breeding season, but slightly more prolonged because of individual variation in the length of the gestation period. As noted above, the timing of the southward migration of pregnant females depends on the stage of gestation. Because late pregnant females pass San Francisco for at least 38 days, we may assume that the calving season lasts about that many days. Therefore, we estimate that calving occupies a period of 5 or 6 weeks from late December to early February. This is corroborated by field observations of recently born calves (Eberhardt and Norris, 1964; Gilmore, 1960*a*, 1960*b*; Gilmore and Ewing, 1954; Hubbs and Hubbs, 1967).

Cyclic Changes in the Uterus.—Gray whales have a bipartite uterus similar to that of other baleen whales (Mackintosh and Wheeler, 1929; Matthews, 1948). The placenta is of the diffuse, nondeciduate, epitheliochorial type. Measurements of the diameter of the uterine cornua of specimens examined in this study are presented in Fig. 30. Histological characteristics of the endometrium

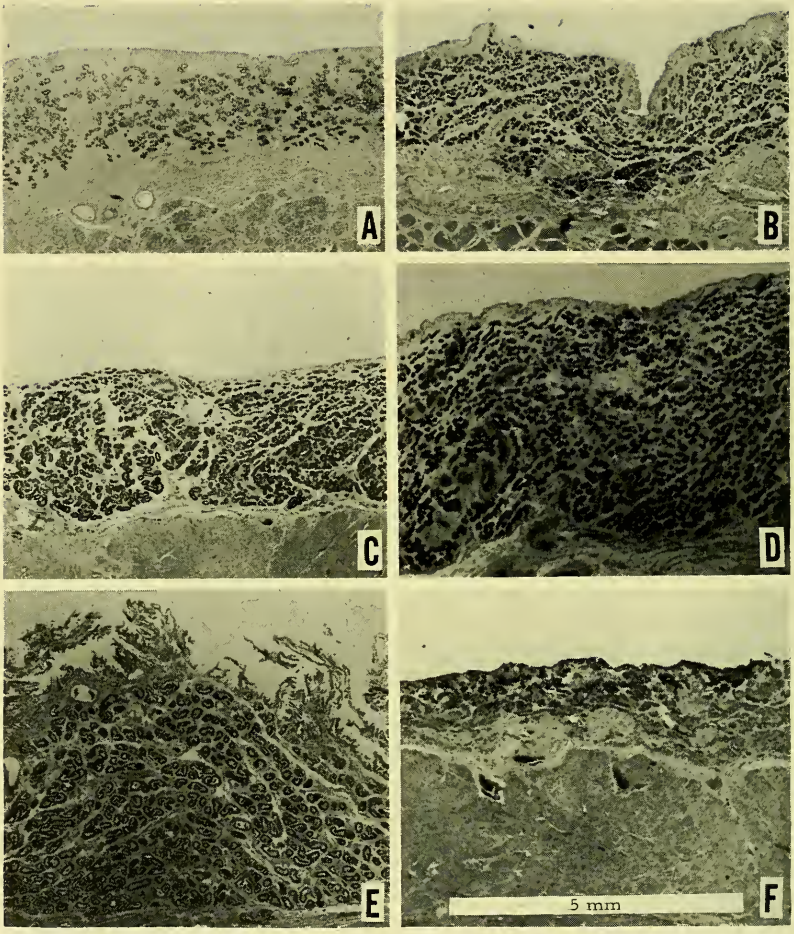

FIG. 31. Photomicrographs of sections of the endometrium of gray whales in different stages of the reproductive cycle. A, immature female; B, northbound anestrous female; C, southbound recently ovulated female; D, northbound early pregnant female (110-millimeter fetus); E, southbound late pregnant female (3.60-meter fetus); F, northbound postpartum female. All sections are to same scale.

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TABLE 12

CONDITION OF THE UTERUS OF GRAY WHALES IN VARIOUS STAGES OF THE REPRODUCTIVE CYCLE.

Direction of migration and reproductive status[1]	Number	Thickness of wall (mm)		Height of folds (mm)		Endometrium thickness: Total (mm)		Endometrium thickness: Stratum compactum (microns)		Endometrial glands: Diameter (microns)		Endometrial glands: Spacing
		Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Immature (S)	10	10.4 ± 3.6	4–16	8.2 ± 3.3	3–12	2.9 ± 1.5	1.1–5.4	63 ± 15.4	30–90	50 ± 12.5	30–70	Wide
Immature (N)	23	9.1 ± 3.7	4–18	10.2 ± 4.3	4–20	1.6 ± 0.8	0.9–3.8	81 ± 28.3	35–150	42 ± 8.0	35–70	Wide
Anestrous (nulliparous) (N)	1	18		11		2.5		65		50		Close
Recently ovulated (multiparous) (S)	7	16.3 ± 4.1	11–23	10.0 ± 5.0	5–20	2.9 ± 0.9	1.9–4.2	109 ± 40.3	75–175	70 ± 18.8	55–65	Close
Early pregnant (primiparous) (N)	2	17.5	17–18	9.5	9–10	4.3	2.6–5.9	165	155–175	68	60–75	Close
Late pregnant (primiparous) (S)	5	13.6 ± 4.2	7–18	3.2 ± 2.5	1–7	3.1 ± 0.4	1.2–5.1	556 ± 360.6	315–1150	102 ± 22.1	95–145	Close
Anestrous (parous) (N)	7	18.6 ± 5.8	9–26	15.1 ± 5.2	4–20	1.8 ± 1.4	0.6–4.0	96 ± 32.9	70–360	39 ± 9.9	30–60	Close
Recently ovulated (parous) (S)	21	23.0 ± 6.5	11–35	9.9 ± 7.5	0–25	3.3 ± 2.6	1.1–13.5	135 ± 54.7	75–250	61 ± 14.1	45–75	Close
Early pregnant (multiparous) (N)	17[2]	18.4 ± 5.0	8–29	9.3 ± 5.4	2–20	3.4 ± 0.9	2.4–5.3	153 ± 30.9	95–200	57 ± 10.4	45–80	Close
Late pregnant (multiparous) (S)	48[3]	24.4 ± 7.5	12–45	4.9 ± 2.7	0–21	3.9 ± 1.5	1.3–10.0	724 ± 400	190–2400	128 ± 17.9	90–170	Close
Postpartum (multiparous) (N)	2	22.5	21–24	19.5	14–25	1.6	1.0–2.1	75	70–80	40	30–50	Close

[1] (S) = southbound migrants, (N) = northbound migrants.
[2] N = 18 for wall thickness; N = 14 for stratum compactum thickness.
[3] N = 45 for stratum compactum thickness.

are illustrated in Fig. 31 and endometrial measurements are presented in Table 12. There was no endometrial epithelium in any of our specimens, probably because of postmortem changes.

In immature whales (Fig. 31A), the diameter of the uterine cornua ranges from 3.5 to 12.0 centimeters. The average thickness of the wall is 9 millimeters and the mean height of cornual folds is 10 millimeters. The average thickness of the endometrium is 2.9 millimeters in southbound animals and 1.6 in northbound animals. The surface of the endometrium is fairly smooth, with only a few small furrows, and it has few glandular ducts that have a mean diameter of 44 microns. The lumina of the glands are either small or not visible. Capillaries are scattered but fairly numerous.

At any stage of the reproductive cycle the uterine cornua of primiparous females average smaller than the cornua of females that have undergone a previous pregnancy, but they cannot be distinguished on the basis of histological criteria.

The cornua of northbound, sexually mature, anestrous females (Fig. 31B) are in the fully involuted condition. They range from 11 to 26 centimeters in diameter and 19 millimeters in thickness, and the folds are high, averaging 15 millimeters. The mean thickness of the endometrium is 1.8 millimeters, of which the stratum compactum comprises 96 microns. The area of division between the stratum compactum and the stratum spongiosum is poorly defined. The glands are small, with a mean diameter of 39 microns, and are more closely spaced than in immature females.

The cornua of southbound whales that have recently ovulated (Fig. 31C) are slightly larger than those of anestrous females. They range from 15 to 28 centimeters in diameter. Mean fold height has decreased to 10 millimeters, and the mean thickness of the endometrium and stratum compactum have increased to 3.3 millimeters and 135 microns, respectively. The inner surface of the uterus is more uneven than in immature individuals, with deeper furrows and a greater number of glandular openings. The average diameter of the glands has increased to 61 microns, and the lumina are mostly open. These data on gray whales differ from Matthew's (1948) observation (based on one specimen) that in fin whales there is a marked temporary increase in endometrial thickness and gland diameter at the time of ovulation.

In early pregnancy (Fig. 31D), the cornua range from 12 to 34 centimeters in diameter, the difference between gravid and nongravid cornua not being statistically significant. Mean fold height is 10 millimeters. The endometrium (mean, 3.4 millimeters) and the stratum compactum (mean, 153 microns) are slightly thicker than in recently ovulated animals, and there are many large vessels visible in the stratum spongiosum. The glands have a mean diameter of 57 microns, slightly less than in females that have recently ovulated. No dendritic structures are visible yet, though the surface is quite uneven and numerous crypts are visible in the stratum compactum.

Whales in advanced pregnancy (Fig. 31E) have wide cornua, ranging from 76 to 120 centimeters in diameter in the horn carrying the fetus and from 40 to 105 in the other horn. The nongravid horn contains part of the placental membranes of the fetus and is filled with fluid. The uterine wall is greatly thickened, mostly as a result of an increase in the thickness of the inner layer of circular muscles. The folds have almost disappeared, contrary to the condition reported in blue and fin whales by Slijper (1956). Their disappearance seems to be a direct result of the distension of the uterine wall, and they tend to reappear when samples of the wall contract in fixatives. The endometrium is relatively thick (mean, 3.9 millimeters) because of highly developed dendritic structures, which average 724 microns in height. One female with a length of 12.98 meters had a maximum stratum compactum thickness of 3600 microns. This is markedly thicker than that of the fin and blue whales in late pregnancy which Matthews (1948) examined, the thickest of which was 200 to 1000 microns. Vessels in the stratum spongiosum are large and many are filled with blood cells. The mean diameter of the glands has increased to 128 microns.

In the two postpartum whales examined (Fig. 31F), the cornua that had contained the fetus were 34 and 70 centimeters wide, whereas the others were 16 and 34. The uterine folds were 14 and 25 millimeters high. The thickness of the endometrium had decreased to 1.0 to 2.1 millimeters and the stratum compactum to 70 to 80 microns. Dendritic structures were absent, and blood vessels were fewer and smaller. Gland diameters also had decreased to 30 to 50 microns.

Position of the Fetus.—All near-term fetuses were positioned in the uterus with the tail towards the cervix; this would ensure caudal presentation at birth, as is usual in cetaceans (Slijper, 1956). Inasmuch as the uterine horns are curved during advanced pregnancy, the head of the fetus is actually oriented towards the tail of the mother.

There was no evidence of differential tendency for implantation to occur in the right or left uterine horns. In 76 pregnant females, the fetus was in the left cornu in 37 and in the right in 39. In three cases, the fetus was in the cornu on the side opposite the ovary containing the corpus luteum, indicating transuterine migration of the ovum.

Weight Gain During Pregnancy.—During the southward migration, females carrying near-term fetuses averaged 35 per cent heavier than those that had recently ovulated and most of which had presumably weaned a calf a few months previously (Table 3; Figs. 7–8). About 1000 to 2000 kilograms of this difference can be attributed to the fetus and fetal membranes and fluids, so that the gain in body weight attributable to fat stores is about 25 to 30 per cent. As there is no difference in blubber thickness between these two classes of females, most of the weight increase may be attributed to increased body fat stores.

Extra energy stores are necessary in late pregnant females to sustain rapid fetal growth and maintain the newborn calf, as well as provide for their own needs during the southward migration, the winter, and the northward migration. Acquisition of extra fat stores during pregnancy is characteristic of some other marine mammals that fast throughout the entire lactation period (Kenyon and Rice, 1959; Rice, 1960).

Lactation

Lactation Period.—According to Tomilin (1957), juvenile gray whales taken during August, September, and October in the Bering and Chukchi seas had already been weaned. He assumed that animals 8.5 to 9.5 meters long were calves of the year, an assumption supported by our data (see section on growth). None had milk in its stomach and even the smallest had been feeding on crustaceans,

although many still accompanied their mothers (Zenkovich, 1937*a*). These Russian workers examined 57 sexually mature females (we are assuming that females 12.0 meters or more in length were sexually mature); of these, 16 were pregnant. Of the remaining 41, only three were still lactating, including one collected on 21 August and another on 1 September. The collection date for the third is not given.

Maher (1960) reported the capture of two lactating females accompanied by calves at Barrow, Alaska, on 19 July and 13 September. The calf of the specimen taken in July had an estimated length of 25 to 28 feet (7.6 to 8.5 meters) and the young of the other was also about 25 feet. On 10 August a 25-foot calf associating with an adult was killed in the same area.

Tomilin and Zenkovich estimated 6 months as the mean length of the lactation period. They believed that most calves were born in February. As the present data indicate mid-January as the peak of the calving season, 7 months seems a more reasonable estimate of the mean duration of lactation. However, more data are needed. As with other cetaceans, weaning is probably gradual and prolonged.

Cyclic Changes in the Mammary Glands.—In gross anatomy, position, and relative size, the mammary glands of gray whales are similar to those of other baleen whales. Changes in thickness of the gland at different phases of the reproductive cycle are shown in Fig. 32. The histological specimens were not fresh enough at time of fixation to allow study of cellular details.

The mammary glands of one 11.8-meter, sexually immature female were 77 centimeters long and 17 wide. The maximum thickness of the glands of immature females was 1.0 to 6.5 centimeters. The fresh tissue of mammary glands of virgin females is pinkish in color. The glands consist mostly of stroma. The lacteal ducts are small, widely spaced, and surrounded by only a thin layer of glandular tissue.

The mammary glands of nulliparous females at puberty and females early in their first pregnancy resemble those of virgin females in their histology, but they may be slightly thicker (up to 9.0 centimeters). The mammary glands of primiparous females in late pregnancy consist of 66 to 91 per cent (mean, 81) glandular

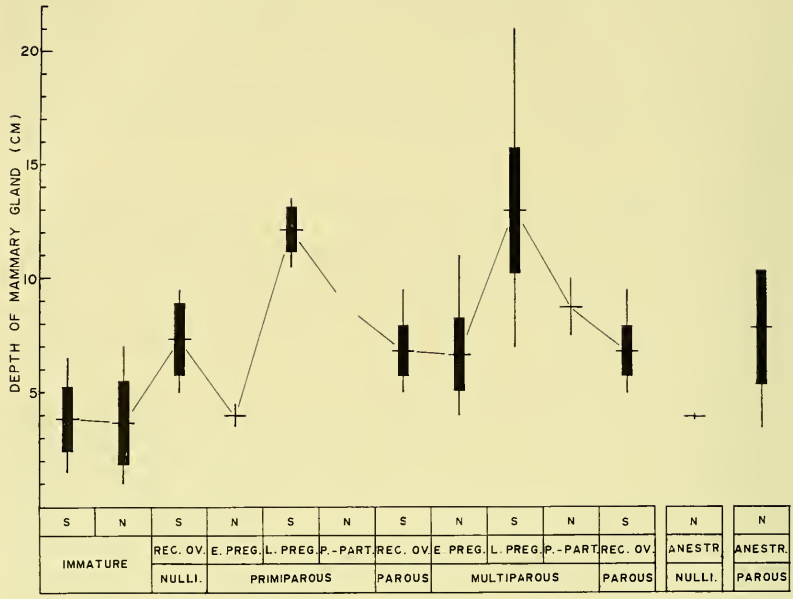

FIG. 32. Thickness of mammary glands of gray whales in different stages of the reproductive cycle. Symbols are as follows: horizontal dashes, mean; vertical bars, one standard deviation on either side of mean; vertical lines, range; S, southbound migrants; N, northbound migrants. Values plotted for postpartum females were from nonlactating individuals.

tissue and are grossly and histologically indistinguishable from those of multiparous females.

The involuted glands of parous animals in anestrus taken during the spring migration are larger than those of virgin individuals. One female 13.3-meters long had mammary glands 145 centimeters long and 32 wide. The mammary tissue varies from 3.5 to 10.0 centimeters (mean, 7.8) in thickness and is pale yellowish-brown in color. Histologically, the glands consist of 37 to 66 per cent (mean, 56) glandular tissue separated by a moderate amount of stroma. They show an extensive system of secretory lobules, which in section are somewhat polygonal and flattened. No secretory activity is apparent.

All females collected during southward migration that had recently ovulated, the majority of which had presumably ceased lactating about the previous July, had nearly or completely involuted glands 5.0 to 9.5 centimeters in thickness. They consisted of 41 to 65 per cent (mean, 53) glandular tissue, and were not distinguishable histologically from the glands of the anestrous females taken in spring. No secretory activity was noted.

The mammary glands of northbound females in early pregnancy also were grossly and histologically indistinguishable from the involuted glands of anestrous females. They consisted of 24 to 63 per cent (mean, 43) glandular tissue.

The mean depth of the lacteal tissue of females in advanced pregnancy was 13.0 centimeters. The mammary tissue is pink and softer than that of involuted glands, and histologically it shows extensive proliferation of the lobule-alveolar system. In section the lobules are large and round, comprising 67 to 91 per cent (mean, 80) of the gland, with relatively little stroma. In a few of the glands examined at this stage, no secretory activity was noticeable, but most already showed a considerable amount of secretory activity. Some had only a small amount of translucent, yellowish fluid in the ducts, others contained so much fluid (colostrum?) that it spurted from the teats when the animals were hauled onto the flensing deck. One female that apparently had recently aborted (or was immediately postpartum), killed on 8 January, had the thickest glands (21.0 centimeters) of any examined and was secreting colostrum copiously.

Unfortunately, we collected no actively lactating animals. The glands of the two nonlactating, postpartum females were grossly and histologically indistinguishable from those of females in late pregnancy. Their thickness was slightly reduced; they consisted of 56 to 72 per cent (mean, 64) glandular tissue and were secreting yellowish, translucent fluid.

Zenkovich (1938) reported that the milk of gray whales taken in August near the end of the lactation period consisted of 53.04 per cent fat, 6.38 per cent dry residue, and 40.58 per cent water. The fat content is greater than has been reported for any other species of cetacean.

Anestrus

Females are probably in anestrus for 3 to 4 months from the end of lactation about August until the onset of the next estrous period in late November or December. As noted earlier, a few females fail to come into estrus at this time and presumably would not do so again until at least a year later; they would thus undergo an anestrous period of 16 months or longer. Other females come into estrus but fail to conceive and return to the anestrous state, probably nearly a year in duration.

Discussion and Conclusions

The complete reproductive cycle of the female gray whale occupies 2 years. Females come into estrus during about a 3-week period in late November and early December. They usually conceive following their first ovulation, but if they fail to do so, they may undergo another estrous cycle about 40 days later. Pregnancy lasts for about 13 months (400 days). Parturition occurs within a period of 5 to 6 weeks from late December to early February. The calf is nursed for about 7 months. After weaning their calf about August, females are in anestrus for 3 or 4 months until November or December, when most of them go into estrus and commence a new pregnancy. A few either fail to ovulate, or ovulate but fail to conceive, and are in anestrus for another year. There is no evidence for postpartum or postlactation ovulation. Evidence for the possible occurrence of ovulation following stillbirth or early loss of the calf is suggestive but inconclusive.

The reproductive cycle of the female gray whale is basically similar to that of the larger rorquals. One important difference is that the extremely long migration route and restricted calving grounds of the gray whale impose a much stricter annual schedule. For example, the majority of gray whale calves are born during a period of 5 to 6 weeks, as contrasted with about 5 months in the rorquals.

The gray whale's ovulation rate of about 0.50 per year is less than that reported by some authors for rorquals. The ovulation rate of the fin whale was estimated as 1.40 per year by Laws (1961) and 1.25 per year by van Utrecht-Cock (1965). Laws, however, admitted

that the rate may be only half his estimate. Nishiwaki *et al.* (1958) estimated the ovulation rate of southern fin whales as 0.90 per year and that of North Pacific fin whales as 0.80 per year. Chittleborough (1959) estimated the ovulation rate of humpback whales at 1.10 per year. Nishiwaki *et al.* and Chittleborough assumed that two growth layers were formed in the ear plug each year, so the true ovulation rates are probably nearer 0.40 to 0.45 per year for fin whales and 0.55 per year for humpback whales. The annual ovulation rate of Southern Hemisphere sei whales is 0.69 (Gambell, 1968). Rorquals, apparently unlike gray whales, sometimes experience postpartum and postlactation or summer ovulations.

When comparing ovulation and pregnancy rates of different species and stocks of whales, it must be borne in mind that the reproductive performances of mammals—even large, late maturing and slow breeding species—are quite labile in response to population density in relation to carrying capacity of the range. Laws (1962) and S. Ohsumi and Y. Shimadzu (personal communication) have shown a reduction in age at sexual maturity and an increase in the pregnancy rate of Southern Hemisphere fin whales in response to excessive exploitation. Among large terrestrial mammals, Buss and Smith (1966) have shown a marked decrease in pregnancy rate in a population of African elephants, *Loxodonta africana,* brought about by an increase in population density and resultant deterioration of the habitat.

Presumably population density influences reproduction through nutrition or through ethological factors. In the gray whale, nutrition could be of critical importance, because the pregnant female must accumulate enough energy stores during the summer to support herself and her fetus through a long migration, to support herself and the newborn calf for a month or more on the wintering grounds, and to sustain both herself and the rapidly growing calf during the long return migration to the summer feeding grounds. Under such conditions, selective pressure for suppression of ovulation at times when the female is not physiologically capable of carrying a new pregnancy to term might be expected. Thus it may be that in the gray whale the potentiality for a postpartum estrous cycle is being or has been genetically eliminated from the population.

MALE REPRODUCTIVE CYCLE

DATA on the reproductive biology of the male gray whale were obtained from a sample of 166 animals. Of this number, 123 had attained puberty, including 67 southbound and 56 northbound migrants.

Testes

The testes of gray whales are cylindrical, moderately elongate, and generally similar to those of rorquals.

WEIGHTS.—No significant or consistent difference in weight between left and right testes was found.

In all sexually immature males examined, both testes weighed less than 8.2 kilograms and, in all individuals except three, the combined weight of the testes was less than 5.0 kilograms (Fig. 33). With one exception, the testes of mature males weighed more than 5.7 kilograms and few had testes lighter than 17.0 kilograms. The exception was a mature northbound animal with unusually small testes that weighed only 0.8 kilogram. Following the abrupt increase in testis weight immediately after puberty, the rate of increase rapidly declines with increasing body length.

The paired testes of the southward migrating adult males taken in December and January ranged from 7.9 to 67.5 kilograms, with a mean and standard error of 38.4 ± 1.4. Mean testis weights for 10-day intervals throughout the southward migration period show no significant changes (Table 13). In northbound adults, the testes were much lighter, ranging from 5.7 to 44.8 kilograms with a mean and standard error of 22.5 ± 0.9. Mean testis weights decreased from 24.8 kilograms in late February to 18.0 kilograms by the end of March. Zimushko (1969*b*) found that the testes of 25 adults taken from July through October ranged from 14 to 27 kilograms (mean, 23).

HISTOLOGY.—Because of the rapidity of postmortem degeneration of testis tissue, detailed cytological study of our material was not possible. Representative histological sections are shown in Fig. 34.

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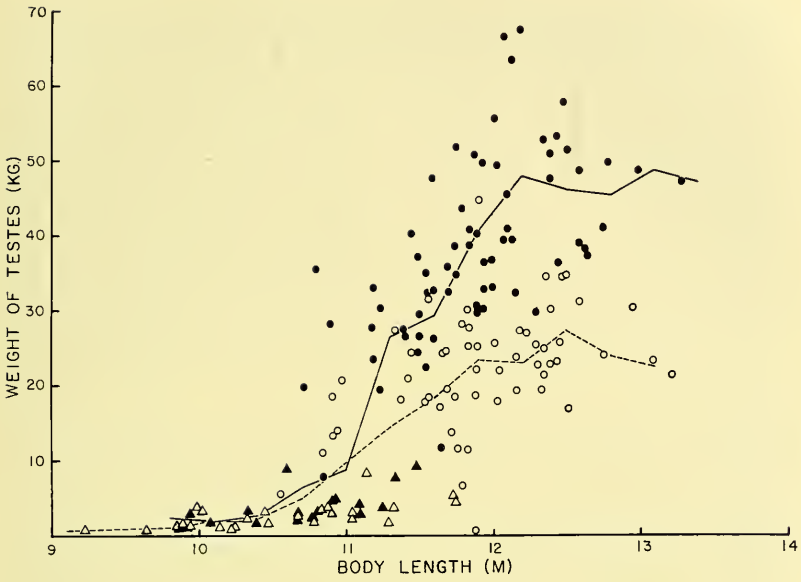

FIG. 33. Testes weights of gray whales in relation to body length. Symbols are as follows: solid triangles, southbound immature males; solid circles, southbound adult males; open triangles, northbound immature males; open circles, northbound adult males. Unbroken line connects means of 0.3-meter length groups of southbound males; broken line connects means of 0.3-meter length groups of northbound males.

In immature testes, the seminiferous tubules were closed and small, their average diameters ranging from 45 to 102 microns (mean, 75). In mature testes, the tubules had open lumina and average diameters ranging from 104 to 214 microns. In males that have reached puberty, there is a significant ($P < .001$) positive correlation between tubule diameter and testis weight (Fig. 35). This correlation is expressed by the formula $Y = 120 + 1.3X$, where Y = tubule diameter in microns and X = testis weight in kilograms.

Mean tubule diameters of the testes of southbound migrants ranged from 114 to 214 microns (mean, 177; standard error, 2). Mean tubule diameter of northbound migrants was significantly smaller, ranging from 104 to 186 microns, with a mean of 148 and a standard error of 3). Mean tubule diameters for each 10-day

TABLE 13

TESTIS WEIGHTS AND SIZE OF SEMINIFEROUS TUBULES OF ADULT MALE GRAY WHALES AT 10-DAY INTERVALS DURING MIGRATION.

Period	Testis weight (kg)			Tubule diameter (microns)		
	N	Mean ± SE	Range	*N*	Mean ± SE	Range
Southward migration						
12–21 December	4	41.3 ± 3.7	33.1–47.6	4	184 ± 3	177–189
22–31 December	6	36.9 ± 6.3	23.5–66.5	6	176 ± 6	154–193
1–10 January	30	36.0 ± 2.3	7.9–63.3	29	171 ± 4	114–206
11–20 January	20	40.4 ± 1.9	26.5–53.2	20	183 ± 4	153–214
21–30 January	7	43.1 ± 5.4	26.1–67.5	7	184 ± 5	161–198
Northward migration						
20 February–1 March	7[1]	24.8 ± 2.6	17.9–34.5	8	147 ± 8	111–179
2–11 March	24	24.0 ± 1.4	11.5–44.8	24	148 ± 4	104–176
12–21 March	15	21.8 ± 1.6	5.7–31.5	14	143 ± 6	107–186
22–31 March	9	18.0 ± 1.4	11.7–23.3	9	156 ± 4	142–186

[1] One male with abnormally small testes weighing 0.8 kg omitted.

interval do not reveal any significant increase or decrease within either migration period (Table 13).

The seminiferous tubules of almost all adult males appeared to be undergoing spermatogenesis, but it was difficult or impossible to ascertain the precise stages. The vasa deferentia and epididymides of all postpubertal males that were examined contained abundant fluid. Because of the long postmortem time, we did not attempt to collect vas deferens fluid for counts of sperm density.

Penis

The penis of the gray whale is an elongate, evenly tapering, conical, flesh-colored organ similar to that of the rorquals, and unlike the slender cylindrical black organ of right whales.

The length of the penis ranged from 55 to 145 centimeters in immature males and from 100 to 170 in adults. There is a significant ($P < .001$) positive correlation between penis length and body length (Fig. 36). This correlation is expressed by the formula $Y = 0.21X - 1.14$, where Y = penis length in meters and X = body length in meters. On the basis of this formula, at a body length of 11.1 meters, which is the average length at puberty, mean penis length is 1.08 meters. A penis length of 114 centimeters correctly separates 79 per cent of our specimens into immature and adult categories.

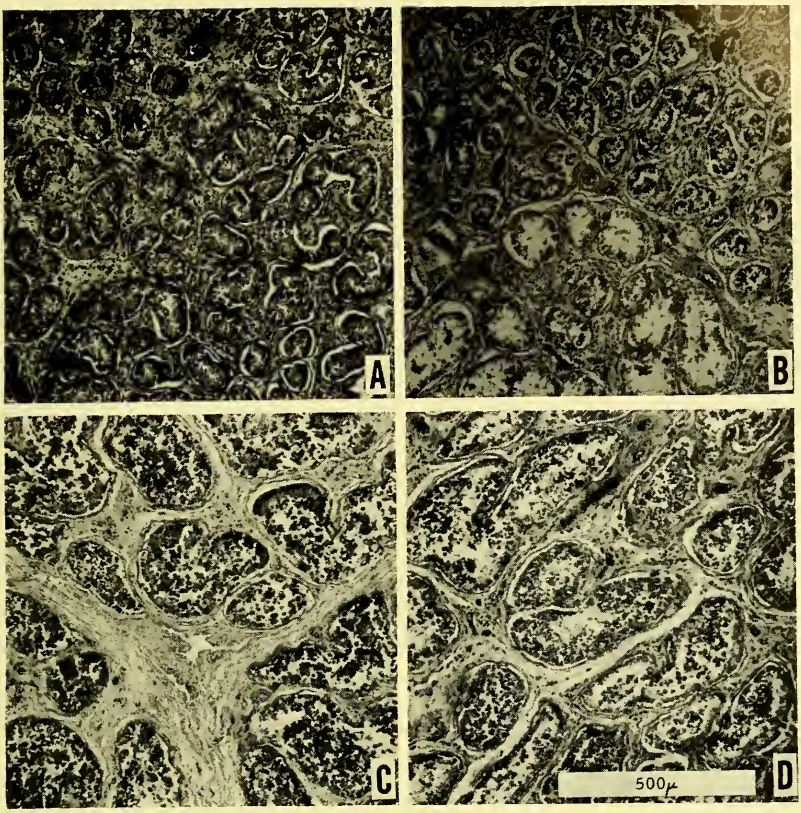

FIG. 34. Photomicrographs of sections of testes of gray whales in different stages of the reproductive cycle. A, immature male; B, pubertal male with both closed and open seminiferous tubules; C, adult southbound male; D, adult northbound male. All sections are to same scale.

Discussion and Conclusions

Testes weighing more than 5.0 kilograms are a reliable indication of maturity in male gray whales. A penis length greater than 1.1 meters also separates most mature animals from those that are sexually immature.

The much heavier testes and larger seminiferous tubules of males taken during southward migration compared with those of males collected during northward migration and on the summer grounds indicate that male gray whales have a marked seasonal sexual

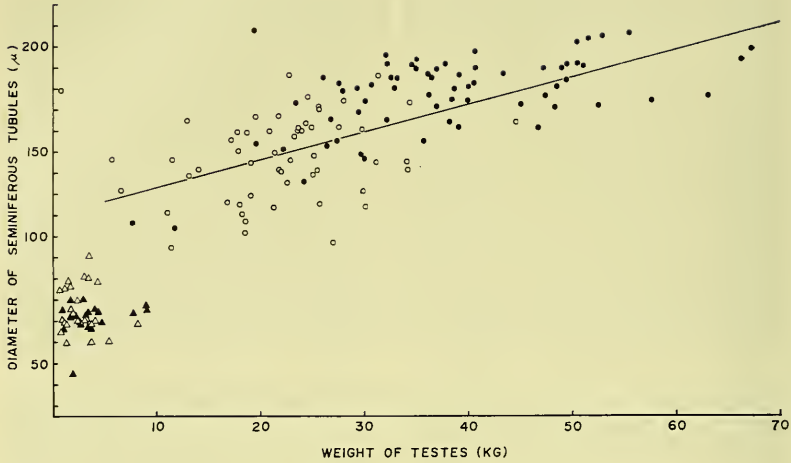

Fig. 35. Relation between size of seminiferous tubules and weight of testes of gray whales. Symbols are as follows: solid triangles, southbound immature males; solid circles, southbound adult males; open triangles, northbound immature males; open circles, northbound adult males. Regression of tubule diameter on testis weight based on adult males.

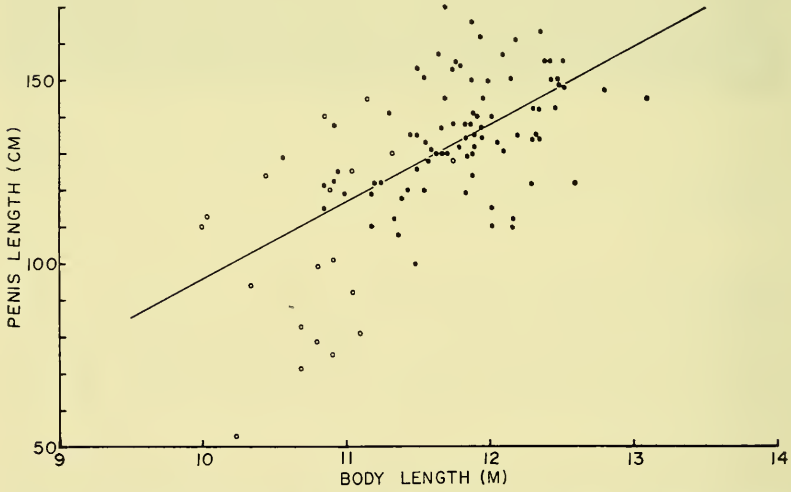

Fig. 36. Relation between penis length and body length of gray whales. Open circles represent immature males and closed circles represent adult males.

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cycle, with a peak of spermatogenetic activity in late autumn or early winter. This period correlates closely with the time females come into estrus. Although there are no reported field observations of copulation at this time, biologists have not studied the behavior of gray whales in southward migration north of San Francisco. Courting and copulating gray whales often are seen on and near the calving grounds in Baja California in January (Gilmore, 1960*a*); this period coincides with the second estrous cycle of those few females that are not impregnated during their first cycle. Apparent courtship behavior, including males with an erect penis, has been observed during northward migration on the coast of California in March (Houck, 1962) and on the coast of Washington as late as April (C. E. Munsen, personal communication). Courtship behavior and apparent copulation also have been observed in the Bering Sea in June, July, August, and September (Sauer, 1963; Fay, 1963; Tomilin, 1937). Its significance at these times is unknown; certainly it never results in successful conception. In the bottlenose dolphin (*Tursiops truncatus*), copulation behavior does not necessarily indicate sexual fertility in males, as males born in captivity may begin to copulate frequently when only a few days old (Caldwell and Caldwell, 1968).

The existence of a male reproductive cycle in other mysticetes appears to be variable. Male humpback whales show a marked seasonal variation in weight of the testes and spermatogenetic activity (Chittleborough, 1955; Nishiwaki, 1959; Omura, 1953; Symons and Weston, 1958). In blue and fin whales there is a less well-marked seasonal cycle in spermatogenetic activity, although available data do not clearly demonstrate an associated cycle in testis weight (Laws, 1961; Mackintosh and Wheeler, 1929). In sei whales there is no seasonal variation in either weight or histology of the testes (Gambell, 1968).

PREDATORS

Killer whales, *Orcinus orca*, are the only known predators of baleen whales (Nishiwaki and Handa, 1958). Killer whales rarely have been observed attacking gray whales. However, Scammon (1874) saw three killer whales attack and kill a gray whale calf accompanied by its mother in a lagoon in Baja California. Gilmore (1961) reported an unsuccessful attack by six killer whales on two gray whales at La Jolla, California. Morejohn (1968) observed an unsuccessful attack by seven killer whales on three gray whales, including a female with a calf, at Moss Landing, California. V. B. Scheffer (personal communication) saw six killer whales unsuccessfully attack a gray whale in Monterey Bay, California, on 9 March 1952. Burrage (1964) observed avoidance behavior of a pod of six gray whales on the approach of five killer whales at La Jolla. Pike and MacAskie (1969) reported killer whales attacking a pair of gray whales off the Queen Charlotte Islands. Andrews (1914) recounted descriptions by whalers of the reaction of gray whales to the approach of killer whales in Korean waters and reported killers feeding on the carcasses of gray whales being towed by catcher boats.

We found healed parallel scars that were obviously the tooth marks of killer whales on 57 (18 per cent) of the gray whales that we examined. Other whales doubtless bore unrecognizable killer whale tooth scars. Fifty-two of the whales had scars on the flukes, and 15 animals had scars on one or both flippers. Eight other whales had scars elsewhere on the body, as follows (number of individuals in parentheses): flanks (four), caudal peduncle (one), anal region (one), dorsal hump (one), throat (one), and snout (one). The predominance of scars on the flukes and flippers suggests that killer whales usually attempt to kill gray whales by seizing their flukes and flippers so as to immobilize and drown them. The number of scarred animals indicates a fairly high frequency of unsuccessful attacks on gray whales by killer whales. The proportion of successful attacks is unknown. Like other predators such as the wolf, *Canis lupus*, killer whales probably succeed

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in killing only a small proportion of the large prey that they attack (Mech, 1966). Jonsgård (1968) has pointed out that there is no incontrovertible proof that killer whales are capable of killing baleen whales that are not incapacitated or otherwise at a disadvantage.

We found no gray whale remains in the stomachs of 10 killer whales taken in the eastern North Pacific, although five of the killer whales were collected at a time when gray whales were present in the vicinity (Rice, 1968).

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PARASITES AND EPIZOITES

Ectoparasites and Epizoites

All gray whales examined were heavily infested with ectoparasites and epizoites, including three species of cyamids and one species of barnacle. Zenkovich (1937*a*) reported that a few gray whales, which had presumably just emerged from brackish lagoons bordering the Bering Sea, carried no cyamids and no live barnacles. He experimentally showed that brief immersion in fresh or brackish waters kills these parasites. We found small patches of an olive-colored skin film on a few whales, but were unable to find any diatoms in scrapings from such areas. Hubbs' (1959) report of kelp growing on gray whales probably was based on observation of whales that had temporarily picked up strands of kelp while swimming through kelp beds. The baleen plates of the whales examined in this study were generally clean and carried no film of microorganisms.

Barnacles.—*Cryptolepas rhachianecti* Dall, 1872 (Fig. 37), is the only barnacle found on gray whales, to which it is host-specific. This sessile species is closely related to the genus *Coronula,* which occurs regularly on humpback whales but rarely on other species. Its mode of attachment to the skin appears to be similar to that of *Coronula* (Darwin, 1854).

These barnacles were present on every whale examined, which has been the experience of other workers who have studied gray whales. They may occur in small clusters almost anywhere on the trunk or on the surfaces of the flukes and flippers, but are most abundant on areas that are exposed to the air when the whale surfaces. They often form a continuous mass on the dorsal aspect of the rostrum and the most anterior part of the back. These areas also are those most directly exposed to food-carrying water currents as the whale stirs up the bottom sediments. The barnacles are oriented with their cirri generally directed towards the anterior end of the whale (Kasuya and Rice, 1970).

Virtually all barnacles on whales taken during the southbound migration are large (20 to 40 millimeters in diameter). Only one

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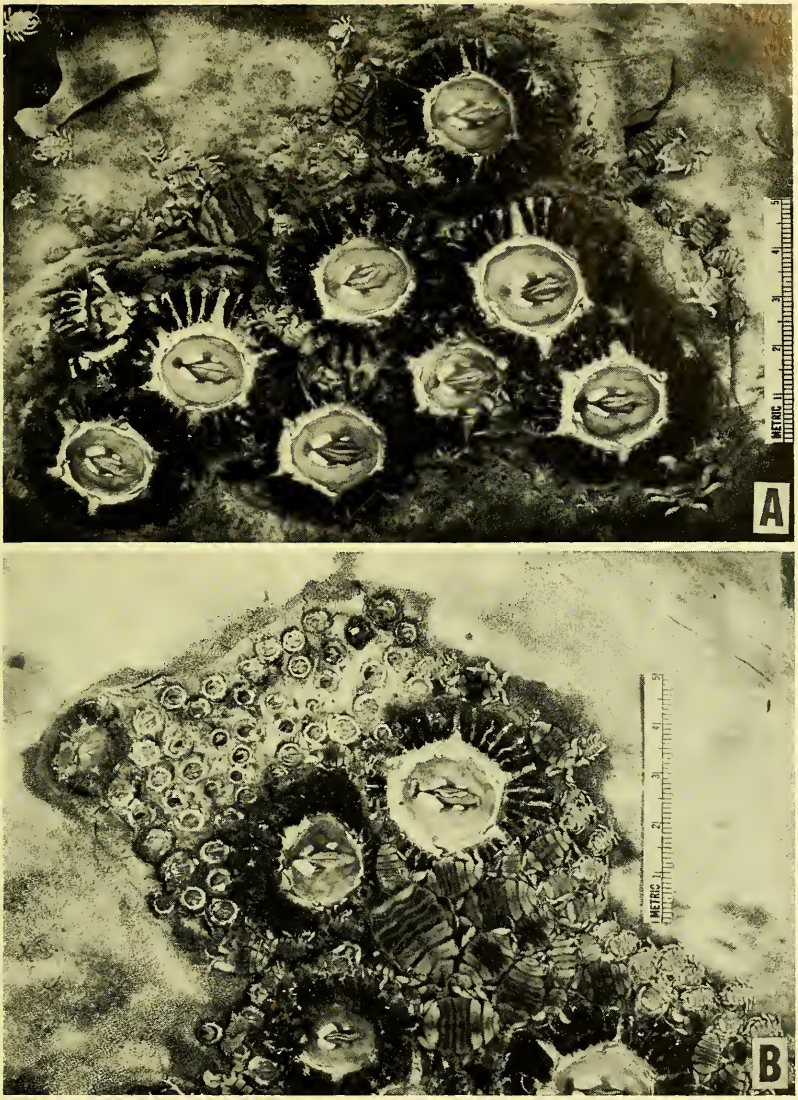

FIG. 37. Barnacles *Cryptolepas rhachianecti* on skin of gray whales. A, southbound whale with large barnacles only; B, northbound whale with many small as well as large barnacles. The anterior end of each whale is to the left. Note the many *Cyamus scammoni* on the barnacle clusters and a few *C. ceti* mostly around the periphery of the clusters.

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southbound whale, a pregnant female taken on 27 December 1968, bore small barnacles (3 to 5 millimeters in diameter). Northbound whales carry two discrete size groups of barnacles. Besides the large individuals that are 20 to 40 millimeters in diameter, there are usually large numbers of small individuals that range from 2 to 5 millimeters in diameter. Thus it is apparent that barnacles spawn while the whales are concentrated on their winter grounds and when the cypris larvae of the barnacles have the greatest opportunity for finding a new host. The small barnacles often are located close together, so there must be much mortality due to crowding as they grow.

CYAMIDS.—Gray whales are host to three species of cyamids (Fig. 37). Most previous workers have reported only one species, the unique and easily recognized *Cyamus scammoni*, but they doubtless overlooked the other species. Hurley and Mohr (1957) were the first to report the other two, *Cyamus ceti* and *C. kessleri*. Few cetaceans are host to more than one species of cyamid. The only other cetaceans on which three species have been found are the right whale and the sperm whale (Leung, 1967), but it is not known how frequently three species of cyamids may occur on a single individual of these host species. All except one of our gray whales were lightly to heavily infested with cyamids, and the three species occurred together on 310 (98.1 per cent) of the 316 examined. However, they tended to segregate on different parts of the body as described below.

Cyamus scammoni Dall, 1872, is invariably the most abundant cyamid on the gray whale and is restricted to this host. We found it on 315 (99.7 per cent) of the 316 whales examined. It is found mostly around clusters of barnacles. A few individuals may be scattered elsewhere on the body, most often in the fold at the axilla of the flippers, in the notch of the flukes, in the umbilicus, and sometimes in the genital groove. We found no trace of the cornified area on the dorsal surface of the rostrum reported by Andrews (1914) and supposed by him to be produced by the action of cyamids. On several whales, we found large numbers of *C. scammoni* in fairly fresh wounds. The two most notable cases were a large adult male taken on 25 March 1964 with a deep wound 1.40 meters long and 0.35 of a meter wide in the blubber of the back slightly to the right

of the middorsal line opposite the flipper; and a female taken on 20 December 1968 with a wound 0.85 by 0.85 meters and 14 centimeters deep on the back about 2 meters anterior to the dorsal hump. In both specimens, the wounds were completely filled with tightly packed masses of cyamids, mostly, if not entirely, *C. scammoni.* More than 100,000 were collected from the male (Leung, 1965). Many of the individuals were exceptionally large.

Cyamus ceti Linnaeus, 1758, was originally described from the bowhead whale from the Atlantic sector of the Arctic Ocean. Hurley and Mohr (1957) first found it on the gray whale at Barrow, Alaska. They reported that their specimens agreed closely with descriptions of this species and with specimens taken from bowhead whales captured at Barrow. L. Margolis (letter, July 1959), however, is somewhat doubtful about the identification of specimens from gray whales as *C. ceti,* because he has found minor differences between specimens from gray whales and those from Atlantic-Arctic bowheads. As most cyamids are host-specific, it would be most unusual for one species to infest hosts belonging to different families. This specificity is, no doubt, primarily a result of cyamids spending their entire life upon the host, so that transference can rarely occur except between members of a pair during copulation or between mother and calf during birth or suckling. This species is much less numerous than *C. scammoni,* but usually more frequent than *C. kessleri.* We recorded it on 314 (99.4 per cent) of 316 whales. It most commonly lives in grooves and skin folds on the body as follows: around the blowholes; in the angle of the gape; in the throat grooves; around the eyes; at the bases of the flippers; on the umbilicus; in the mammary slits; and, rarely, in the genital and anal grooves. Small patches of them are sometimes found elsewhere on bare skin. A few may be found adjacent to *C. scammoni* around the edges of clusters of barnacles, but competition with the larger species appears largely to exclude *C. ceti* from barnacle clusters.

Cyamus kessleri Brandt, 1872, was first described from an unidentified species of whale from the Bering Sea. Hurley and Mohr (1957) rediscovered it on a gray whale killed at Barrow, Alaska. It has subsequently been found only on gray whales. This is usually the least abundant species of cyamid on the gray whale. We found it on 310 (98.1 per cent) of 316 whales. It occurred almost exclusively

around the anus and in the genital grooves. A few were occasionally located in the mammary slits and elsewhere on the body.

Endoparasites

Before these studies, no endoparasites had been identified from the gray whale, although an unidentified cestode was reported by Tomilin (1937) from individuals of this species in the Chukchi Sea. We found eight species of endoparasites in the digestive system, including three trematodes, two cestodes, one nematode, and two acanthocephalans. Some of these seem to represent undescribed species. The taxonomy of the cestodes is being studied by R. Rausch and that of the acanthocephalans by K. Neiland. We found no parasites in the kidneys, lungs, peribullary air sinuses, or blubber. Treshchev *et al.* (1969) have published an abstract of recent studies on the helminthofauna of gray whales in the Bering and Chukchi seas.

Trematodes.—*Lecithodesmus goliath* van Beneden, 1959, was found in only two gray whales. These large flukes live in the bile ducts of the liver. Specimens from gray whales range from 35 to 54 millimeters (mean, 45) in length and 10 to 14 millimeters (mean, 12) in width. This species differs from *L. spinosus* Margolis, 1955, in its incompletely spined cuticle. *L. goliath* has been reported from many species of baleen whales (Delyamure, 1955). Two flukes were found in an immature female whale taken on 16 March 1969; no pathological conditions were grossly visible in the liver. Forty-seven flukes were recovered from a mature male whale taken on 13 March 1969, and many others were doubtless present. The bile ducts of this whale had distorted, inflamed biliary epithelium and were rimmed with thick walls of dense scar tissue. We have never observed such marked pathogenic effects associated with heavy infestations of *Lecithodesmus* in sei whales, which suggests that the gray whale is not a normal host for these flukes.

Orthosplanchnus pygmaeus was described by Yurakhno (1967) from the intestine of a gray whale taken off the Chukotskiy Peninsula. Other members of this genus infest the bile ducts and gall bladder of Arctic pinnipeds.

Ogmogaster pentalineatus Rausch and Fay, 1966, was described as a new species on the basis of our specimens and the type series

collected by Fay from a gray whale at St. Lawrence Island, Alaska. The name *Ogmogaster delamurei* Treshchev (1966*a*), based upon specimens found in gray whales taken in the Chukchi Sea near Enurmino on the Chukotskiy Peninsula, is a junior synonym of *O. pentalineatus* (Skriabin, 1969). *O. pentalineatus* has been found only in gray whales. Entire specimens are easily recognized by the smoothly rounded or weakly undulate edge of the body and by the five ridges on the ventral surface. The species usually does not attain a length greater than about 3.5 millimeters, although one specimen measured 5.6 millimeters.

Field inspection of the surface of the mucosa of the small intestine at several randomly selected points revealed *O. pentalineatus* in only eight (2.5 per cent) whales. A more careful search of a section of the small intestine in a tray of water sometimes showed these flukes to be present in whales in which our spot-check had revealed none. The type series of more than 200 individuals was found in the small intestine (Rausch and Fay, 1966). In 1967, large numbers of this species were discovered in the rectum of one whale, so in 1968 and 1969 that portion of the rectum exposed on the inner side of the blubber after the blubber had been flensed from the whale was routinely examined. *O. pentalineatus* was recorded from 31 (22 per cent) of 139 whales examined in this manner. In all except seven cases, this species was living alongside *O. antarcticus*, although usually in lesser numbers. Of 1280 *Ogmogaster* collected from the rectum of 53 whales, only 227 (18 per cent) were *O. pentalineatus*. Usually fewer than 20 individuals of the latter species were present, but one whale contained well over 100.

Ogmogaster antarcticus Johnston, 1931, occurred in 46 (33 per cent) of 139 whales examined in 1968 and 1969. This species is distinguished from *O. pentalineatus* by the greater number of ridges (12 to 15) on the ventral surface, the 15 to 20 conspicuous marginal crenulations on each side of the body, and the four or five lateral loops in each intestinal caecum. It also typically attains larger size, reaching 6.0 millimeters in length. In rorquals (*Balaenoptera* species), this species has a maximum length of 10 millimeters (Rausch and Fay, 1966). Our specimens agree well with the descriptions of *O. antarcticus* as diagnosed by Delyamure (1955) and Rausch and Fay (1966). *O. antarcticus* has been reported previously from the intestines of Antarctic seals (tribe Lobodontini) and from

the intestines of rorquals in the North Pacific and North Atlantic as well as the Southern Hemisphere. In this study *O. antarcticus* was found only in the rectum. The maximum number recovered from one whale was 199. In 24 of the 139 whales examined it was associated with lesser numbers of *O. pentalineatus*. Treshchev *et al.* (1969), strangely enough, did not find this species in gray whales collected on the summer grounds.

Ogmogaster plicatus Creplin, 1829, was reported in a gray whale obtained off the Chukotskiy Peninsula (Treshchev *et al.*, 1969). Otherwise the species has been found only in the intestines of rorquals in the North Pacific and North Atlantic; we have found it in fin whales collected off San Francisco. This species differs from *O. antarcticus* in having more ventral ridges (19 to 28), more than 20 marginal crenulations on each side of the body, and larger size (maximum length 14 millimeters).

The life histories of the species of *Ogmogaster* are unknown. The food habits of their definitive hosts suggest that their second intermediate hosts are crustaceans.

Cestodes.—The genus *Priapocephalus* includes cestodes characterized by a bulbous scolex that lacks suckers and has a basal collar. *P. eschrichtii* recently has been described by Murav'eva and Treshchev (1970) from gray whales in the Chukchi Sea. The other two described species are *P. grandis* Nybelin, 1922, from rorquals (*Balaenoptera* species) and right whales in the Southern Hemisphere, and *P. minor* Nybelin, 1928, from rorquals in the North Atlantic and North Pacific (Baer, 1954; Delyamure, 1955; Markowski, 1955). The larval host of *Priapocephalus* is unknown. We collected two kinds, apparently different species, from the gray whale.

The commonest species has a narrow (less than 1 millimeter wide) strobila that is of uniform width throughout. It is difficult to collect complete strobilae, but they attain a length of at least 25 centimeters. The proglottids are about 0.3 to 0.4 of a millimeter long, and the scolex is about 3 millimeters in diameter. This species was found in the small intestine of 94 (30 per cent) of the 316 whales. Usually infestations were light and rather local, although a few whales were heavily infested.

The second species differs from the previous species in that its strobila is much wider—2 to 4 millimeters. Although the proglottids

adjacent to the scolex are as narrow as those of the previous species, they rapidly become wider distally. The proglottids are about 0.5 to 0.8 of a millimeter long. The scolex is similar to that of the previous species. This cestode was found in the large intestine of an immature female whale taken on 11 April 1968. The whale was heavily infested with this parasite, and no other species of cestode was present.

Tomilin (1937) reported an unidentified cestode from the gray whale. He stated (translation): "In 1934, internal parasites (tapeworms) Cestoda Ord. Pseudophaliidae [sic] (species not determined) 40 meters in length (deposited in parasitological laboratory of the Institute of Zoology, MGU) were found in the intestines of two gray whales. Their segments attained a width of 2 centimeters. The worms equaled about 48 liters in volume, in each animal." From their size, we would guess that these must be *Diplogonoporus balaenopterae* Lönnberg, 1891, a species frequently found in rorquals (*Balaenoptera* and *Megaptera*). The life cycle of *Diplogonoporus* is unknown, but the plerocercoids can be expected to occur in fishes (Rausch, 1964).

Nematodes.—*Anisakis simplex* Rudolphi, 1809, was found in only one gray whale. There were many immature individuals, 20 to 35 millimeters long, of this species in the first and second chambers of the stomach of an immature male killed on 3 April 1968. They were not attached to the mucosa. In a recent revision of this genus, J. T. Davey (personal communication) recognized only three species. Our specimens differ from *A. physeteris* Baylis, 1923, in the possession of a sigmoid esophagus. Only mature males of *A. simplex* can be distinguished from *A. typica* Diesing, 1860. *A. simplex* occurs in all species of balaenopterid whales as well as many other species of marine mammals from all over the world, especially from colder seas, whereas *A. typica* is known only from delphinids from warmer seas. Therefore Davey (personal communication) had little hesitation in assigning our specimens to *A. simplex*. The life cycle of *Anisakis* is unknown, but it is probable that two intermediate hosts are needed (Berland, 1961). Fishes are the usual source of infestations in marine mammals (van Thiel, 1966), in which these worms reach maturity.

ACANTHOCEPHALANS.—*Corynosoma* sp. was found in 18 (5.7 per cent) of the 316 gray whales studied. They were rather loosely attached to the mucosa of the small intestine. Most infestations were light, the heaviest being a whale that had 60 individuals within a 0.3-meter section of intestine. Specimens from gray whales are 4 to 5 millimeters long; the anterior half of the trunk is bulbous, the posterior half elongate and tapering. Treshchev (1966*b*) described a new species, *C. septentrionalis,* and reported (Treshchev *et al.,* 1969) *C. semerme* Forssell, 1904, *C. strumosum* Rudolphi, 1802, and *C. validum* Van Cleave, 1953, from gray whales collected off the Chukotskiy Peninsula. The life cycles of a few species of *Corynosoma* are known. All these involve crustaceans as first intermediate hosts, and fishes as second intermediate hosts (Golvan, 1959). Seals and aquatic birds are the definitive hosts of most species of this genus; a few species parasitize toothed whales (Delyamure, 1955; Golvan, 1959). The discovery of species of this genus in gray whales is the first known occurrence in a baleen whale, although we recently have found *Corynosoma* in fin whales.

Bolbosoma sp. was present in the small intestine of an immature male whale captured on 3 April 1968. The two specimens found were white and about 30 millimeters long. The trunk (when turgid after being placed in fresh water) was slightly more than a millimeter in diameter. One was loosely attached to the mucosa; the head of the other was imbedded in a small, thick-walled, pus-filled cyst in the mucosa. The life cycles of species of *Bolbosoma* are unknown.

Discussion and Conclusions

The gray whale is more heavily infested with a greater variety of ectoparasites and epizoites than any other species of cetacean. This may be at least partly due to the fact that they swim slowly and live throughout the year in shallow coastal waters rich in nutrients. In contrast, they are infrequently infested with endoparasites. Their long period of fasting each year may inhibit the survival of parasites in the digestive tract. Except for liver flukes, none of the ectoparasites or endoparasites appears to have any significant pathogenic effects.

POPULATION

Although a reasonably complete understanding of the population dynamics of the California stock of gray whales will require further investigation, data obtained in the present study provide a basis for some tentative conclusions.

Present Numbers

Because gray whales migrate close to the coast, a large proportion of the population may be counted from vantage points on shore, providing an index of population size. Between the migration seasons of 1952–53 and 1960–61, four essentially full-time counts were made at the Point Loma coastal station (Gilmore, 1960*a*, 1960*b*; Rice, 1961). In the course of offshore cruises for marking whales of other species, beginning in 1964, we found unexpectedly large numbers of southbound gray whales passing the coast of southern California far offshore (Rice, 1965; unpublished data). However, in the area of the counting station south of Yankee Point, observations during whale marking cruises indicated that few gray whales pass so far offshore that they cannot be seen from land.

Daily counts of southbound whales migrating past these two points are shown in Fig. 38. In 1967–68, 3120 whales were counted at Yankee Point and 1324 at Point Loma. In 1968–69, 3280 were counted at Yankee Point and 1154 at Point Loma. Thus, of the number of whales that passed Yankee Point only 35 to 42 per cent were seen passing Point Loma. In 1969–70, 3345 were counted at Yankee Point, and no count was made at Point Loma.

To calculate total population size from these counts, we must estimate the number of whales that were missed because of poor visibility, the whales that passed too far offshore to be seen, and the whales that passed at night. We estimated the number of whales missed because of poor visibility by considering only the counts made during days when visibility was good. As visibility is limited most by fog, drizzle, or rain, and by winds strong enough to create whitecaps, we considered only the days when there was no precipitation or fog and winds were below 19 kilometers per

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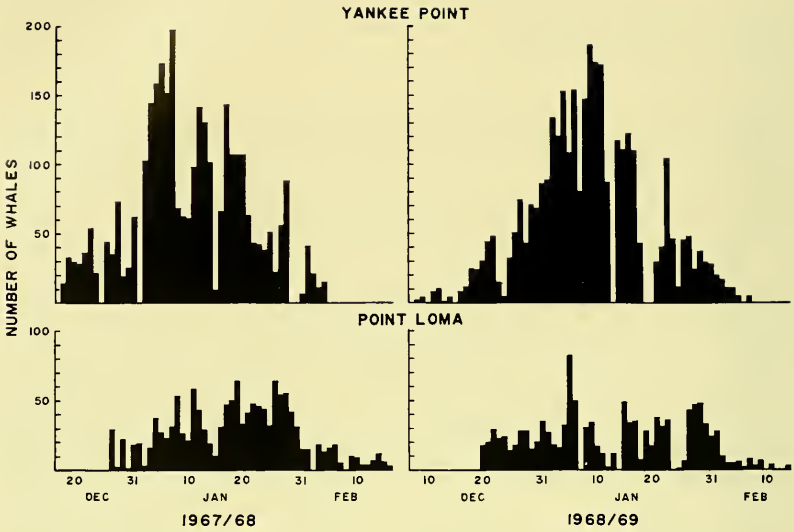

Fig. 38. Daily counts of gray whales passing Yankee Point and Point Loma, California, during the southward migrations of 1967–68 and 1968–69.

hour (10 knots). Days with good visibility and days with poor visibility were interspersed at random throughout each census period, so we extrapolated the counts made during the days with good visibility to include the entire period of each census. Some whales were doubtless missed even during days with good visibility, and, of course, a few passed early in the season before the counts began and late in the season after the counts ended.

To determine the number of whales passing too far offshore to be seen, we ran transect cruises from Yankee Point and Point Loma across the migration path of the whales. In a transect from Yankee Point on 18 January 1968, extending 37 kilometers offshore, no gray whales were seen farther from shore than 6 kilometers, and only nine of the 33 whales sighted were beyond 4.5 kilometers from shore. The remaining 24 were within 1.5 kilometers of land. Under conditions of good visibility, observers on shore could detect whales at an estimated distance of 7.4 kilometers, but 95 per cent of the whales were estimated to be within 1.9 kilometers of shore. Therefore, we conclude that the number of whales passing too far off-

shore from Yankee Point to be seen by the observers during periods of good visibility was insignificant.

Between 25 January and 9 February 1968, we ran seven transects totaling 1572 kilometers between Point Loma and longitude 119°20′ W, just beyond Tanner and Cortez Banks. During 100 kilometers of cruising within 9.3 kilometers of shore, 37 gray whales were seen, an average of 0.37 per kilometer cruised. During 1472 kilometers of cruising beyond 9.3 kilometers from shore, 40 gray whales were sighted, an average of 0.027 per kilometer. The width of the migration path at this latitude is at least 194.5 kilometers, of which 9.3 kilometers is within sight from Point Loma. The ratio of whales passing offshore to those passing within sight of land is thus $(185.2 \times 0.027) : (9.30 \times 0.37) = 5.00 : 3.44$. This ratio indicates that only 41 per cent of the whales migrating south past southern California passed within sight of Point Loma. This agrees with our estimates of 35 to 42 per cent based upon a comparison of the Point Loma and Yankee Point counts. Therefore, we have multiplied the Point Loma counts by 2.44 (100/41), to estimate the total number of whales moving past the latitude of Point Loma during daylight hours.

Because there is no evidence that migrating gray whales slow down at night, we have multiplied the estimated number of whales passing during the 10 hours of daylight during which counts were made by 2.4 to estimate the total number of whales passing each counting station during each of the two seasons.

Estimates of total population size, based on the foregoing corrections, are shown in Table 14. The Yankee Point estimates are probably more accurate than the Point Loma estimates, because of the greater possibility of error in adjusting for offshore migration at Point Loma. The 1968–69 and 1969–70 estimates are probably more accurate than those for 1967–68 because the counts started earlier in the season. The best estimate of the present population size of the California gray whale stock is approximately 11,000.

The reliability of this estimate is difficult to assess. A probable lower limit may be estimated by multiplying the actual counts at Yankee Point by 2.4 to allow for the whales passing at night, which gives figures of about 7500 for all three seasons. An upper

TABLE 14

COUNTS OF SOUTHWARD MIGRATING GRAY WHALES AND ADJUSTED ESTIMATES OF TOTAL GRAY WHALE POPULATION SIZE, 1967–68 TO 1969–70.

Season	Locality	Entire period		Days with good visibility			Estimate of whales passing during daylight	Adjusted for offshore migration	Adjusted for night migration
		No. of days	No. of whales	No. of days	No. of whales	Whales per day			
1967–68	Yankee Point	49[1]	3,120	32	2,430	76	3,724		8,938
	Point Loma	52	1,324	29	879	30	1,560	3,806	9,134
1968–69	Yankee Point	60	3,280	29	2,174	75	4,500		10,800
	Point Loma	57	1,154	26	758	29	1,653	4,033	9,679
1969–70	Yankee Point	64	3,345	32	2,257	71	4,544		10,906

[1] No count made on two of these days.

limit was estimated by drawing a line connecting the highest daily counts at Yankee Point and measuring the area under the line to estimate the number of whales passing during daylight. The total was then calculated by multiplying this value by 2.4 to compensate for night migration. The resulting estimates of the upper limit were about 13,000 in 1967–68, and 12,000 in 1968–69 and 1969–70.

Population Trends

In the decades prior to 1947, before legal protection was afforded by the International Convention for the Regulation of Whaling, the gray whale population is believed to have been considerably lower than it is now, but there are no quantitative data available upon which to base an estimate of its size during this period.

The estimated population size based upon four complete counts made at Point Loma from 1952–53 to 1959–60 (Gilmore, 1960*a*; Rice, 1961) showed a rather consistent increase of about 11 per cent per year. A regression analysis of the logarithms of these counts gives an estimate of the rate of population change as +12.2 per cent per year, with a 95 per cent confidence interval of −4.0 to +31.2 per cent. This study, however, has thrown doubt on the reliability of estimates of absolute population size based upon these counts.

The most questionable factor is the estimate of the extent of offshore movement, which Gilmore arbitrarily estimated at 5 per cent of the inshore movement. In contrast, present evidence indicates that offshore movement is about 144 per cent of the inshore movement along this stretch of coast.

The 1967–68 and 1968–69 counts at Point Loma were 44 and 51 per cent, respectively, below the 1959–60 count of 2344. Either some factor such as increase in small boat traffic has caused a larger proportion of the population to pass farther offshore at Point Loma, or the population in 1959–60 actually was much higher than estimated and has since decreased.

Hubbs and Hubbs (1967) made aerial surveys of the gray whale wintering grounds in Baja California between late January and early March in most years from 1952 to 1964. They suggested that the population increased from 1952 to 1954 and thereafter remained constant at about 3000. A regression analysis of the logarithms of their five complete counts from 1954 to 1964 gives an estimated rate of population change of +0.8 per cent per year, with a 95 per cent confidence interval of −4.5 to +6.4 per cent. Their estimate of absolute population size was based on an "admittedly rather intuitive estimate that about half of the population was observed on the flights." Between soundings, gray whales are at the surface or sufficiently near it to be visible for only about 1 out of every 5 minutes. Therefore, applying this correction to the data of Hubbs and Hubbs would give an estimate of about 7500 animals. Gilmore (1960*a*), who participated in some of these aerial counts, came to a similar conclusion.

In 1966–67, Adams (1968) made a partial count during the southward migration at Yankee Point. His counts were conducted only during periods of optimum visibility and included only 9.16 per cent of the daylight hours during the migration period. The number of whales actually counted was 1084. This count was adjusted to cover all daylight hours, increased by 5 per cent to account for offshore migration and 70 per cent for night migration, to yield a total estimate of 18,300. This estimate is probably too high because the counts were made only during limited periods when the most whales could be seen. Adams reported an average of up to 55 whales passing per hour, which extrapolates to a rate

of 550 per 10-hour day; we never counted more than 46 whales in one hour nor more than 197 per day during our full-time counts from 1967–68 to 1969–70.

Our counts at Yankee Point suggest that the population remained essentially stable from 1967–68 to the 1969–70 season.

Density and Biomass

Population density is ecologically most significant in relation to the feeding grounds. The summer range of the gray whale in the Bering and Chukchi seas occupies about 1,000,000 square kilometers. With a population of about 10,000, the average density is approximately one whale per 100 square kilometers. Density, of course, may vary markedly between different portions of the summer grounds (Berzin and Rovnin, 1966).

The total biomass of the gray whale population based on estimated numbers, sex and age structure, and mean body weights of each sex, age, and reproductive category is estimated at approximately 1.4×10^5 metric tons. The weight of an average gray whale is thus about 14 metric tons. The mean biomass on the summer grounds would thus be about 14 metric tons per 100 square kilometers, or 140 kilograms per square kilometer.

As a gray whale requires an estimated 19 kilocalories per kilogram per day, a 14-ton individual will require about 2.7×10^5 kilocalories per day, or 9.7×10^7 kilocalories per year. Inasmuch as gray whales must consume enough food during about half the year to sustain them the entire year, their daily energy requirements on the summer grounds would be about 5.3×10^5 kilocalories. Thus, if one kilogram of amphipods supplies 500 kilocalories, a gray whale weighing 14 tons must consume about a ton, or approximately 7 per cent of its weight, of amphipods per day.

The gray whale population consumes about 10 kilograms of food per day, or nearly 2 tons a year, per square kilometer. This quantity represents about 0.2 to 1.0 per cent of the standing crop of benthos (Neiman, 1963). Energy exchange amounts to 5.3×10^3 kilocalories per day. Although these figures are rough approximations, they provide some indication of the magnitude of the ecological role of the gray whale in the shallow waters of the Bering and Chukchi seas.

TABLE 15

SEX RATIOS OF GRAY WHALE AGE GROUPS.

Age group	No. males	No. females	Per cent males
Early fetuses	9	13	41
Near-term fetuses	30	25	55
Immatures	43	34	56
Adults	123	116	51
Combined total	205	188	52

Population Structure

SEX RATIO.—The combined sex ratio of fetal, immature, and adult gray whales was 52 per cent males to 48 per cent females (Table 15). In none of the age classes does the ratio differ significantly from one to one. The observed slight preponderance of males is probably not real, especially in view of the fact that lactating females were not represented in the sample.

TABLE 16

AGE COMPOSITION OF ADULT FEMALE COMPONENT OF SAMPLE BASED ON COUNTS OF CORPORA IN OVARIES.

Number of corpora	Estimated age (years)	Number of individuals
1	8–9	8
2	10–11	15
3	12–13	12
4	14–15	11
5	16–17	9
6	18–19	11
7	20–21	11
8	22–23	6
9	24–25	8
10	26–27	5
11	28–29	3
12	30–31	5
13	32–33	4
14	34–35	2
15	36–37	2
20	46–47	1
22	50–51	1
35	76–77	1

TABLE 17
AGE COMPOSITION OF GRAY WHALE SAMPLE BASED ON COUNTS OF GROWTH LAYERS IN EAR PLUGS.

No. of growth layers	Estimated age (years)	Number of individuals		
		Males	Females	Total
2	1	3	5	8
3	2	5	2	7
4	3	2	1	3
5	4	4	2	6
6	5	3	4	7
7	6	5		5
8	7	7	5	12
9	8	3	3	6
10	9	5	3	8
11	10	6	3	9
12	11	3	5	8
13	12	6	4	10
14	13	6	1	7
15	14	2	1	3
16	15		3	3
17	16	4	2	6
18	17	3	1	4
19	18	3	3	6
20	19	3	5	8
21	20	6	1	7
22	21	4	1	5
23	22	2		2
24	23	1	4	5
25	24	1		1
26	25		1	1
27	26		1	1
28	27	1	2	3
29	28	2		2
30	29		2	2
33	32	1		1
35	34	1		1
38	37	1		1
40	39	4	1	5
41	40		1	1
47	46	1		1
48	47		1	1
58	57	1		1
70	69	1		1

AGE COMPOSITION.—Age composition of our sample, based on counts of corpora in the ovaries of adult females and counts of growth layers in the ear plugs of both sexes, is given in Tables 16 and 17. Although corpora counts are believed to be more

reliable than the data from ear plugs, the latter are useful because they are the only known means of determining the ages of males and of immature whales, and they permit a comparison between the sexes.

Immature whales comprised 24 per cent of the sample (26 per cent males, 23 per cent females). The data for this age class are biased because gunners select against smaller animals and because a larger proportion of immature whales have "readable" ear plugs. The proportion of immature whales in the population is certainly higher than indicated by our sample. If the apparent annual survival rate (S) of immature whales were the same as that of adults (0.92—see below) and sexual maturity were attained at 8 years of age, the proportion of immature whales 1 to 7 years old in the population would equal $1-S^7$, or 44 per cent. This is probably an underestimate, as the mortality of immatures is more likely to be greater than that of adults.

Another method of estimating the proportion of immature whales in the population based on the birth rate is applicable only if the population is stable. The birth rate is about 0.23 of the adult stock (see below). Since births must balance deaths in a stable population, the birth rate would be $(1-S)/S$, or 0.09 of the total stock alive at the beginning of the calving season. With a birth rate of 0.23 of the adult stock, the proportion of immature whales in the population would be $(0.23 - 0.09)/0.23$, or 61 per cent.

Population Dynamics

Natality.—On the basis of our estimate of a pregnancy rate in adult females of 0.46 per year and an assumption of an equal sex ratio, the birth rate in the California gray whale population is about 0.23 of the adult stock. As the present data indicate that adults constitute no more than 56 per cent of the population, the overall birth rate would not exceed 0.13. The approximate potential maximum rate of increase would approach this value.

Mortality.—The mean annual mortality rate of the adult female component of the sample, based on ages estimated from corpora counts, was calculated using Chapman and Robson's (1960) formula $M = 1 - (T/[N + T - 1])$, where M = annual mortality

rate and T = Σ(age–8) (frequency). The resulting estimate of the mortality rate is 0.082.

The mortality rate for each sex was also calculated from the ear-plug data. As the proportion of immature whales in the sample is apparently biased, only whales of estimated ages of 8 years or older were used in the analysis, thus making the estimates directly comparable with those based on ovarian data. The resultant mortality values are 0.081 for males and 0.095 for females, which agree well with the estimates based on ovary analysis. They also indicate that there is probably little sex difference in mortality rate, a conclusion further supported by the essentially equal sex ratio at all ages.

Discussion and Conclusions

The California gray whale population was probably at least 8000 but less than 13,000 during the southward migration in 1969–70, with 11,000 being the most reasonable estimate.

Estimates of population size in earlier years based on shore counts at Point Loma (Gilmore, 1960*a*, 1960*b*; Rice, 1961) and aerial censuses in Baja California (Hubbs and Hubbs, 1967) are probably too low. However, they suggest that the population increased moderately from the early 1950's to 1960. The evidence for population trends from 1960 to 1967 is equivocal. The counts at Yankee Point suggest that the population has remained essentially stable from 1967–68 to 1969–70.

The sex ratio is about one to one at all ages. Probably at least 44 per cent of the population is sexually immature. The birth rate is 0.13 or slightly less. The age structure of the population suggests that the mortality rate has been 0.08. The size of any age class at a given time depends on its initial size and on its mortality rate. Therefore, the mortality rate calculated from the age composition represents the true mortality rate only if the initial size of each age class was the same, a situation likely to exist only in a stable population with a constant birth rate. In an increasing population with a constant birth rate, the initial size of each succeeding age class is greater. If the gray whale population was increasing at a rate of about 0.12 per year between 1952–53 and 1959–60, as the

counts from Point Loma suggest, mortality would have to have been almost zero to produce the observed age structure. A low mortality rate would be expected in an initially small, rapidly increasing population comprised predominantly of younger animals. Inasmuch as the population has been stable since 1967, the mortality rate must have increased to equal the birth rate, but this change would have been too recent to have had a noticeable effect on the age structure of the population. However, additional data are needed, particularly on the actual age structure of the immature segment of the population and on population trends, before recruitment and mortality can be more accurately estimated.

EXPLOITATION

Aboriginal Whaling

The Nootka, Makah, Quillayute, and Quinault indians, the renowned aboriginal whalers living on the west coast of Vancouver Island and the State of Washington, regularly hunted gray whales since prehistoric times. Gray whale bones have been found in ancient middens near Lapush, Washington (Reagan, 1917). Indians chased whales in dugout canoes and struck them with harpoons attached to a line and float (Swan, 1870; Swanson, 1956; Waterman, 1920). Aboriginal whaling survived until 1928 on the coast of Washington (Anonymous, 1949).

Indians of the Kodiak Island and eastern Aleutian area killed whales with aconite-poisoned lances, a method also used by the Kamchadal in Kamchatka (Heizer, 1943). It is not known to what extent these people captured gray whales; their usual quarry was probably the right whale or the humpback whale.

The Koryaks who lived on the shores of Olyutorskiy Gulf north of the Kamchatka Peninsula in the 18th century regularly caught gray whales in large nets made of strips of walrus skin, which they set at the mouths of inlets (Krasheninnikov, 1755; Steller, 1774). Gray whales still are occasionally caught in this manner (Tomilin, 1957).

The Eskimos of Arctic Alaska and the Chukchi of eastern Siberia have for thousands of years hunted the bowhead whale and the gray whale from skin-covered "umiaks." In aboriginal times they used hand harpoons. After contact with American whalers in the late 19th century, they adopted the darting-gun and bomb-lance (Rainey, 1947). Whaling is still regularly practiced by the Eskimos of the villages of Barrow, Wainwright, and Point Hope on the Arctic coast of Alaska. In this area the catch is mostly bowhead whales. From 1954 through 1959, only nine gray whales were killed at Barrow and one at Wainwright (Maher, 1960). The natives of the village of Gambell on St. Lawrence Island (Francis H. Fay, personal communication) and the villages of Sireniki, Imtuk, Chaplino, Naukan, Uelen, and Enurmino on the Chukotskiy Peninsula

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(Tomilin, 1957; Treshchev, 1966*a*) also still hunt whales. The catch in these areas is almost entirely gray whales. One hundred fourteen were killed in 1965 and 53 in 1966 off the Chukotskiy Peninsula (Zimushko, 1969*a*).

Commercial Whaling

Whaling in Japan dates back more than a thousand years, but it was not until about 1606 that commercial whaling was established. From the town of Taiji, the industry spread rapidly throughout the islands. At first, hand harpoons were used, but in 1674 the use of nets was introduced and widely adopted. Early 19th century Japanese illustrations show that gray whales were hunted in addition to the commonly taken right and humpback whales (Fraser, 1937; Japanese Fisheries Agency, 1954; Omura *et al.*, 1953).

The possibility that gray whales survived in the North Atlantic until the early 18th century and were pursued by New England whalers is suggested by Dudley's (1725) account of the enigmatic "scrag whale" mentioned earlier.

During the late 18th and 19th centuries the American high-seas, open-boat whale fishery developed and gradually spread to all oceans. In 1846, the whalers discovered the winter grounds of the Pacific gray whale along the west coast of Baja California. Scammon (1874) estimated the gray whale population as "probably not over 30,000" between 1853 and 1856. The annual congregations of gray whales in the lagoons attracted the American whalers, and by the winter of 1860–61 about 60 whaling vessels were engaged in lagoon whaling in Baja California (Starks, 1922). The first shore whaling station was established in 1854 (Starks, 1922), and by 1874, 11 shore stations were operating along the coast of California and Baja California (Scammon, 1874; Jordan, *in* Clark, 1887). Scammon estimated that about 10,800 gray whales were killed there between 1846 and 1874. Others were killed in the Bering Sea and Arctic Ocean. Scammon estimated the population of gray whales as 8000 to 10,000 in 1874. By 1886 only five shore whaling stations remained; they took 58 gray whales in 1883–84, 68 in 1884–85, and 41 in 1885–86 (Townsend, 1887). During the latter season, Townsend estimated that only 160 southbound gray whales passed

San Simeon, California, in December and January. Regular shore whaling ceased about 1900 (Starks, 1922).

During the early 20th century there was little exploitation of gray whales, although American whaling ships doubtless took a few; 31 were taken in waters off Mexico and California, and one off Alaska, by the whaling schooner "Carolyn Frances" as late as 1921 (Starks, 1922; Bower, 1923). During this period the stock probably increased.

The perfection of the modern harpoon gun in 1864 by the Norwegian whaler Svend Foyn ushered in the era of modern whaling. Captain H. G. Melsom of the Toyo Hogei Kabushiki Kaisha [Oriental Whaling Co., Ltd.] of Osaka, Japan, inaugurated a winter fishery for the gray whale at a shore station at Ulsan on the east coast of Korea, about 1899 (Andrews, 1914). A total of 1474 gray whales was killed off Korea from 1910 to 1933. Catches were declining by the 1920's, and whaling ceased after 1933, when only two gray whales were taken. This rapid decline suggests that the Korean stock numbered only some 1000 to 1500 whales in 1910, and was virtually extinct by 1933.

Exploitation of the California stock of gray whales by modern methods began with the establishment of several shore whaling stations along the west coast of North America, the first in 1905. Few gray whales were killed, however, because they were rare and could be taken only during the winter and early spring when the weather was bad. The few taken were brought into the stations at Port Hobron on Sitkalidak Island and Port Armstrong on Baranof Island, Alaska, Bay City, Washington, and Trinidad and Moss Landing, California.

The introduction of floating factory ships gave modern whalers a mobility that greatly increased their efficiency. Because whales were flensed while floating alongside the ship, these early floating factories could operate only in sheltered anchorages. A Norwegian factory ship, "Capella I," took 19 gray whales off Baja California in the spring of 1914. From 1924–25 until 1928–29, Norwegian whaling interests operated factory ships each winter and spring at Bahia Magdalena and other points along the coast of Baja California. Catches of gray whales steadily declined from 100 in 1924–25 to two in 1928–29 as the whalers turned their attention

TABLE 18

RECORDED CATCH OF GRAY WHALES BY MODERN STYLE WHALING FROM 1910 TO 1946. SEE TEXT FOR SOURCES OF DATA.

	California stock														Korean[1] stock
	Baja California				California			Wash-ington	Alaska		Bering and Chukchi seas			Total	
Year	Fl. F. *Capella I*	Fl. F. *Kommandören I*	Fl. F. *Mexico*	Fl. F. *Esperanza*	Sh. St. Moss Landing	Sh. St. Trinidad	Fl. F. *Lansing*	Sh. St. Bay City	Sh. St. Port Armstrong	Sh. St. Port Hobron	Fl. F. *Kommandören I*	Fl. F. *Aleut*	Fl. F. *Tonan Maru*		
1910															6
1911															121
1912															193
1913									1					1	131
1914	19													19	155
1915															139
1916															178
1917															69
1918															104
1919															46
1920					2									2	68
1921					1									1	78
1922					5									5	40
1923															27
1924								1						1	17
1925		82	18								33			133	10
1926		36	5			1								42	11
1927		16		13			3							32	10
1928				9			1			2				12	9
1929				2										2	12
1930															30
1931															11
1932															7
1933										2		2		4	2
1934												54		54	
1935												34		34	
1936												102		102	
1937												14		14	
1938												54		54	
1939												29		29	
1940												47	58	105	
1941												57		57	
1942												101		101	1
1943												77		77	
1944															
1945												30		30	
1946												22		22	

[1] Catch by shore stations, almost all in Korea; for particulars see Mizue (1951). The whale taken in 1942 was killed in the Kuril Islands.

to the abundant and more profitable blue and humpback whales. A total of 181 gray whales was killed during these five seasons. One of these Norwegian factory ships, the "Kommandören I," took 33 gray whales in Natal'inskiy Bay, northeastern Kamchatka, in the summer of 1925. An American floating factory, the "Lansing," began operating in California in 1927. In 1932 she was replaced by the "California," which operated until 1937.

The invention of the stern slipway in 1925 made it possible to haul whales aboard the factory ship, thus permitting whalers to operate on the high seas and freeing them from regulation by national governments. The Soviet floating factory "Aleut" began operating in the western Bering Sea in 1933. Gray whales were an important part of her catch. The Japanese floating factory "Tonan Maru" took 58 gray whales in the Chukchi Sea in 1940, and the "Aleut" continued to take gray whales until 1946. From 1933 to 1946, a total of 681 gray whales was killed in the Bering and Chukchi seas. Annual catches provide no clear evidence of any changes in population size during this period.

The 1937 International Agreement for the Regulation of Whaling, which forbade the killing of gray whales, was adhered to by the governments of many whaling nations, including the United States, Canada, and Mexico, but not Japan or the Soviet Union. The 1946 International Convention for the Regulation of Whaling was ratified by the Governments of 17 nations, including Canada, Japan, Mexico, the Soviet Union, and the United States. This convention forbids the killing of gray whales, except by aborigines or a contracting government on behalf of aborigines and only when the meat and products are to be used exclusively for local consumption by the aborigines. Contracting governments may also grant special permits authorizing the collecting of gray whales for scientific research.

Statistics on catches of gray whales by modern style whaling as published in the International Whaling Statistics (IWS) are incomplete and in some instances erroneous; many data from prior to 1937 are combined under the category "North Pacific." We have attempted to compile a complete record of all gray whales killed from 1910 to 1946 (Table 18). No data are available on Korean catches before 1910. Although modern style whaling began on the

west coast of North America in 1905, no gray whales were killed until 1913. No gray whales have been taken commercially since the International Convention for the Regulation of Whaling went into effect in 1947, except for one taken in error by the shore station at Coal Harbour, British Columbia, in 1951. In 1953, 10 specimens were taken under a special scientific permit at Coal Harbour. As far as we can ascertain, these statistics are complete except for possible catches off California during the years 1930 and 1932–36, as noted below, and for any that might be included under a few unspecified whales taken in California, British Columbia, and Alaska. The sources of our data for each area in which modern whaling has been conducted are given below.

Baja California.—Data on the 1914 catch of the floating factory "Capella I" are from Tønnessen (1967). Catch figures for 1924–25 through 1929 and for 1935 are from original daily catch records submitted by whaling companies to the Bureau of International Whaling Statistics and kindly made available by Einar Vangstein.

California.—Data from 1918 through 1929 are from Starks (1922), Radcliffe (1933), and Kellogg (1931). Catch statistics by species are not available for the floating factory "Lansing" in 1930 or the floating factory "California" from 1932 through 1936 (total catches for all species are listed in the annual statistical issues of "Pacific Fisherman"). No whaling was conducted in 1931. Catch statistics subsequent to 1936 are from files of the U. S. Bureau of Commercial Fisheries.

Washington.—Catch statistics of the shore station at Bay City, Washington, from 1911 to 1925, as compiled by Scheffer and Slipp (1948).

British Columbia.—Catch statistics for 1905 through 1946, compiled by Gordon Pike (1962*b*) from Annual Reports of the Canadian Department of Fisheries, list no gray whales.

Alaska.—Catch statistics are on file with the U. S. Bureau of Commercial Fisheries.

Bering and Chukchi seas.—Catch statistics for the Norwegian floating factory "Kommandören I" are from IWS, those for the Soviet floating factory "Aleut" are from Sleptsov (1955), and those

for the Japanese floating factory "Tonan Maru" are from Sakiura *et al.* (1953).

Korea.—Catches by Korean shore stations are from Mizue (1951) and IWS. Their figures for the period 1920 to 1930 are erroneous; correct figures were published by Tønnessen (1967) and in Norsk Hvalfangst-Tidende, 16:13 (1927), 19:161 (1930), and 20:142 (1931).

Kuril Islands.—Mizue (1951) recorded one gray whale taken by a shore station at Otomae (on Shiashkotan Island), in the northern Kuril Islands, in 1942; this locality is outside the normal range of the species.

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SUMMARY

1. This study is based on data obtained from 316 gray whales collected off the coast of central California between 1959 and 1969 and on field observations. The latter included counts of southward migrating whales from shore stations during the winters of 1967–68 to 1969–70, observations made during cruises off California and Mexico from 1962 to 1969, and aerial observations along the coast of Washington, Oregon, and California in 1969. In addition, the stomach contents of a gray whale killed by Eskimos at St. Lawrence Island, Alaska, were analyzed.

2. Gray whales usually travel within a few kilometers of shore while migrating from their summer grounds in the Bering and Chukchi seas to their winter grounds along the coast of Baja California, but off southern California the majority take a more direct offshore route from Point Conception to northern Baja California. The northward migration follows the same route, except that females with calves apparently travel offshore. Migrating gray whales swim at about 8.5 kilometers per hour; on the southward migration they travel about 185 kilometers per day. There is no evidence that the whales travel slower at night than during daylight. Migrating gray whales are temporally segregated according to sex, age, and reproductive status. During southward migration, the sequence of passage is as follows: females in late pregnancy, females that have recently ovulated, adult males, immature females, and immature males. During northward migration, the sequence is as follows: newly pregnant females, anestrous females, adult males, immature females, immature males, and postpartum females. The earliest southbound migrants (mostly late pregnant females) usually travel singly, whereas later migrants usually are in pods of two or more.

3. Food of gray whales on their summer grounds in the northern Bering and Chukchi seas includes at least 17 species of benthic gammaridean amphipods, among which *Ampelisca macrocephala* predominates. The nature of the food indicates that gray whales are bottom feeders. Virtually no food is consumed during migration,

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although rarely small quantities of decapod nauplii (*Pachycheles rudis* and ?*Fabia* sp.) are eaten. There is little evidence that gray whales feed on their winter grounds off Baja California. In the interval between their southward and northward migration past San Francisco, the whales lose from 0.21 to 0.37 per cent of their body weight per day. This weight reduction is sufficient to account for the estimated energy expenditure during the winter. Blubber thickness and oil yield also decrease during winter.

4. Age may be estimated from the number of growth layers in the ear plug, indirect evidence suggesting that two layers are formed the first year and one each year thereafter. However, the value of ear plugs for age determination is limited because many plugs do not have clear laminations, and earlier laminations may disappear in older animals. The number of corpora albicantia in the ovaries provides a more reliable estimate of the age of adult females. Growth zones in the baleen plates are of little use for age determination because of rapid wear.

5. Mean body length at birth is about 4.9 meters. Mean length at weaning at an age of 7 months is about 8.5 meters. Puberty is attained at an estimated mean age of 8 years (range, 5 to 11 years) and a mean body length of about 11.1 meters in males and 11.7 meters in females. Physical maturity is attained at about 40 years at a mean body length of about 13.0 meters in males and 14.1 meters in females.

6. Ontogenetic changes in body proportions are slight. From late fetal life to a year of age, relative length of the flippers decreases and relative length of the tail increases. There are no significant changes in body proportions between the end of the first year and physical maturity. Females have slightly shorter flippers and longer tails than do males.

7. In immature females, seasonal enlargement of the follicles begins at a body length of about 9.9 meters and an age of 2 or 3 years. Mean weight of individual ovaries increases rapidly from about 140 to 300 grams when body length reaches about 11.3 meters at about 5 years of age. The ovaries weigh about 340 grams at sexual maturity and continue to increase slowly throughout life,

reaching about 646 grams at 50 years of age. The uterine cornua are 3.5 to 12.0 centimeters in diameter in immature females and more than 11.0 centimeters in adult females. The mammary glands do not develop until the female is well into her first pregnancy.

8. Female gray whales normally come into estrus biennially in late November and early December. Most individuals ovulate only once each season, although whales failing to conceive after their first ovulation may experience a second estrous cycle the same season. Multiple ovulations are extremely rare. Mean ovulation rates are 1.20 per breeding season for nulliparous females and 0.96 per breeding season (0.52 per year) for parous females. There is no evidence for postpartum ovulation or for ovulation at any other time of year. However, increase in follicle size following stillbirth or early loss of the calf suggests that females might ovulate following such an event. Females continue to breed at an advanced age. Corpora lutea of pregnancy average 8.7 centimeters in diameter, whereas corpora lutea of ovulation do not exceed 2.5 centimeters (at least if another estrous cycle soon follows). Corpora albicantia derived from corpora lutea of ovulation are indistinguishable from those derived from corpora lutea of pregnancy. Corpora albicantia persist in the ovaries throughout life. About 55 per cent of ovulations occur in the left ovary and 61 per cent occur in the anterior half of the ovaries.

9. Most conceptions occur within a 3-week period during southward migration, with a peak about 5 December. The pregnancy rate is 0.86 per breeding season (0.46 per year). The gestation period is about 13 months, and fetal growth is accelerated during the last half of pregnancy. During southward migration, late pregnant females (exclusive of their conceptus) average 25 to 30 per cent heavier than the other adult females. Births occur within a period of 5 to 6 weeks, with a peak occurring about 10 January. Caudal presentation at birth is normal.

10. Lactation lasts an average of about 7 months, ending in August.

11. Females are usually in anestrus from August to November or December. However, females that fail to ovulate or conceive

during the winter are probably in anestrus for the following 12 months.

12. In immature males, the weight of both testes is usually less than 5 kilograms, and the seminiferous tubules average 45 to 102 microns in diameter. Testis weight of sexually mature males is more than 5 kilograms, and the average diameter of the seminiferous tubules exceeds 104 microns. Penis length is correlated with body length and is usually less than 1.1 meters in immature males.

13. The average weight of the testes of adult males during southward migration in December and January is 38 kilograms, and the mean diameter of the seminiferous tubules is 177 microns. During northward migration in February and March, mean testes weight and tubule diameter are 22 kilograms and 148 microns, respectively. From July through October, the testes average 23 kilograms. These differences suggest a marked seasonal sexual cycle in the male, with a peak of spermatogenetic activity in autumn or early winter.

14. The killer whale, *Orcinus orca,* appears to be the only predator on gray whales. The mortality rate from killer whale attacks is unknown. However, frequency of tooth scars indicate that killer whale attacks on gray whales are often unsuccessful.

15. Epizoites of gray whales include the following (percentage of occurrence in parentheses): the barnacle *Cryptolepas rhachianecti* (100) and the cyamids *Cyamus scammoni* (99.7), *C. ceti* (99.4), and *C. kessleri* (98.1). Endoparasites collected include the trematodes *Lecithodesmus goliath* (0.6), *Ogmogaster pentalineatus* (more than 22), and *O. antarcticus* (33); two apparently undescribed species of the cestode *Priapocephalus,* one in the small intestine (30) and the other in the large intestine (0.3); the nematode *Anisakis simplex* (0.3); and two acanthocephalans, *Corynosoma* sp. (5.7) and *Bolbosoma* sp. (0.3). Obvious pathogenic effects were noted only for the liver fluke, *Lecithodesmus goliath.*

16. Population size of the California stock during the southward migration of 1969–70 was estimated to be about 11,000. Although previously published estimates of numbers of the California stock are questionable, the population appears to have increased from

1947 to 1960. Trends from 1960 to 1967 are uncertain. Since 1967, population size has remained essentially stable.

17. The sex ratio is essentially equal in all age groups. The birth rate does not exceed 0.13. The calculated annual death rate of adults is 0.08. This is probably an overestimate, although, if the population is now stable, the death rate must have recently increased to near the birth rate.

18. The California gray whale stock was severely overexploited between 1846 and 1900. During the present century this population has been only lightly exploited. Factory ships took an average of 36 gray whales per year in Mexico from 1924–25 to 1928–29 and an average of 48 per year in the Bering Sea from 1933 to 1946. Since then the species has been protected from commercial whaling by the International Convention for the Regulation of Whaling. The Korean stock was virtually exterminated between 1899 and 1933.

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Gray whale (*Eschrichtius robustus*) in the Mediterranean Sea: anomalous event or early sign of climate-driven distribution change?

AVIAD P. SCHEININ[1], DAN KEREM[1], COLIN D. MACLEOD[2], MANEL GAZO[3,4], CARLA A. CHICOTE[3] AND MANUEL CASTELLOTE[5]

[1]Israel Marine Mammal Research and Assistance Center (IMMRAC), The Leon Recanati Institute for Maritime Studies and Department for Maritime Civilizations, The University of Haifa, Mount Carmel, Haifa 31905, Israel, [2]IBES, University of Aberdeen, Aberdeen, UK, [3]SUBMON—Conservation, study and awareness of the marine environment, Rabassa, 49-51. 08024 Barcelona, Spain, [4]Department of Animal Biology, University of Barcelona, Diagonal 645, 08028 Barcelona, Spain, [5]National Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA, Sand Point Way NE, Seattle, WA 98115 USA

On 8 May 2010, a gray whale was sighted off the Israeli Mediterranean shore and twenty-two days later, the same individual was sighted in Spanish Mediterranean waters. Since gray whales were last recorded in the North Atlantic in the 1700s, these sightings prompted much speculation about this whale's population origin. Here, we consider three hypotheses for the origin of this individual: (1) it represents a vagrant individual from the larger extant population of gray whales found in the eastern North Pacific; (2) it represents a vagrant individual from the smaller extant population found in the western North Pacific; or (3) it represents an individual from the previously thought extinct North Atlantic population. We believe that the first is the most likely, based on current population sizes, on known summer distributions, on the extent of cetacean monitoring in the North Atlantic and on the results of a performed route analysis. While it is difficult to draw conclusions from such singular events, the occurrence of this individual in the Mediterranean coincides with a shrinking of Arctic Sea ice due to climate change and suggests that climate change may allow gray whales to re-colonize the North Atlantic as ice and temperature barriers to mixing between northern North Atlantic and North Pacific biomes are reduced. Such mixing, if it were to become widespread, would have implications for many aspects of the marine conservation and ecology of these two regions.

Keywords: global warming, climate change, migration, vagrancy, sea ice, ecosystem sentinels

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INTRODUCTION

Gray whales (*Eschrichtius robustus)* (Lilljeborg 1861) were once found in the coastal waters of both the North Pacific and the North Atlantic. However, while historical sources indicate that gray whales were recorded on both sides of the North Atlantic until 1700, the North Atlantic population(s) seems to have been eradicated a few decades later (Lindquist, 2000). The southernmost specimen of gray whale in the eastern North Atlantic was found on the southern coast of England (Mead & Mitchell, 1984), while the southernmost western record is from Florida, USA (27°04.6′N 080°07.7′W) (Odell, 1983). While the latter record implies that a part of the North Atlantic population may have bred and calved in the lagoons of the central and south-eastern Florida coasts, the breeding and migratory habits of the gray whales that once inhabited the North Atlantic are not known.

In the North Pacific, two populations currently exist. These are a large (18,000) eastern North Pacific stock and a small (125), remnant western North Pacific stock (Swartz *et al.*, 2006). Both populations migrate northward through coastal waters in spring and summer to high latitude feeding grounds. The eastern population summers in feeding grounds in the northern Bering and southern Chukchi Seas (Moore *et al.*, 2002), yet some whales of this population have been reported to reach longitude 174°E off the northern Chukotka coast, Russia (Berzin, 1984) and east to longitude 130°W in the Beaufort Sea, Canada (Rugh & Fraker, 1981). In autumn, this population migrates south along the eastern Pacific coast primarily to the west coast of Peninsula de Baja California, but also into the Gulf of California (Mead & Mitchell, 1984). The western population summers on feeding grounds primarily on the shallow-water shelf of north-eastern Sakhalin Island, Sea of Okhotsk (Weller *et al.*, 2002), but also off the south-eastern coast of the Kamchatka Peninsula (Vertyankin *et al.*, 2007). The wintering grounds of the western population are currently unknown, but may be in Asian coastal waters at latitudes as low as 20°N (Zhu, 2002).

The gray whale is the only baleen whale known to regularly consume benthic resources (Mead & Mitchell, 1984). They bottom-feed by using suction to take in food, water, and sediment, then expelling the water and sediment, while trapping the prey on the inside of their coarse baleen plates. However, gray whales are flexible foragers and respond to a variety of feeding opportunities throughout their coastal range

Corresponding author:
A.P. Scheinin
Email: scheinin@research.haifa.ac.il

(Moore *et al.*, 2007). For example, while most gray whales forage primarily upon the shallow benthic communities of the northern seas (Nerini, 1984), whales spending the summer in lower latitudes (e.g. off Vancouver Island, Canada) can rely heavily on planktonic prey (Dunham & Duffus, 2001).

In this paper, we report on a record of an individual gray whale from two locations in the Mediterranean Sea in May 2010. Three possibilities are suggested for the population of origin of this whale:

(1) it represents a vagrant individual from the larger extant population of gray whales found in the eastern North Pacific;
(2) it represents a vagrant individual from the smaller extant population found in the western North Pacific; or
(3) it represents a surviving individual from an extant (rather than extinct) North Atlantic population.

Of the three, the first was deemed to be the most plausible, and a route analysis was done to suggest how the whale travelled to the Mediterranean and to account for its movements therein. The implications of this record for both our understanding of gray whale behaviour and the potential impacts of climate change on marine ecosystems in the North Atlantic and the North Pacific are also considered.

MATERIALS AND METHODS

Sighting records from the Mediterranean Sea

Sightings of a gray whale were recorded first off Israel and later Spain during routine cetacean surveys conducted in May 2010 in the Mediterranean Sea. During each sighting, information was gathered on the size of the individual, its body condition, behaviour such as speed and direction of travel, and photographs were taken to confirm species and individual identification, as gray whales are characterized by unique pigmentation patterns (Darling, 1984).

Investigating potential routes from the North Pacific to the North Atlantic and within the Mediterranean

In order to assess how a gray whale could have reached the Mediterranean, a geographical information system (GIS) was created in Arcview 9.3. Information entered into this database included water depth (ETOP02, 2006), land forms and the minimum Arctic ice extent in September 2009 (from the National Snow and Ice Data Center, http://nsidc.org/data/seaice_index/), as it was assumed the odyssey began at this time. This information was then used to estimate the position and length of a number of likely migration routes from a starting point in the Bering Sea to Israel, and within the Mediterranean, for two separate scenarios. The lengths of time taken to traverse these possible routes were assessed using typical gray whale migration swimming speeds recorded in the eastern North Pacific (Mate & Harvey, 1984).

Individual identification attempts

Several eastern and western gray whale biologists were contacted and asked to review their photographic catalogues of individual gray whales in an attempt to find a match to the gray whale sighted in the Mediterranean Sea. Western population: the Russia–US western gray whale research program catalogue, 1994–2009 (181 individuals), and in two catalogues of the A.V. Zhirmunsky Institute of Marine Biology, Russian Academy of Sciences (Vladivostok, Russia): (1) The Western Pacific Gray Whales of Sakhalin Island, 2002–2009 (177 individuals); and (2) The Pacific Gray Whales of Kamchatka Peninsula, 2004 & 2006–2009 (116 individuals). Eastern population: Cascadia Research Collective's catalogue of 'seasonal resident' gray whales that feed in the summer and autumn off California, Oregon, Washington and British Columbia (approximately 1000 individuals); the catalogue of Cape Caution in northern British Columbia (approximately 100 individuals); the catalogue of Vancouver Island (approximately 200 individuals); and the catalogue of Laguna San Ignacio Ecosystem Science Program (LSIESP) and Programa de Investigacion de Mamiferos Marinos (PRIMMA–UABCS) representing the Mexican breeding lagoons (approximately 6500 individuals).

RESULTS

Description of the sightings

Israel: a ~13 m long gray whale (estimated visually relative to the length of a boat) was spotted on 8 May 2010 2 km off Herzliya Marina (32°11.5′N 034°47.4′E) at 9:00 hours and followed for an hour and 10 minutes, southward along the coast. It maintained a distance of 2 km offshore, travelling at a constant speed of 5–7 km/h and performing a continuous series of short (3–5 minutes) dives occasionally displaying its flukes. A few reports of a whale near the shore had been received by the IMMRAC (Israel Marine Mammal Research and Assistance Center) stranding network two weeks before the documented sighting, suggesting that the whale was not simply transiting the area. Assessing the whale's body condition following the scale of Bradford *et al.* (2008), scapular condition scored 1, post-cranial condition scored 1 and lateral flank condition scored 1, for an overall inclusion in the 'poor condition' category; however, the whale did not appear to be in critical condition (i.e. near starvation) (J. Calambokidis, personal communication).

Spain: a gray whale was spotted by a sailing vessel at 16:30 hours on 30 May 2010 0.9 km away from the coast of Barcelona (41°21.32′N 002°12.2′E; north-east Spain). The whale was swimming in shallow waters of about 40 m deep, at an average speed of 7.2 km/h. The sighting lasted 20 minutes. During this period, the whale was diving constantly and displayed its flukes 4–5 times. The whale was moving southwards during the sighting period. Photographs of the tail fluke confirmed that this was the same individual previously sighted in Israel (Figure 1).

Investigating potential routes from the North Pacific to the North Atlantic

While we cannot entirely rule out the possibilities of a wintering east Pacific gray whale passing through the lock systems of the Panama Canal or around Cape Horn in order to reach the North Atlantic, nor that of a wintering west Pacific gray whale

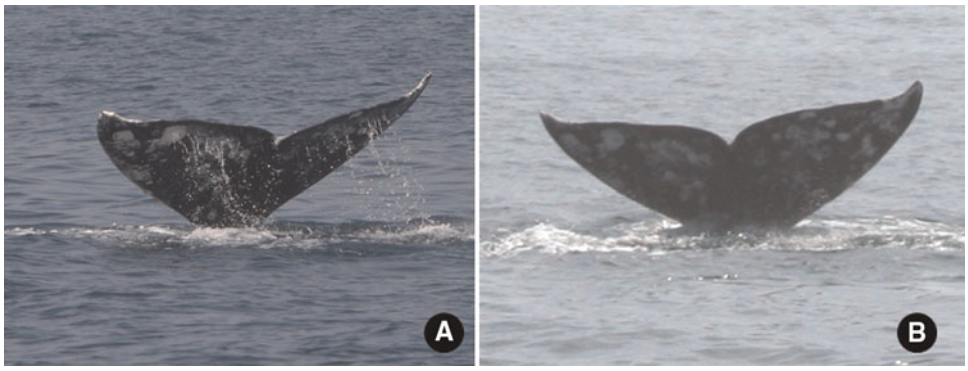

Fig. 1. The pigmentation patterns of the flukes photographed in (A) Israel and (B) Spain, confirm that the two sightings are of the same individual. Photographs: (A) ©A. Scheinin/IMMRAC; (B) © R.Barahona/SUBMON.

traversing the South Pacific, Indian Ocean and Red Sea to enter the Mediterranean through the Suez Canal, these highly unlikely possibilities were not considered. Consequently, we considered the two most likely routes of summer-feeding whales from the Bering Sea to the North Atlantic and from there to the Mediterranean: one along the northern coast of Eurasia and the other along the northern coast of North America. Passage along either route would require that it is not blocked by sea ice. In summer 2009, of these two possible routes, the one across the northern coast of Eurasia was the most open and ice free (Figure 2), potentially making it more likely. In addition, if gray whale movements during migration are restricted to shallow shelf waters, with minimal deep-water crossings, the route via the Northwest Passage has a number of large barriers in the form of the Faroe–Iceland Rise and the Faroe–Shetland channels, while the Eurasian route does not require any deep-water crossings. On average, an eastern gray whale migrating south travels 127 km per day or 5.3 km/h (Mate & Harvey, 1984). At this speed, these two coastal routes would take a whale more than 100 days to travel between the Bering Strait and Israel. In contrast, if substantial deep-water crossings are not a barrier to migration, both routes shorten to around 85 days.

Investigating routes of movements within the Mediterranean

We considered two possible routes between the locations in Israel and Spain where this gray whale was recorded. One is a direct route over deep water, while the other is a coastal route passing only through shallow shelf waters. The former route is around 3000 km in length, while the latter is almost twice as long (Figure 2). As a result, while it would take an average swim speed of around 5.7 km/h to complete the direct route within 22 days, it would take an average swim speed of around 11 km/h to complete the coastal route. This is twice the typical migration speed for gray whales, making this route unlikely. As a result, the length of time between these two sightings suggests that this gray whale made substantial deep-water crossings during its movements.

Individual identification

The attempts to find a photographic match of the Mediterranean individual to catalogued eastern and western gray whales were unsuccessful. This might partly be due to the fact that we have good quality images of the fluke and of the left dorsal ridge while many photo-identification catalogues are based on the right dorsal ridge and reflect surveys in shallow water areas where individuals do not regularly show their flukes.

DISCUSSION

Of the three considered points of origin, it is least likely that the gray whale observed in the Mediterranean is a remnant of a previously thought extinct North Atlantic population. In particular, given the extensive whaling and cetacean research conducted in the North Atlantic in the last 100 years, it seems unlikely that a population of shelf-foraging, large baleen whales could have survived almost 300 years without being detected.

Of the two possible North Pacific origins, the most likely origin is that of the eastern North Pacific. This population is much larger than the western Pacific population and eastern gray whale summering grounds penetrate higher into the Arctic waters to both the east and the west of the Bering Strait (Figure 2). As a result, vagrant individuals which moved further east or west than usual during the summer feeding period could end up in the North Atlantic. In contrast, the known summering grounds of the western population are at lower latitudes in the Okhotsk Sea and the eastern side of the Kamchatka Peninsula (Figure 2). This hypothesis is supported by the results of the photo-identification catalogue comparison. Given the high photographic coverage of the small western gray whale population and the more limited coverage of the larger eastern population, the fact that a match was not made suggests that the Mediterranean vagrant was not a western gray whale.

For a gray whale from the eastern population to migrate to the Mediterranean, it requires that there is an ample ice-free passage between the North Pacific and the North Atlantic, either across the top of Eurasia or North America. Therefore, the occurrence of a gray whale within the Mediterranean suggests that ice barriers to the movements of species between these two oceans have weakened to the point where passage between them is possible (MacLeod, 2010). While it is not yet clear whether such passage will become a regular event as sea ice continues to decline in response to climate change, this event suggests that such exchanges are becoming more feasible.

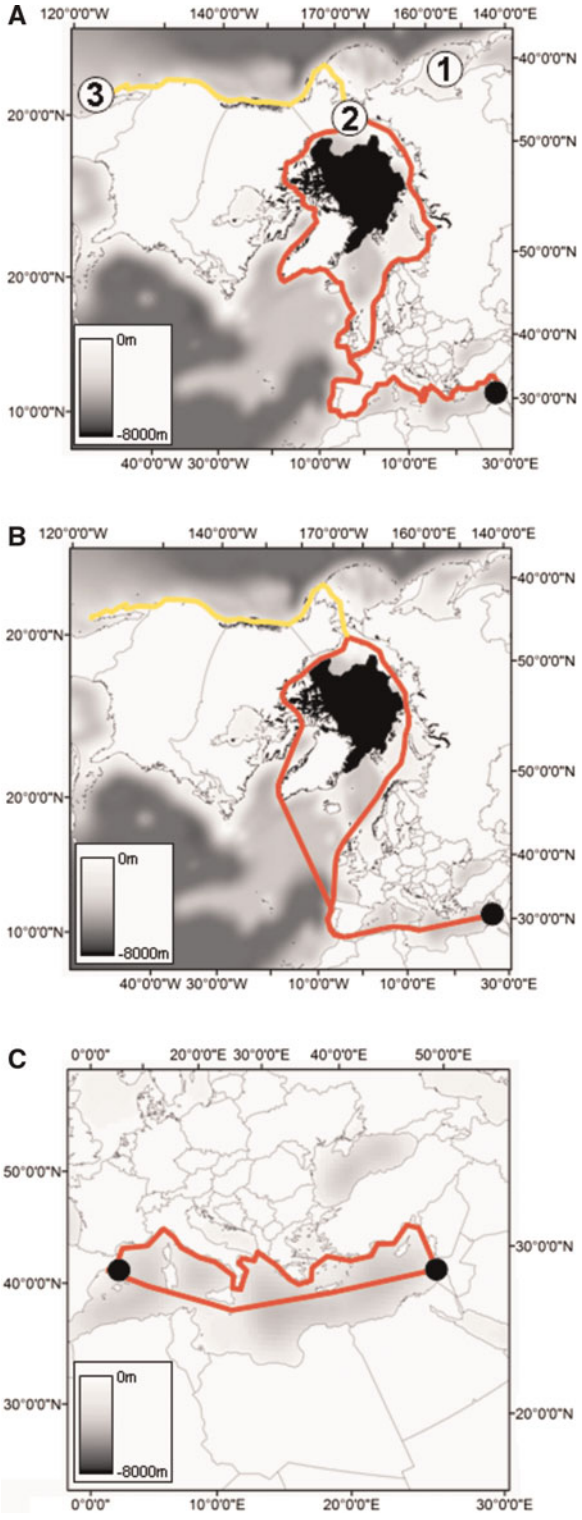

Fig. 2. (A) Possible routes from the typical summering ground of eastern gray whales in the Bering Sea if the whale remained in shelf waters as much as possible and restricted travel over deep water to a minimum; (B) possible routes allowing for extensive crossing of deep-water areas to minimize the distance travelled; (C) comparison of coastal versus shortest route between the sighting in Israel and the sighting near Barcelona 22 days later. Yellow lines: usual migration route for eastern Pacific gray whales; red lines: possible routes to reach the Mediterranean and to move between sighting locations; black circles: sightings locations in the Mediterranean; (1) summer feeding area for western Pacific population; (2) summer feeding area for eastern Pacific population; (3) winter breeding area for eastern Pacific population. Background shading represents depth. The solid black is the ice extent in September 2009.

Thus, as this species and others (such as fin, humpback, and minke whales and harp, hooded, ribbon, and spotted seals) are already predisposed to disperse and become established further northward if the current overall trend toward a warmer Arctic climate continues (Moore & Huntington, 2008), the Arctic could soon become a dispersion corridor between ocean ecosystems. Therefore, the presence of a gray whale in the Mediterranean Sea concurrently with an ice-free summer Arctic passage could potentially be considered the first manifestation of such biome mixing between the North Pacific and the North Atlantic due to global climate change.

The occurrence of new species in non-native regions is thought to negatively impact marine ecosystems in many parts of the world (Ruiz *et al.*, 1997; Hayes & Sliwa, 2003) and the spread of such species may be facilitated by changes in climate (Stachowicz *et al.*, 2002). Specifically, the breakdown of barriers between previously isolated oceans as a result of climate change, such as that which allowed a gray whale to move into the Atlantic, could result in species moving between ocean basins with implications for the well-being of native marine ecosystems (Stachowicz *et al.*, 2002). The record of this gray whale suggests that this species could potentially provide an easy-to-detect indicator of such potential exchange between the North Pacific and the North Atlantic as the Arctic ice-cap continues to shrink in response to climate change. In particular, since gray whales are a seasonally migrant species for which sea ice can act as a barrier, climate change impacts on sea ice might result in noticeable effects in their migratory behaviour, which is a conspicuous sign of ecosystem change (Laidre *et al.*, 2008). As such, gray whales are already considered ideal sentinels of the effects of climate change on Arctic ecosystems (Moore & Huntington, 2008) and this capacity could be extended to include their use as an indicator of the ease of movement of marine mammal and other species between the Pacific and Atlantic Oceans through the currently warming Arctic corridor.

The presence of this whale within the Mediterranean also provides us with novel information about gray whales. In particular, in order to make the passage between Israel and Spain in 22 days, it is likely that this individual whale made substantial directional movements over deep-water areas where it could not forage benthically. We fully acknowledge the fact that this whale was in extraordinary circumstances, likely unfamiliar with its surroundings, such that its behaviour cannot be presumed as normal. Yet, its performance suggests that gray whales, when faced with such circumstances, can utilize and potentially forage in deep water. These observations support the concept of gray whales as the most adaptable and versatile of the mysticete species (Moore & Huntington, 2008).

Finally, the arrival of this individual to the Mediterranean also suggests that gray whales may be capable of much longer movements than are exercised during their routine migrations. If we take the breeding grounds of the eastern population as a starting point and Israel as being the south-eastern extent of this individual's migration route, the whale covered a minimum distance of between ~22,000 km and ~23,500 km, depending on the exact starting point in the eastern Pacific wintering grounds. Stevick *et al.* (2010) report on a humpback whale that travelled more than 9800 km from breeding areas in Brazil to those in Madagascar, setting a record for the largest geographical displacement ever documented in a mammal. Our results suggest

that the Mediterranean gray whale travelled more than twice that distance, resulting in what is by far the most extreme vagrancy known to have been exercised by a mammal.

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Correspondence should be addressed to:
A.P. Scheinin
Israel Marine Mammal Research and Assistance Center (IMMRAC)
The Leon Recanati Institute for Maritime Studies and Department for Maritime Civilizations
The University of Haifa, Mount Carmel, Haifa 31905, Israel
email: scheinin@research.haifa.ac.il

SC/M18/CMP/01

Plausibility of stock structure hypothesis 6b

Jonathan Scordino, John Bickham

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Plausibility of stock structure hypothesis 6b

Jonathan Scordino – Makah Fisheries Management
John Bickham – Professor Emeritus Texas A&M University

A workgroup of the IWC has conducted annual meetings on a range-wide review of gray whale stock structure and status since 2014 (IWC 2014). One of the primary objectives of the range-wide review was to develop one or more plausible stock structure hypotheses for use in population modeling (IWC 2014). The workgroup proposed seven hypotheses, with 12 sub-hypotheses, at the 2014 meeting based on review of Bickham et al. (2013) and discussions of the workgroup (IWC 2014a). These hypotheses were presented in table 7 of the 2017 workgroup report (IWC 2017) and are included in this paper as table 1. The workgroup decided that two of the hypotheses had low plausibility and these were excluded from further evaluation. The workgroup decided to assign low priority for modeling any of the remaining hypotheses that would use the same modeling framework as other hypotheses. In addition, low priority was assigned to hypotheses that have little to no data to test plausibility.

Table 1: List of stock structure hypotheses considered by the workgroup

A summary of the stock structure hypotheses initially under consideration (2015, 2016) and their status

Description	Status	Comment
(1) Panmixia with no matrilineal fidelity to feeding grounds - persistent		
A single breeding stock; no matrilineal fidelity to feeding grounds	No	not consistent with available data (IWC 2015)
(2) Panmixia with no matrilineal fidelity to feeding grounds - post-exploitation		
A single breeding stock exists, although multiple stocks may have existed in the past. No matrilineal fidelity to feeding grounds.	No	not consistent with available data (IWC 2015)
(3) Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating		
(a) A single breeding stock (EBS) exists. The EBS includes three feeding groups: NFG, PCFG, WFG. SKNK is used by some whales that belong to the WFG and some whales that belong to the NFG.	*High*	
(b) The EBS is as described in 3a, except that NFG whales do not feed off SKNK. In addition, a WBS exists that overwinters in VSC and feeds in the OS (but not SI) and SKNK. Thus SKNK is used by both the WFG whales and the whales of the WBS.	Low	few or no data to assess plausibility (IWC 2015), but may be reconsidered during SC67a
(c) Same as 3a except that WFG whales migrating from SI to M occasionally travel through BSCS.	Medium	Sensitivity test
(d) Same as 3a except the EBS contains the original three feeding groups and a fourth feeding group that uses SEA.	Low	few or no data to assess plausibility (IWC 2015)
(e) Same as 3a except that a WBS exists that feeds in the OS (but not SI), EJPJ, and KWJ and overwinters in VSC.	*High*	
(4) Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, non-random mating		
(a) Two breeding stocks exist and overwinter in M. One breeding stock includes NFG and PCFG, and the second breeding stock includes WFG whales. Separation between breeding stocks is maintained by WFG whales mating largely with each other while migrating to M.	Low	represented in the same way as other hypotheses in modelling (IWC 2015)
(b) Same as 3b except that a WBS exists and is made up of WFG whales that largely breed with each other while on migration to M.	Low	represented in the same way as other hypotheses in modelling (IWC 2015)
(5) Maternal feeding ground fidelity, two migratory routes/wintering grounds used by Sakhalin whales, random mating.		
(a) Two breeding stocks exist: EBS and WBS. The EBS includes three feeding groups: PCFG, North, and the WFG that feeds off SI. The WBS whales feed in SI, OS, and SKNK and then migrate to VSC to overwinter. SKNK is used by the WFG, the NFG, and the feeding whales that are part of the WBS.	*High*	
(b) Three breeding stocks exist. The EBS is as described in 5a. Two breeding stocks exist in the WNP. Both W breeding stocks feed in SI, OS, and SKNK but whales show fidelity to two different migratory routes (Pacific coast of Japan and eastern Sea of Japan) and use two separate wintering grounds.	Low	few or no data to assess plausibility (IWC 2015)
(6) Maternal feeding ground fidelity, Sakhalin whales use two migratory routes/wintering grounds without fidelity, random mating		
(a) A single breeding stock exists that uses wintering grounds off M as well as of VSC. Whales do not exhibit fidelity to a wintering ground. Three feeding groups exist: WFG, NFG, and PCFG. SKNK is used by both WFG and NFG.	Low	few or no data to assess plausibility (IWC 2015)
(b) Same as 6a, except the WFG whales largely breed with each other during migration, creating a second breeding stock. Whales from both breeding stocks overwinter in M and in VSC, and show no fidelity to a wintering ground.	*High*[1]	
(c) Same as 6a except that females' part of the WFG show fidelity to one of the two wintering areas (M and VSC), while males of the WFG do not show fidelity to a wintering ground.	Low	few or no data to assess plausibility (IWC 2015); modelling framework represented in the same way as other hypotheses (IWC 2015)
(7) Maternal feeding ground fidelity, Sakhalin whales use two migratory routes/wintering grounds with fidelity, non-random mating		
Three breeding stocks exist - a breeding stock comprised of WFG whales that migrate to M, a breeding stock (EBS) comprised of PCFG and NFG whales, and a WBS that includes whales that feed off SI and in the OS.	Low	modelling framework represented in the same way as other hypotheses (IWC 2015)

[1] Initially considered to be of low priority because modelling framework represented in the same way as other hypotheses (IWC 2015); when revisited, the Workshop determined that this hypothesis does differ from 5a, in that: (1) all catches off Japan are assumed to be Western stock animals; and (2) the abundance estimates off Sakhalin are assumed to relate only to the Western stock. Thus the Workshop agreed to change the status of this hypothesis to high priority (IWC 2017).

In 2014, the workgroup rated three hypotheses as high priority for modeling: hypotheses 3a, 3e, and 5a (IWC 2014a). Hypothesis 3a considers there to be a single breeding stock that winters in Mexico (EBS), with matrilineal fidelity to feeding grounds, and the EBS includes three feeding groups: Pacific Coast Feeding Group (PCFG), Northern (NFG), and Sakhalin (WFG). Hypothesis 3e is identical to 3a except that the Asian breeding stock is extant and feeds in the Okhotsk Sea but not at Sakhalin Island, whales that feed at Sakhalin Island overwinter in Mexico. Hypothesis 5a considers Sakhalin Island a mixed stock feeding ground with both whales that have fidelity to either Asian or North American wintering grounds.

The workgroup decided that hypothesis 3c should be included as a sensitivity test (IWC 2014a). Hypothesis 3c is structurally the same as 3a except that Sakhalin whales who migrate to North American wintering grounds occasionally use northern feeding grounds in the Chukchi Sea and are available to the Chukotkan harvest.

In 2016, the working group decided to add hypothesis 6b to the high priority list of hypotheses to model (IWC 2016). Under hypothesis 6b, there are two breeding populations of gray whales. The whales of the ENP breeding population migrate to feeding grounds in the PCFG (BCNC), Southeast Alaska (SEA), Bering Sea and Chukchi Sea (BSCS), and Kamchatka (SKNK). Whales of the WNP breeding population migrate to feeding grounds in the Okhotsk Sea (OS), Sakhalin Island (SI), and Kamchatka (SKNK). The text in table 1 from IWC (2017) states erroneously that both breeding stocks utilize wintering grounds at Mexico (M) and at Vietnam and South China Sea (VSC). As can be seen clearly in figures 1 and 2, taken from Annex D of IWC (2017), the correct wording for the hypothesis should be as follows: *ENP gray whales have fidelity to their wintering ground but the WNP breeding population has no fidelity to a wintering ground and uses both M and VCS*.

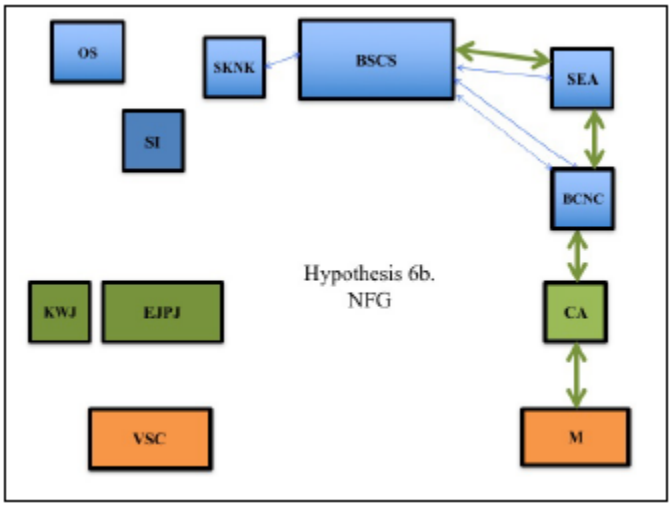

Figure 1: Hypothesized range, migratory routes, feeding grounds, and wintering grounds of the ENP population.

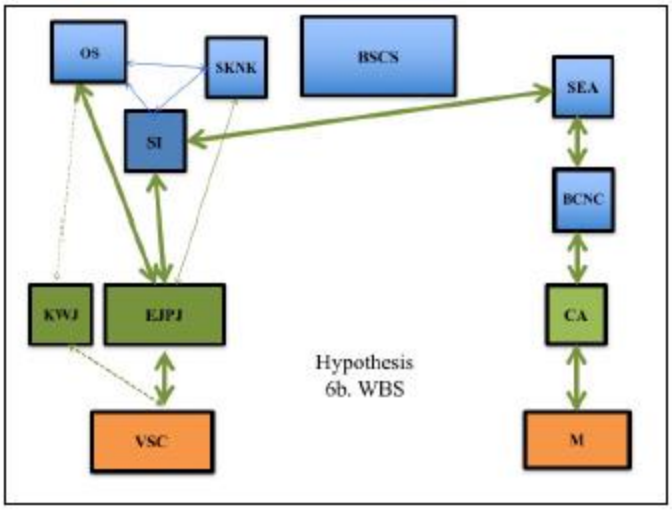

Figure 2. Hypothesized range, migratory routes, feeding grounds, and wintering grounds of the WNP breeding population. Figures from IWC (2017) Annex D.

Prior to 2016, the workgroup considered hypothesis 6b a low priority for modeling because it was thought that the modeling framework would be the same as hypothesis 5a. Hypothesis 6b was upgraded to high priority in 2016 because it was noted that modeling would be different from 5a in that, under hypothesis 6b 1) all catches off Japan and at Sakhalin Island are assumed to be western (Asian) stock animals and 2) the abundance estimates of the Sakhalin feeding group are assumed to relate to the western stock only (IWC 2016). With relatively little discussion of the plausibility of hypothesis 6b, the workshop agreed to ranking hypothesis 6b as high priority for modeling.

The objective of this paper is to open the discussion on the plausibility of the high priority hypotheses with special emphasis on hypothesis 6b. As noted in the first workshop report, the normal procedure of the IWC is to evaluate the plausibility of stock structure hypotheses and only use those that are not of low plausibility.

The limited discussion at the 2016 meeting on the plausibility of hypothesis 6b focused on a humpback whale modeling paper. The report does not document this discussion, but our recollection is that the paper referenced in the discussion was Clapham and Zerbini (2015).

The objective of the Clapham and Zerbini (2015) paper was to conduct population simulations to evaluate whether their Social Aggregating Hypothesis (SAH) could explain the exceptionally fast growth rates observed in the humpback whale wintering population in Eastern Australia. The population growth rates in Eastern Australia are currently close to the theoretical maximum growth rate. The premise of the Social Aggregating Hypothesis is that one population (the base population) can attain a critical mass that draws humpbacks from another population (the source population) to temporarily immigrate into the rapidly growing base population. The whales immigrating into the base population cause the observed population growth rate to increase and this rate of increase remains as long as the proportion of the source population that immigrates into the base population increases through time. Likewise, the source population would appear to have depressed growth rates since a portion of its true increase is allocated to the base population. It is important to note that the model assumes that the whales temporarily immigrating from the source population only mate with each other despite their use of a different wintering ground.

Clapham and Zerbini (2015) showed that it is mathematically possible that the high rate of increase observed in the Eastern Australia humpback whales was due to the SAH. They postulated that it is unrealistic for humpback whales to continue to return to largely empty wintering grounds when there is an alternative, more attractive destination available. Their suggested mechanism for whales finding the new wintering ground is through hearing the singing of the humpback whales at the more populated wintering ground, thus drawing migrating whales of the source population to the new wintering ground outside their normal migratory path.

However, the authors also note that there are reasons to be skeptical of the application of SAH to humpback whales. The simulations required an increasingly larger proportion of the source stock temporarily immigrating into the base population each year. Eventually the demand for new immigrants would exceed the supply and exhaust the source population (Clapham and Zerbini 2015). The scenario in the paper that produced a rate of growth most similar to the observed rate of increase in Australia was scenario 12. In this scenario the source population was modeled to have a negative population trend by 2015. However, recent surveys have shown that the hypothetical source population in Fiji is increasing. An issue that the authors did not discuss is the fact that, if SAH were occurring, you would expect to observe more genetic, photographic, and acoustic matches of humpback whales between the wintering grounds. For scenarios that had a rate of change of 10% or greater, between 8 and 33% of the population making up the count at the base wintering ground would be from the source population. Humpback studies have documented some mixing of individuals on the wintering grounds, but not to the scale suggested by the modeling of Clapham and Zerbini (2015). In summary, although mathematically possible, it does not seem very plausible that the SAH is occurring among humpback whales. It appears even less plausible that SAH has led to a change in the migratory behavior of WNP gray whales.

The SAH was proposed for humpback whales due to their tendency to aggregate for mating. In contrast, gray whales are thought to primarily mate during the fall southbound migration (Rice and Wolman 1971), although mating behaviors are observed on the wintering grounds and to a lesser extent on the northbound migration and on the feeding grounds (Youngson and Darling 2016). There are no reports of gray whales aggregating during migration for mating. Migrating to North America rather than Asia from Sakhalin would cost whales ~4,000 km more migratory distance and greater energetic demands than migrating to Asia (Villegas-Amtmann et al. 2017). Biologically there does not appear to be any benefit to WNP whales to change their wintering ground from Asia to North America, especially given the expectation in hypothesis 6b that they primarily mate within their own group.

Clapham and Zerbini (2015) hypothesized that the singing behavior of male humpback whales during migration and on their 'modified leks' could provide other migrants auditory clues to adjust their migratory path to a base population. In contrast to humpback whales, gray whales appear to only produce sounds when there is a need to be acoustically active (Dahlheim et al. 1984). Dahlheim et al. (1984) reported that gray whales produce sound when grouped together, when on collision course with other whales or boats, when interacting with dolphins, and when single whales are chasing a cow/calf pair. They also noted that no signals were detected in presence of courting whales (Dahlheim et al. 1984), although Youngson and Darling (2016) did record sound in the presence of gray whales they thought were mating during the feeding season off Vancouver Island, Canada. Given that generally gray whales are quiet (Cummings et al. 1968, Dahlheim et al. 1984), there is no obvious acoustic mechanism for gray whales to learn of

a new wintering ground. This is particularly true under hypothesis 6b where ENP and WNP whales are found together only at Kamchatka, whereas the majority of the ENP population is found over the vast area of the Bering and Chukchi Seas and isolated from WNP whales.

Clapham and Zerbini (2015) explored the SAH to determine if the rapid increase of the East Australia humpback population could be due to temporary immigration from neighboring source populations. There is no similar basis for exploring the SAH with respect to gray whales. The gray whale population has been monitored thoroughly since the 1970s and during that time the rate of increase of the population has been well within the biological expectation for the population (Laake et al. 2012; Punt and Wade 2012). Efforts to model the ENP population of gray whales back through the mid-1800s likewise do not show a rapid rate of increase consistent with the rate of increase observed in the East Australia humpback whale population, suggesting that immigration from the WNP did not affect population dynamics (Punt and Butterworth 2002).

It is possible under hypothesis 6b that the WNP had a long-established behavior pattern of using both wintering grounds of both Asia and North America instead of a change in behavior through the SAH. However, if that were the case, the whaling efforts that pushed the ENP close to extinction in the 1800s should have severely depressed the WNP population, making it unlikely that the whale hunting observed by Andrews in the early 1900s would have been possible. As such, it is not plausible that the WNP whales had a long-established tradition of migrating to both Asian and North American wintering grounds.

Genetic arguments on why hypothesis 6b has lower plausibility than other stock structure hypotheses are supplied in Bickham et al. (2013) for their hypothesis 5, which is essentially the same as our hypothesis 6b. They gave four reasons that their hypothesis 5 is unlikely. These include: 1) the population does not show a significant signature of a bottleneck. This is not particularly important because as they point out bottleneck tests are not very sensitive. Nonetheless, the observation of a significant genetic bottleneck would be consistent with the Sakhalin whales being the surviving remnant of the western gray whales; 2) paternity analysis revealed a high percentage of "missing fathers" within this population (Lang et al., 2010a), these likely are part of the eastern gray whale population; 3) the population possesses a number of nuclear microsatellite loci that are out of Hardy-Weinberg equilibrium which could be evidence of a Wahlund effect (mixing of populations). Thus, both points 2 and 3 are more consistent with the Sakhalin population being a mixed stock assemblage rather than a pure breeding stock.

There is likely a continuum of plausibility for the hypotheses considered (Table 1). We have already concluded that hypothesis 1 and 2, which have panmixia and no fidelity to feeding grounds, have low plausibility based on genetic and behavioral data. Based on the arguments presented in this paper hypothesis 6, and 6b in particular, should rank as low plausibility. Of the other priority hypotheses, hypothesis 3a and 5a are the most consistent with the available data and should be considered the most plausible. The plausibility of hypothesis 3e is questionable. It is doubtful that western breeding stock whales would feed in the Okhotsk Sea in all areas except near Sakhalin Island where there is abundant prey that has supported a large aggregation of feeding whales since at least the mid-1990s (Cooke et al. 2017).

Ranking the plausibility of hypotheses based on the biology of gray whales should help us improve our ability to interpret the final results of the range-wide review. We suggest focusing future discussions on hypotheses 3a and 5a since they are the most biologically defensible hypotheses. There may be value in modeling hypothesis 6b as a sensitivity test to understand what the impact would be if all of the whales caught in Asia were from the western

feeding group. Likewise, there could be value in modeling 3e for sensitivity to not having an abundance estimate of the western breeding stock. When presenting our results we should be clear that hypotheses 3c, 3e, and 6b were run as a sensitivity tests and not because they represent biologically plausible models of gray whale stock structure.

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SHORT COMMUNICATIONS

Observation of the Gray Whale (*Eschrichtius robustus*) in the Laptev Sea

O. V. Shpak, D. M. Kuznetsova, and V. V. Rozhnov

Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, 119071 Russia
e-mail: ovshpak@gmail.com

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The gray whale (*Eschrichtius robustus*, Lilljeborg, 1861) as an Arctic species with seasonal migration may serve an indicator for climate changes in the Arctic (Moore and Huntington, 2008). The gray whale earlier inhabited the Pacific and Atlantic oceans and the adjacent northern seas; however, by the beginning of the 18th century, this species had been extirpated in the Atlantic (Mead and Mitchell, 1984). In the Pacific Ocean, two gray whale populations are recognized (LeDuc et al., 2002): Okhotsk–Korean and Chukotka–Californian. The Okhotsk–Korean population spends summer in the Sea of Okhotsk, while the Chukotka–Californian population summer feeding grounds lie mainly in the Arctic between 174° E and 130° W in the Bering, Chukchi, and Beaufort seas; there are records of the gray whales visiting the East Siberian Sea (Rice, 1998). In the summer months of the years with poor ice conditions, individual gray whales were sighted near the mouth of the Kolyma River (Bogoslovskaya, 2002) and even more westward, "on the approach to the New Siberian Islands" (Matishov et al., 2000), namely, according to the map scheme in the publication, between 153° E and 158° E. In the fall, the Chukotka–Californian population migrates southward, crosses the Pacific Ocean, and descends along the North American coast to California and Mexico to their reproduction area; and in the spring these whales again cross the ocean to return to the north, to the coasts of Kamchatka and Chukotka (Swartz et al., 2006).

Recently, the gray whale was again recorded in the Atlantic basin. On May 8, 2010, an individual of this species was observed in the Mediterranean Sea off the Israeli coast and, three weeks later, near the coast of Spain. The proposed explanation, supported by many specialists, was that this gray whale had entered the Mediterranean Sea by the Northern Sea Route (Scheinin et al., 2011). No matter what brought this gray whale to the Mediterranean, its migration along the northern Eurasian coast became possible due to a considerable reduction in the ice-covered area in the Arctic.

In September–October, 2011, a series of observations on marine mammal distribution was conducted under the White Whale Program onboard the RV *Mikhail Somov* in the White, Barents, Kara, and Laptev seas.

The observations were conducted from a platform located at 18 m a.s.l. At the beginning of each shift, as well as additionally in the case of changing conditions, the meteorological parameters (cloud cover, presence/absence of precipitation, wind direction and force) and quality of visibility (sea state according to the Beaufort scale, presence and position of the sun glare, and general estimate of visibility according to five-point scale) were recorded. When marine mammals were sighted, the species, number, vessel GPS coordinates (using a Garmin 60csx) at the moment of detecting animals, distance to the animals, and bearing angle relative to the vessel course were recorded, as well as their behavior when possible. The animals were photographed with a Nikon D300S camera equipped with Nikkor 80–200 mm f2.8, 70–200 mm f2.8, 18–200 mm f3.5–5.6 lenses; a Kahles 10 × 42 binoculars was used for species identificatlion.

On September 23, 2011, observer O. Shpak sighted two whales at 2:40 a.m. UTC (13:40 local time). At that moment, the vessel was 90 km to the west of the northern part of Kotel'nyi Island (New Siberian Islands) and kept westward. The GPS coordinates for the vessel position at the moment the whales were detected were 76°06.8′ N and 134°47.5′ E. The animals were sighted right ahead at a distance of 1.5 km from the vessel and were approaching (moving eastward) being close to one another. The precise distance between the individuals was not possible to detect, but their mutual position was assessed as "next to each other." The weather was good for observation: air temperature, 7°C; pressure, 1008 hPa; 50% cloud cover; sea surface state at Beaufort scale, 2; sea

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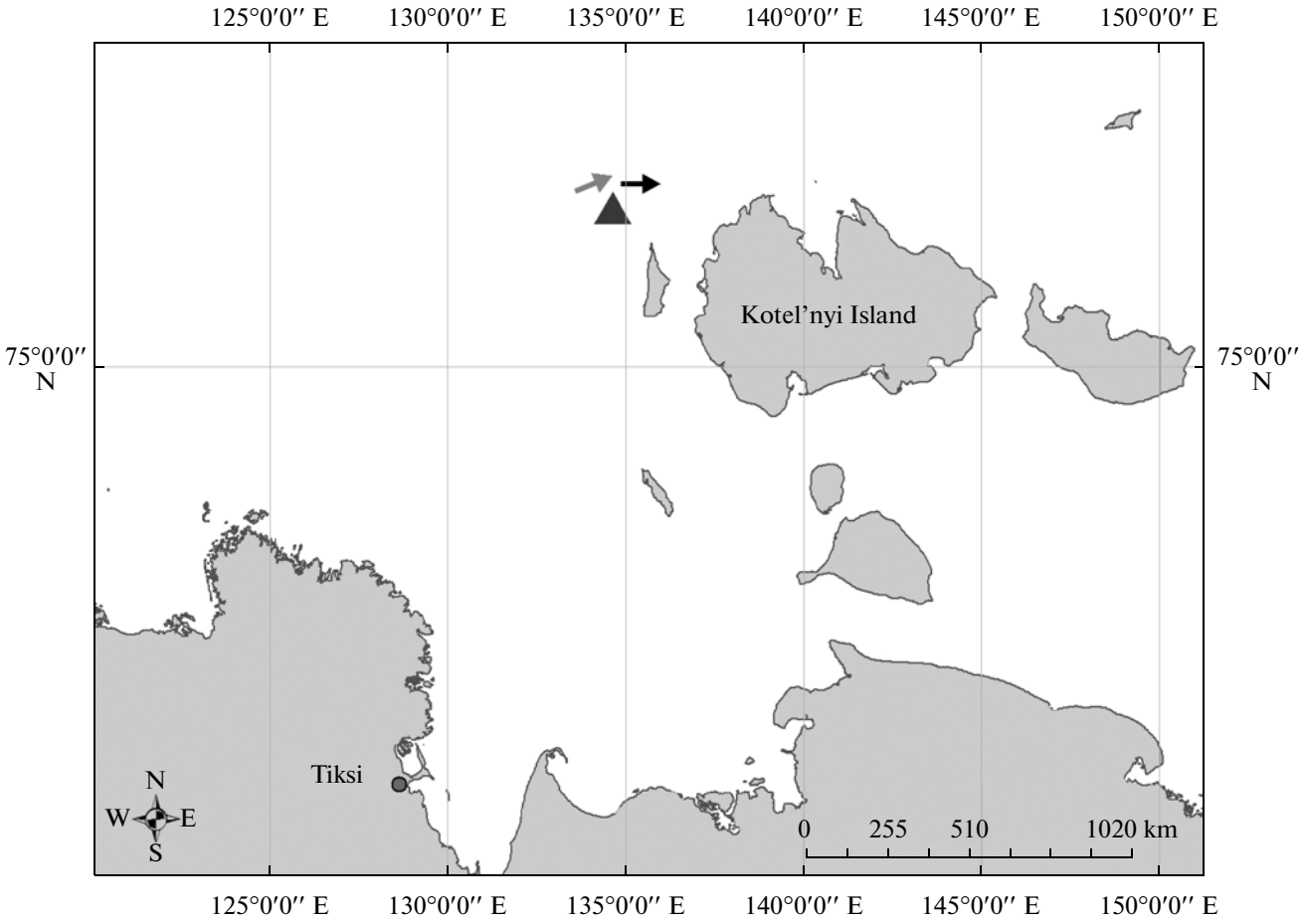

Fig. 1. The site where gray whales were encountered in the Laptev Sea (denoted with triangle). Arrows show the directions of their athwartships movement (signs are not scaled).

swell, 1–1.5 m; the sun glare at 8:00–8:30 o'clock relative to the vessel course; and total visibility according to five-point scale, 5–. When approaching the vessel, the whales separated, one of them passed by the portside retaining its previous direction, while the other individual turned by 20°–30° and passed by the starboard at approximately half a kilometer from the vessel (Fig. 1).

Athwartships, the former whale was at a distance of approximately 100 m from the observer and was photographed several times. Although the whale's position during hyperventilation coincided with the sun glare, and correspondingly, its images were taken against a back light, these photos nonetheless allow for confirmation of its species (Fig. 2). The second whale was too far from the observation platform for sufficient quality photography; and only the cloud of its blow was photographed. In its external appearance (observation with binoculars) and the shape of the blows in photos, the second whale appeared similar to the first individual.

As compared to the other gray whales sighted by the observer in the Sea of Okhotsk, the one that passed near the vessel was darker and had no pronounced light spots (dark uniform coloration is, possibly, an observation artifact due to the back light). A poorly noticeable neck depression, a blow in a shape of a woolpack, and, most importantly, the dorsal ridge knuckles, later detected in the photos, prove that the whale photographed in the Laptev Sea belonged to the species *Eschrichtius robustus*. All observations allow us to attribute the second individual to this species as well.

The whales reacted to the vessel (hull length, 133 m; the speed at the moment of encounter, 16 km/h) in the following way: the first whale displayed no anxiety, advanced to the vessel, and then passed by its side, surfacing several times and spouting water while exhaling. The whale's body condition looked normal (Fig. 2). The second whale, although it deviated from its initial course upon the vessel approach and passed by at a considerable distance, also surfaced several times

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Fig. 2. A gray whale in the Laptev Sea. The inset shows the dorsal ridge knuckles characteristic of the gray whale.

while athwartships. Thus, the whales' reaction to the vessel may be regarded as neutral.

This observation is the first documented encounter of the gray whale in the Laptev Sea, which is over 500 km farther from the earlier recorded western boundary of the species penetration, the East Siberian Sea (Matishov et al., 2000). It is also interesting that this encounter took place at the end of September rather than at the beginning of the Arctic summer when several weeks or even months of open water are ahead, and the whales may move westward along the continent with a low risk. Presumably, in recent years, the trend of an expansion in the summer distribution range of this species is observed, and the visits of the gray whale to the East Siberian and Laptev seas is no longer an extraordinary event, while the small number of encounters may be explained by a very low intensity of the studies in the Arctic.

The described observation conforms well to the hypothesis on the migratory route of the "Mediterranean" gray whale along the Eurasian coast via the Northern Sea Route, and favors an interhemispheric dispersal of marine organisms through the Arctic corridor.

Taking into account the current changes in the distribution of Arctic and Subarctic species (ACIA, 2005), monitoring of marine animals in the Arctic seas has acquired paramount importance. This implies the presence of qualified observers onboard the ships cruising along the Northern Sea Route and in the Arctic as well as establishment of a network of observers from the staff of polar meteorological and hydrographic stations, supplying of ship crews with descriptive material for species identification, and stimulation of their interest in studying Arctic fauna.

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PHOTOGRAPHIC IDENTIFICATION STUDY OF GRAY WHALES (*Eschrichtius robustus*) OFFSHORE NORTHEAST SAKHALIN ISLAND AND SOUTHEAST KAMCHATKA PENINSULA, RUSSIA: 2002-2011

Olga Yu. Tyurneva[1], Yuri M. Yakovlev[1], Vladimir V. Vertyankin[2]

1 - A.V. Zhirmunsky Institute of Marine Biology, Far Eastern Branch of the Russian Academy of Sciences (IBM FEB RAS), Vladivostok, 690041, Russia. (E-mail: olga-tyurneva@yandex.ru)
2 - Kronotsky State Biosphere Reserve, Elizovo, 684000, Russia.

ABSTRACT

Since 2002, annual photo-identification (photo-ID) research of gray whales offshore Sakhalin Island has been conducted by the Institute of Marine Biology, Far East Branch, Russian Academy of Sciences (IBM FEB RAS) . Two main feeding areas were studied offshore Sakhalin Island (Piltun and Offshore) and one area along the Kamchatka coast (Olga and Vestnik Bay). This paper reports the data collected in the summer and fall of 2011 and compares results to data collected since 2002.

In 2011, the data of the IBM FEB RAS photo-ID team were supplemented with the data obtained within the joint research program of A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences (IPEE RAS) and Oregon State University (OSU) of the Okhotsk-Korean Gray Whale (*Eschrichtius robustus*) population habitat using satellite telemetry, which is coordinated by International Whaling Commission and funded by Exxon Neftegas Limited and Sakhalin Energy Investment Company (hereinafter referred to as the satellite tagging program). The latter team photographed 192 whales, including repeat sightings, of which 94 individuals were identified. Of these, 13 individuals were not recorded by the IBM team in 2011; 30 individuals were identified only by the IBM team and not seen by the satellite tagging program team.

In 2011, a total of 124 whales, including 15 calves (including 13 calves and 2 possible calves) were documented in the Sakhalin area and 30 individuals (including 2 calves) were recorded in Olga Bay (Kamchatka). A total of 12 whales from the Sakhalin WGW catalogue were identified in Olga Bay (Kamchatka) and one whale was registered in both regions during the same season of 2011. Five whales from Sakhalin catalogue were registered in Vestnik Bay (Kamchatka) by another research team, three of these were found on Sakhalin shelf in the same season of 2011. Thus, during the 2011 field season, a total of 137 whales were documented off Sakhalin and Kamchatka. Currently, there are a total of 205 identified whales in the Sakhalin GW Catalogue maintained by the IBM team, and 150 whales in the Kamchatka GW Catalogue.

KEY WORDS: WESTERN GRAY WHALE, PHOTO-ID, DISTRIBUTION, COW-CALF, SAKHALIN, PILTUN, KAMCHATKA, OIL AND GAS.

Introduction

From 2002 to 2011, photo-ID studies of the endangered population of western gray whales (*Eschrichtius robustus*) have been conducted annually offshore northeast Sakhalin Island as part of an industry-sponsored monitoring program jointly funded by the Sakhalin-1 and Sakhalin-2 oil and gas development projects, operated by Exxon Neftegas Limited (ENL) and Sakhalin Energy, respectively. Two main feeding areas utilized by whales during the ice-free season have been identified along the northeast Sakhalin coast: the nearshore Piltun feeding area

adjacent to Piltun Bay (52°40' N to 53°30' N), where whales predominantly feed in shallow waters <20 m depth, and the Offshore feeding area approximately 30-40 km east of Chayvo Bay (51°50' N. to 52°25' N), where whales feed in greater water depths of 35-60 m (Fig. 1).

The discovery of the Offshore feeding area in 2001 gave the IBM research team an opportunity to gather evidence on whale movements between the two (Piltun and Offshore) feeding areas off Sakhalin Island (Maminov and Yakovlev, 2002). Observations of solitary gray whales within the range of the Offshore area were reported before 2001 (Sobolevsky 2000; Miyashita *et al.* 2001) and it is possible that the Offshore area was used as a feeding ground by gray whales before 2001. However, whale sightings in the Offshore area prior to 2001 were sporadic. Photo-ID of gray whales in the Offshore area was initiated in 2002 (Yakovlev and Tyurneva 2003) and demonstrated that some of the individuals observed in this area were also observed in the Piltun feeding area during the same year. Photo-ID research in subsequent years confirmed the existence of intra- and interannual exchange of whales between the Piltun and Offshore feeding areas (Yakovlev and Tyurneva 2005, 2011; Tyurneva *et al.,* 2009, 2011a,b; Yakovlev *et al.,* 2009, 2011).

Since 2006, gray whales have also been identified feeding along the southeast coast of the Kamchatka Peninsula. Gray whales were observed in Nalycheva Bay (2004) in water depths of about 30 m, in Vestnik Bay (2006, 2007, 2009) in water depths of about 15-24 m, and in Olga Bay (2006-2011) in water depths of about 5-17 m (Tyurneva *et al.* 2009, 2010a; Yakovlev *et al*. 2012). Since 2005, a number of individuals from the IBM Sakhalin catalogue have been recorded near the coast of the eastern Kamchatka Peninsula (Yakovlev et al. 2009, Tyurneva et *al.* 2010a,b). To reach Sakhalin from Olga Bay, tagging studies have shown that whales swim along a direct (i.e., straight line across the Sea of Okhotsk) route of ~ 1500 (Fig. 1) (http://mmi.oregonstate.edu/sakhalin2010Map).

In 2005 and 2007, individual whales were observed by the IBM team over an extended period of time, i.e. over most of the feeding season. The physical condition in some underweight whales was observed to improve over the course of the feeding season (Yakovlev and Tyurneva 2006; Yakovlev *et al.* 2007). Improvement in the whales' physical condition was also recorded throughout the field seasons of 2008 -2011 (Yakovlev *et al.* 2009b; Tyurneva *et al.* 2010b).

Visual assessment of (presumed) indicators of health such as skin anomalies, body conditions, etc. have been used to monitor the overall health of individuals, which is used as an indicator of the health of the entire population. Photo-ID research is instrumental in monitoring skin condition, including skin sloughing and white patches (blotches), and barnacle load on the skin. For example, white patches or blotches on skin surface have been observed in Gray Whales

although these are poorly understood and their origins are still unknown (Tombach Wright *et al.* 2007).

When multi-annual photo ID data sets are available individuals expressing changes in skin condition over time (e.g. intra and inter seasonal) can be visually monitored through multiple resightings. Repeat encounters allowed the researchers to track the dynamics of the condition throughout the season and between seasons

Methods

During the 2011 feeding season, photo-identification of gray whales took place on the northeastern shelf of Sakhalin and in Olga Bay in southeastern Kamchatka. In the Offshore feeding area off Sakhalin whales were not photographed from "Zodiac" due to technical limitations. Photographs were obtained opportunistically from the deck of the vessel. During marine mammal surveys in the Offshore area MMOs reported the presence of a significant number of gray whales by the end of field work.

In 2011, in addition to the IBM team, the satellite tagging program team photographed whales opportunistically while carrying out their primary task of placing tags on candidate whales. Hence two teams performed photo-ID surveys. Photographs of the satellite tagging program team were included in this report as well.

In 2011, no work was planned in Vestnik Bay as part of the annual Gray Whale Study Program, but as a result of pilot studies associated with another project, gray whale photographs taken in Vestnik Bay in 2011 were obtained. These materials were given to the IMB photo-ID laboratory for identification and permission was obtained to use them in this report.

Field photo-ID procedures used by the IBM team offshore Sakhalin Island since 2002 are based on IWC recommendations for photo-ID work of marine mammals (Hammond *et al.* 1990). The research vessel *Akademik Oparin* was the base vessel for the photo-ID research, with the actual work conducted from a 3.8 m long Zodiac launched from the vessel.On scheduled photo-ID days, weather and sea conditions permitted, the Zodiac was deployed from the mother vessel whenever gray whales were sighted. The whales' position (computed from the GPS position of the Zodiac), the time, behavior, number of whales in the group1, direction of their movement, the presence of other groups of gray whales, killer whales and passing vessels, airplanes, or helicopters, and presence of mud plumes in the observation area were documented.

A Nikon D2X digital camera with a fixed 300 mm f/4 telephoto lens or a Nikkor 80-400 mm zoom lens with image stabilizer (IS) was used for photography. The photographs were

recorded at a high resolution in large JPEG and RAW format. An attempt was made to photograph all aspects (head, flanks and flukes) of each whale. A whale was photographed in sequence, from head to fluke on both the right and left sides, and the dorsal and ventral fluke surfaces. Priority was given to photographing the right and left sides of each whale, as fluking frequency varies with individual behavior and foraging depth. Preference was given to photographing the right sides (flanks) of whales as right sides have been arbitrarily chosen among gray whale researchers as a baseline identifier. Matchable right side photographs are required for an individual whale to be included in the photographic identification catalogues. A matchable quality photograph for photo-identification of gray whales is any photograph of the appropriate region of the body (aspect) that can be reliably identified as belonging to a particular individual whale when compared to other photographs of the same target region of that same whale.

Annual photo-ID research conducted in Olga Bay, Kamchatka Peninsula, by the Kronotsky State Biosphere Reserve, (Fig. 1), used vessel-based field procedures similar to those used in the Piltun and Offshore feeding areas along Sakhalin Island. A Canon 40D digital camera equipped with Canon 75-300 mm zoom lens with IS was used. All photographs were taken at the highest resolution and saved in JPEG format. To recognize whales by their distinguishing marks on their sides and flukes, standard IWC-recommended methods were applied (Hammond *et al.* 1990). Confident left-to-right side matches were established based on the following criteria: (1) the whale was photographed as a solitary individual; (2) sequences of the left and right sides were compared with flukes in common for a single sighting; and (3) as a final check to compare matches and assist with right to left matches, whale knuckle height, spacing and ratios were considered (Calambokidis *et al.* 1999; Weller *et al.* 2002). Whale body coloration and pattern of spots served as the basic feature for whale identification; scars and barnacle spots were used as additional features for comparison. Whales identified offshore Kamchatka Peninsula were assigned catalogue numbers KamGW# in the Kamchatka catalogue, and whales identified offshore Sakhalin Island were assigned catalogue numbers KOGW# in the Sakhalin catalogue. Whales identified in both regions carry two (KamGW# and KOGW#) catalogue numbers and appear in both the Kamchatka and Sakhalin catalogues.

Cow/calf pairs were recorded in accordance with methods outlined in the 2010 annual report (Yakovlev and Tyurneva, 2011). Analysis of photo-ID data also incorporated the identification of whales with deviations from the“physiological norm”. Such deviations included: (1) emaciation (“skinny” whales); and (2) obvious sloughing of skin or other anomalous skin conditions.

Results

The main results of the photo identification studies in 2011, combined with results from previous years, are as follows:

Catalogue Overview

The Sakhalin WGW Catalogue now contains 205 individual gray whales. Some of these whales were registered repeatedly over several years, whereas others (18 whales) are new to the catalogue.

The Kamchatka catalogue consists of photographs of animals observed in three areas - Khalaktyrskyi Beach, Vestnik Bay and Olga Bay - during 2004 and 2006-2011. At present, this catalogue contains 150 fully gray whales. A total of 84 whales were also observed on Sakhalin shelf during various years. It is yet unclear where the other 66 animals photographed near Kamchatka Peninsula reside during the feeding season, since they are not identified in the Sakhalin catalogue.

Whales Identified in 2011 on Both Sakhalin and Kamchatka Shelves

In 2011, between August 19 and October 19, 124 whales were observed off the shore of Sakhalin by the two research teams. This number is higher than in 2008 (98 whales), 2009 (117 whales), and 2010 (105 whales), but comparable with 2007 (125 whales), and the high number might have been a result of a long observation season and the efforts of two combined photo-ID teams (2011) as there is a correlation between the length of the studies and the number of whales sighted. The IBM team recorded 233 whales, including repeat sightings, with 111 individuals identified. The satellite tagging program team photographed 192 whales, including repeat sightings, of which 94 individuals were recognized. Thirty individuals were identified only by the IBM team and not seen by the satellite tagging program team, while 13 individual whales were not recorded by the IBM team during the 2011 expedition.

In 2011, 18 new gray whales, including 15 calves, were identified off Sakhalin. Two of the adult animals were first sighted in Olga Bay (Kamchatka), and had only been recorded there until 2010 when they were first seen near Sakhalin. One of the new whales was recorded for the first time in the northern part of the Sea of Okhotsk and in subsequent years was recorded only in Olga Bay (Kamchatka).

Between July 22 and August 8, 2011, 30 whales including 2 calves were sighted in Olga Bay, Kamchatka. This number is lower than in 2010 (82 whales), 2009 (75 whales) and 2008 (50

whales) (Table 1). This might have been due to a later start to the field season and briefer study period compared to previous years (Table 1, fig. 2).

Twenty-one of these 30 whales were already known, having been observed previously in Olga Bay. The other 9 were new to Olga Bay; 2 of them had previously been seen off NE Sakhalin. Twelve of these 30 whales were registered in the Sakhalin WGW catalogue. Of the 30 whales identified in Olga Bay (Kamchatka) in 2011, only two whales were registered near Sakhalin later in the season. Ten whales had been seen in Sakhalin in previous years but were not sighted in 2011.

Every year since the start of the surveys in Olga Bay in 2006, researchers have identified some whales that had been registered as calves in Piltun area in the previous years. Three of the five calves registered in the Sakhalin shelf in 2008 were identified in Olga Bay in 2009. In 2009, out of eight calves observed in Olga Bay (of which only one was sighted in Olga Bay in 2010), five were recorded off Sakhalin. Not a single calf encountered in Piltun in 2010 was encountered in 2011 in Olga Bay, but five yearlings were identified on the Sakhalin shelf that had first been sighted in 2010.

In 2011, no work was planned in Vestnik Bay as part of the annual Western Gray Whale Monitoring Program, but as a result of pilot studies associated with another project, gray whale photographs taken in Vestnik Bay in 2011 were obtained. These materials were given to the IBM photo-ID laboratory for identification and permission was obtained to use them in this report.

In 2011, two days, May 8 and May 16, were spent in Vestnik Bay. As a result 847 images were shot of six individual whales, five of which had already been identified in the Sakhalin catalogue, of which two whales had not been encountered on the Sakhalin shelf in 2011. Three of the five were observed in the Piltun and Offshore areas in 2011. Two whales were new to the Kamchatka catalogue. One of these two had previously been observed in Sakhalin and was assigned a dual identification number and one whale was new to both catalogues. None of the 6 whales seen in Vestnik Bay was also seen in Olga Bay in 2011.

In 2011, a total of 137 individual whales (out of 205 whales contained in the IBM Sakhalin catalogue of gray whales) were recorded off both Sakhalin and Kamchatka. The total number of identified gray whales included in the Kamchatka and/or Sakhalin catalogues in 2011 alone was 156 whales, 120 of which were registered only on Sakhalin shelf, 32 only off the shore of Kamchatka (13 of which have been registered in the Sakhalin catalogue in the previous years), and 4 were seen in both locations.

Migration of Gray Whales between Feeding Areas in 2011

For this section on migration between different feeding areas only data obtained by the IBM team was used, since the satellite tagging program team did not record the location of whales. The 13 whales photographed only by the satellite tagging program team were encountered in coastal areas (Piltun and Chayvo areas).

In 2011, of the 111 animals identified by the IBM team, a total of 89 whales were identified in the Piltun feeding area, of which 74 were observed only in this area. A total of 14 individuals were identified in the Offshore feeding area off Sakhalin Island, of which nine whales were observed in that area only.

In the Offshore area, a smaller number of whales was identified in 2011 compared to most of earlier years (Table 2), which can be attributed to a reduction of survey effort designated for photo-ID in the Offshore area due to (a) a shorter field season and (b) a new increased satellite tagging program effort in the Piltun area. For this last reason, the vessel could not leave the coastal areas to conduct work in the Offshore area from August 23 to September 21. After the satellite tagging program team completed their work, worsening weather conditions and a tight work schedule for executing other expedition tasks did not allow the IBM team to perform Zodiac-based surveys in the Offshore area. In contrast to 2010, whales were registered in the Chayvo area in 2011; 35 whales were photographed off Chayvo, including repeat sightings. Of the 23 identified individuals, 14 were photographed only in this area, based on the data collected by the IBM team (Table 2).

During the 10 years of the study (2002-2011), out of a total of 205 whales currently included in the IBM catalogue, 99 whales were identified in both the Piltun and Offshore feeding areas over the years. In addition, 102 individual whales were sighted only in the Piltun area and 3 individual whales were sighted only in the Offshore area. One whale was photographed near Cape Elizabeth in 2005 and was never seen since. In all the years of the study, 12 individuals have been encountered near Okha, all of these have been sighted in other areas as well.

In 2011, the number of whales, which used both Kamchatka and Sakhalin regions within the same season, was substantially lower than before. Of the 82 whales identified in Olga Bay (Kamchatka) in 2010, 25 whales were spotted near Sakhalin later in the season, while in 2011 out of 30 whales, only 4 whales were registered in both regions (Fig. 2). This can be explained partly by a later start of the field season in Kamchatka in 2011 compared to the three previous years.

During all these years, cow/calf pairs were registered only in the Piltun area and not in the Offshore area. Cow/calf pairs have recently been observed in Olga Bay as well.

The dynamic nature of the utilization of available feeding grounds offshore Sakhalin by gray whales appears to be a normal behavior aimed at exploiting ever-changing forage habitat.

Body Condition

Since 2005, data have been collected to monitor gray whales' body condition (BC) within and between feeding seasons. If the BC of a particular whale improved upon subsequent observation, then the data used in calculations of the number of visually malnourished animals was based on the latest observation. In 2011, 33 whales with poor body condition (BC) were identified, including 7 nursing females. This constitutes 20.7% of the total number of identified animals (111 individuals – data of the IBM group). All calves observed during these years were physically normal (BC 0). According to our observations, 9 whales improved their BC during the 2011 study period.

In Olga Bay, 20 of the 30 whales (66.6%) showed poor BC. Two of these were nursing females in 2011. Yearly we recorded high percentage of gray whales with poor body conditions near Kamchatka versus Sakhalin (Yakovlev *et al.* 2012), which may be explained by the early photo-identification survey period, as whales have just arrived to the feeding grounds from their winter-long fast and have not had time to accumulate body fat.

Cow/Calf Pairs

In 2011, 7 cow/calf pairs and 8 calves without mothers (15 calves in all) were recorded off Sakhalin, which is the highest number of calves ever recorded over a season. Cow/calf pairs were first sighted on August 21, 2011. One of the photo-identified mothers was sighted with a calf for the first time; the other six had been recorded with calves in prior years. Eight calves unaccompanied by cows were encountered either near females who were not their mothers or in calf groups.

Two cow/calf pairs were recorded in Olga Bay (Kamchatka) in 2011. Both cows were sighted only in Olga Bay (Kamchatka). One of them had been there with a calf in 2009. These data show that the Piltun area of the Sakhalin shelf is not the only feeding area for cow/calf pairs and that another foraging, and potential "nursery", ground is located in Olga Bay.

CONCLUSIONS

Based on the reproductive success, the number of animals observed, and the ability to recover after malnourishment or skin abnormalities, it can be concluded the population is in satisfactory state of health.

In 2009-2011 a total of 182 KOGW individuals, including calves, were observed by IBM teams (Sakhalin and Kamchatka regions).

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Table 1. Number of gray whales (GW) identified during photo-ID studies offshore northeast Sakhalin Island and southeast Kamchatka Peninsula for all years of studies.

A	B	C	D	E	F
Year	**GW identified off the Kamchatka coast**	**GW identified only off the Kamchatka coast and unknown in Sakhalin Catalogue, 2002-2010**	**GW identified off the Kamchatka coast and already known in Sakhalin Catalogue, 2002-2010**	**GW identified off the Sakhalin coast, 2002-2010**	**Numbers of GW known in Sakhalin Catalogue (2002-2010) identified in both regions during one year**
2002	**No data**	**No data**	**No data**	**47**	**47**
2003	**No data**	**No data**	**No data**	**82**	**82**
2004	**3**	**1**	**2**	**96**	**98**
2005	**No data**	**No data**	**No data**	**117**	**117**
2006	**13**	**8**	**5**	**121**	**128**
2007	**37**	**18**	**19**	**125**	**132**
2008	**50**	**25**	**24**	**98**	**122**
2009	**75**	**36**	**39**	**117**	**138**
2010	**82**	**34**	**48**	**105**	**128**
2011	**36**	**19**	**17**	**124**	**137**

Table 2. Whale movement among the feeding areas offshore northeast Sakhalin in 2002-2011*

Year	Number of Whales Identified in the Piltun Area	Number of Whales Identified in the Offshore Area	Number of Whales Identified in the Offshore and Piltun Areas	Number of Whales Identified in the Chayvo Area	Number of Whales Identified in the Chayvo+Piltun / Chayvo+Offshore areas	Number of Whales Identified in Northern areas	Number of Whales Identified in the Chayvo+Piltun+Offshore areas	Number of Whales Identified Near Okha
2002	**13(12)**	**35(34)**	**1**					
2003	**51(47)**	**35(31)**	**4**					
2004	**95(89)**	**7(1)**	**6**					
2005	**115(105)**	**7(1)**	**6**			**5 (1)**		
2006	**102(64)**	**33(14)**	**17**	**26(5)**	**19/0**		**2**	
2007	**102(44)**	**69(23)**	**38**	**20**	**12/0**		**8**	
2008	**61(35)**	**62(36)**	**25**	**1(1)**				
2009	**79(60)**	**39(24)**	**13**	**14(6)**	**6/2**			
2010	**92(76)**	**21(9)**	**11**	**-**	**-**	**-**		**9(4)**
2011	**89(75)**	**14(9)**	**5**	**23(14)**	**9/0**			

** Values in parentheses indicate the number of whales reported only in the specified area and not sighted in other surveyed areas. Numbers in table can change annually to reflect updates to the catalogue, for example due to matched temporary whales.*



Figure 1. Map showing the recoding of photo-identified whales in known feeding areas offshore NE Sakhalin Island, southeast Kamchatka in the summer-fall season of 2011.

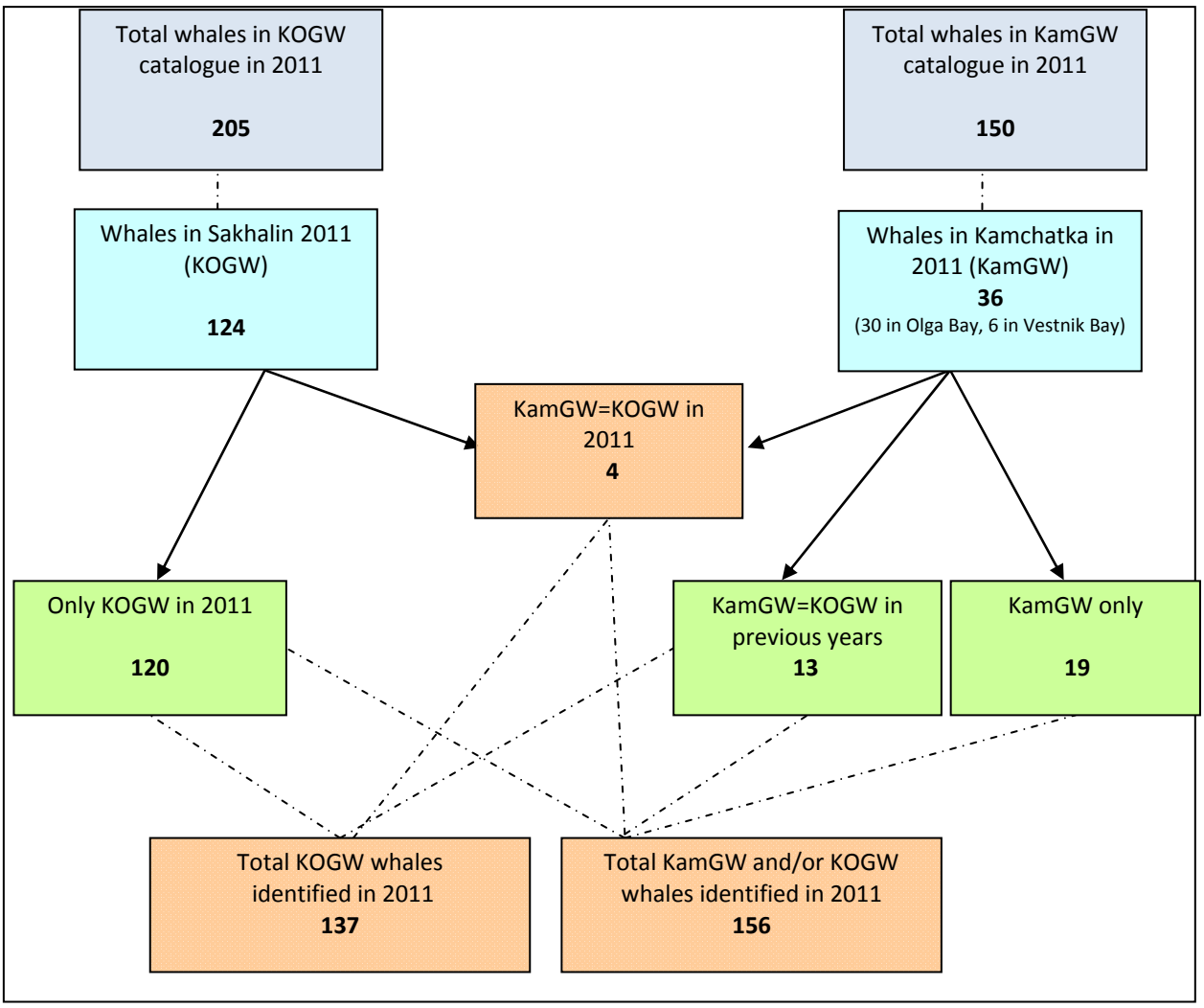

Figure 2. Population migration between the feeding grounds in 2011

REPORT ON THE PHOTOGRAPHIC COMPARISON OF THE WESTERN AND MEXICAN GRAY WHALE CATALOGUES.

J. Urbán R.[1], D. Weller[2], O. Tyurneva[3], S. Swartz[4], A. Bradford[5], Y. Yakovlev[3], O. Sychenko[6], H. Rosales N[1]., S. Martínez A[1]., A. Burdin[6] and A. Gómez-Gallardo U.[1]

[1] *Programa de Investigación de Mamíferos Marinos. Universidad Autónoma de Baja California Sur, La Paz, B.C.S., Mexico*

[2] *Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 3333 North Torrey Pines Court, La Jolla, CA, 92037-1022 USA*

[3] *A.V. Zhirmunsky Institute of Marine Biology, Far Eastern Branch of the Russian Academy of Sciences, Vladivostok, 690041, Russia.*

[4] *Laguna San Ignacio Ecosystem Science Program, Darnestown, MD, USA*

[5] *Protected Species Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Honolulu, HI, USA*

[6] *Kamchatka Branch of Pacific Institute of Geography, Far East Branch - Russian Academy of Sciences, Petropavlovsk, Kamchatka, Russia*

ABSTRACT

Photographs of 217 identified gray whales obtained from the Sakhalin Island, Russia feeding grounds were compared with 6,546 photo-identified individuals from the Baja California Peninsula, Mexico breeding lagoons to identify matches between these two populations. A total of 13 matches of individuals were found, including six males, five females and two of unknown sex. Twelve whales had sightings prior to and after to their respective sighting in Mexico. Twelve whales were observed in Laguna San Ignacio and one in Laguna Ojo de Liebre. Ten of the 13 whales were photographed in Mexico only in one year and the other 3 in two years. Twelve whales were sighted in Sakhalin in the summer of 2011. Eleven whales were sighted in consecutive seasons, eight of them in three consecutive seasons (summer-winter-summer), three in two seasons (summer-winter), and four in two seasons (winter-summer). Three whales were sighted the same day in Laguna San Ignacio suggesting that these animals were traveling in association with each other. Four females with calves were sighted in the winter in Mexican waters and in the next summer off Sakhalin, three of them without calves suggesting that these females had either separated from their calves or that their calves did not survive. The time between the last sighting in one season and the first one in the next season was $\bar{x}$=195.4 days (n=11, 141-255) during the summer-winter migration, and $\bar{x}$=150.9 days (n=12, 131-213) during the winter-summer migration. The matches made between whales sighted off Sakhalin and the Mexican Pacific are the first results of the multinational collaboration "PACIFIC WIDE STUDY ON POPULATION STRUCTURE AND MOVEMENT PATTERNS OF NORTH PACIFIC GRAY WHALES" initiated under the coordination and support of the International Whaling Commission last year.

INTRODUCTION

Recent results of genetic and photographic identification comparisons between western and eastern North Pacific gray whales (see IWC, 2011) suggest a mixing of these populations during the winter reproductive season, and illustrate the great conservation and management importance of a more comprehensive examination of gray whale movement patterns and population structure in the North Pacific. The Scientific Committee recommended that a collaborative Pacific-wide study be developed

under the auspices of the IWC, recognising that *inter alia* this will contribute to the Committee-endorsed Conservation Plan for western North Pacific gray whales and incorporate previous recommendations made by the Committee. Such a study will involve collaborative analysis and sharing of existing data as well as the collection of new data. This report summarizes the results of the "(Phase 1) photo-identification project". The purpose of this project was to undertake a comparison of two western gray whale catalogues from Sakhalin Island, Russia with the Mexican gray whale catalogue.

METHODS

The comparison was done based on two catalogues of photo-identified gray whales from Sakhalin Island and one catalogue of gray whales from Laguna San Ignacio and Laguna Ojo the Liebre on the west coast of the Baja California Peninsula, México.

The Sakhalin catalogues

The first step was to compare the two catalogues available at that moment:

1) The Russia-US catalogue (2012).

Burdin, A. M., Weller, D., Sychenko, O., and Bradford, A. 2012. "*WESTERN GRAY WHALES OFF SAKHALIN ISLAND, RUSSIA: A CATALOG OF PHOTO-IDENTIFIED INDIVIDUALS"*.
205 individuals. Period 1994-2011
2) The IBM catalogue.

Tyurneva, O. Yu. and Yakovlev, Yu. M. 2010. "THE WESTERN PACIFIC GRAY WHALES OF SAKHALIN ISLAND 2002-2008, LEARING ABOUT A POPULATION OF WHALES THROUGH PHOTOGRAPHS".
165 individuals. Period: 2002-2008

As result of these comparisons 217 photo-identified gray whales from Sakhalin were used in the comparison with the Mexican catalogue. All are represented by the right-side dorsal flank and 215 are associated with the left-side dorsal flank

The Mexican catalogue

This catalogue includes 6,546 gray whales. 5366 photo-identified in Laguna San Ignacio between 1993 and 2011, and 1180 in Laguna Ojo de Liebre (Scammon´s Lagoon) between 2001 and 2003. Of the 6,546 whales in the catalogue 5,890 are represented by a right-side of the dorsal flank image and 1,837 were associated with a left-side dorsal flank image (Table 1).

Table 1. Number of photo-identified gray whales in the Mexican catalogue.
Laguna Ojo de Liebre = LOL, Laguna San Ignacio = LSI.

year	Total photo-id whales	Right and left sides	Only right side	Only left side	Lagoon
2001	398	0	398	0	LOL
2002	462	0	462	0	LOL
2003	320	0	320	0	LOL
1996	157	0	155	2	LSI
1997	310	0	310	0	LSI
1998	392	0	392	0	LSI
1999	253	0	253	0	LSI
2000	448	0	448	0	LSI
2003	247	0	247	0	LSI
2005	438	18	420	0	LSI
2006	249	22	226	1	LSI
2007	495	150	217	128	LSI
2008	358	114	137	107	LSI
2009	662	286	238	138	LSI
2010	750	250	319	181	LSI
2011	607	341	167	99	LSI
Total	**6546**	**1181**	**4709**	**656**	

RESULTS.

The Sakhalin to Mexico catalog comparison resulted in a total of 13 confirmed matches of individuals, including six males, five females and two of unknown sex. Twelve whales had sightings prior and after to their respective sighting in Mexico. Twelve whales were observed in Laguna San Ignacio and one (#3) in Laguna Ojo de Liebre. Ten of the 13 whales were photographed in Mexico only in one year and the other 3 in two years. Twelve whales were sighted in Sakhalin in the summer of 2011(Table 2).

All 13 whales were sighted in consecutive seasons, eight of them in three consecutive seasons (summer-winter-summer), three in two seasons (summer-winter), and five in two seasons (winter-summer). Whale #2, male, was sighted in summer-winter (2006-2007), and summer-winter-summer (2009-2010); the whale #9, female, was sighted in summer-winter-summer (2006-2007), and in the winter-summer (2011); and the whale #11, was sighted in summer-winter-summer (2007-2008), and in the summer-winter (2009-2010) (Table 3).

The whales #5, #6 and #12 were sighted the same day, February 24 2006, and whale # 20 was sighted two days later in Laguna San Ignacio. The whales #5 and #12 were in the same group and #6 in a different group, suggesting that these animals were traveling in association with each other (Table 3).

The five known females were sighted with calves in the winter in Mexican waters and in the next summer in their feeding grounds, three of them without calves (Table 3), suggesting that these females had either separated from their calves (e.g. weaned) or that their calves did not survive (e.g., due to predation).

The female #7 was observed with calf in March 11, 2009 in Laguna San Ignacio and 122 days later, on July 11, off the Kamchatka Peninsula where she stayed with her calf at least until September 2.

The time between the last sighting in one season and the first one in the next season was $\bar{x}$=195.4 days (n=11, 141-255) during the summer-winter migration, and $\bar{x}$=164.3 days (n=13, 122-213) during the winter-summer migration. The shorter time between Laguna San Ignacio and Sakhalin was of the whale #13, of unknown sex, with 131 days followed by the whale #4, a male, with 139 days, and the whales #8 and #11, mothers with calves, with 144 and 143 days respectively (Table 3).

Table 2. Sighting summary information for 13 gray whales matched between Sakhalin and Mexico. * = With calf.

	Russia-US		IBM		UABCS		Russia-US
#	No.	Years	No.	Year(s)	No.	year(s)	Sex
1[1]	20	97,02-04,07,09,11	80	06,07	06-0209-D-LSI	06	M
2[1]	52	98,99,00,01,02, 03,05,06,08,09,10,11	26	02,05,08	07-0328-I-LSI, 10-0639-D-LSI	07,10	M
3	27	95,97,98,99,00,01,02, 04,05,06,07,09,10,11	2	02,05	02-0336-D-LOL	02	M
4	91	00,05,07,08,09,11	137	07	11-0273-D-LSI	11	M
5	28	97,98,99,00,01,03,04, 05,06,07,09,11	59	05,07	06-0131-D-LSI	06	M
6	69	98,00,01,02,03,04, 08,09,11	113	04,05,07	06-0176-D-LSI	06	M
7[1]	42	97,98,99,00,03, 04,05,11	90	03,05,09*	09-0696-D-LSI-M	09*	F
8[1]	63	97,98*,00,01,02 05,07,08,10,11*	47	03,05,07	08-107-I-LSI-M	08*	F
9	103	01,02,04,05,11	119	05,06,07	07-0457-D-LSI, 11-0526-D-LSI-M	07,11*	F
10	29	97,98,00,01,02,03,04, 05,07,09,10,11	28	03,05	10-0739-D-LSI-M	10*	F
11	85	99,01,02,04,05,08*,09, 11	51	04,05,07	08-0051-D-LSI-M, 10-0396-D-LSI	08*,10	F
12	94	00,03,04,05,07,11	57	03,06,07,08	06-0132-D-LSI	06	U
13			166	09	09-0506-D-LSI	09	U

[1]Reported in Weller *et al*. 2011

Table 3. Gray whales sighted in consecutive seasons.

#	Sakhalin (Summer) RusUS	IBM	Mexico (Winter) UABCS	Sex	Summer	Days	Winter	Days	Summer
1	20	80	06-0209-D-LSI	M			26-Feb-2006	213	27-Sep-2006
2	52	26	07-0328-I-LSI, 10-0639-D-LSI	M	22-Aug-2006 07-Aug-2009	181 217	20-Feb-2007 13-Mar-2010	 177	 06-Sep-2010
3	27	2	02-0336-D-LOL	M	31-Jul-2001	217	06-Mar-2002	150	03-Aug-2002
4	91	137	11-0273-D-LSI	M			01-Mar-2011	139	18-Jul-2011
5	28	59	06-0131-D-LSI	M	07-Aug-2005	200	24-Feb-2006	179	22-Aug-2006
6	69	113	06-0176-D-LSI	M	23-Ags-2005	184	24-Feb-2006		
7	42	90	09-0696-D-LSI-M	F			11-Mar-2009*	122	11-Jul-2009*
8	63	47	08-107-I-LSI-M	F	09-Sep-2007°	201	29-Mar-2008*	144	20-Aug-2008°
9	103	119	07-0457-D-LSI, 11-0526-D-LSI-M	F	17-Oct-2006”	141	08-Mar-2007° 08-Mar-2011*	189 170	13-Sep-2007” 25-Aug-2011°
10	29	28	10-0739-D-LSI-M	F	07-Aug-2009°	219	14-Mar-2010* 29-Mar-2010*	176	06-Sep-2010°
11	85	51	08-0051-D-LSI-M, 10-0396-D-LSI	F	16-Sep-2007” 24-Jul-2009	163 255	26-Feb-2008* 06-Mar-2010*	143	19-Jul-2008*
12	94	57	06-0132-D-LSI	U	06-Sep-2005	171	24-Feb2006	203	16-sep-2006
13		166	09-0506-D-LSI	U			04-Mar-2009	131	113-Jul-2009

*with calf
°without calf
“presence of calf unknown

DISCUSSION

The 13 individuals sighted in Mexican waters represent about 10% of the western gray whale population based on the population assessment of an estimate of 130 individuals (90% Bayesian CI = 120-142) (Cooke *et al.* 2008). If we combine these matches with the six matches found off the coast of Vancouver Island reported by Weller *et al.*, (2011), presumably during their migration from the breeding lagoons along the Mexican coast, and the two genetic matches noted by Lang *et al.*, (2011) with whales sampled in southern California, a total of 21 whales identified as part of the western gray whale population have migrated, at least in some years, to the eastern North Pacific during the winter breeding season.

The presence of three of these whales the same day in Laguna San Ignacio, two in the same group, indicate that these whales may travel in association or in groups, as Weller *et al.*, (2011) observed

based on six matches off Vancouver Island, British Columbia, Canada. This also suggests that these whales may stay together in groups while on the breeding grounds.

The sex of the whales (six males, five females and two of unknown sex) indicates that both sexes, in approximately equal numbers, migrate to Mexican waters during the winter breeding season.

The sighting of females without their calves on the Russian feeding grounds suggests a high mortality of the calves, based on the small sample of four mothers with calf sighted in Laguna San Ignacio and the next summer off Sakhalin and one off Kamchatka (i.e., only a 40% survivorship). The long distance of their migratory destination compared to the Bering and Chukchi Seas could be an important factor in the survivorship of the calves. Alternatively, these females may have separated from their calves as the normal weaning process when the calves were of sufficient age to begin foraging for themselves.

The number of days between the last photograph of the season and the first one of the next season represents the maximum migration time and depends on the presence of the whale, the chance to find and photograph it, and the field work seasons of the different research teams. The shorter times observed between Laguna San Ignacio and Sakhalin, 131-143 days, could be close to the real migration times of these whales.

The matches made between whales sighted off Sakhalin and the Mexican Pacific are the first results of the multinational collaboration "PACIFIC WIDE STUDY ON POPULATION STRUCTURE AND MOVEMENT PATTERNS OF NORTH PACIFIC GRAY WHALES" initiated under the coordination and support of the International Whaling Commission last year. Additional comparisons and analyses of photographs from the Western and Eastern gray whales are ongoing and will include photographs from the IBM Sakhalin catalogue 2008-2011, IBM Kamchatka catalogue, and from Laguna San Ignacio and Bahia Magdalena winter aggregation and breeding areas, obtained during the winter 2012.

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REPORT ON THE PHOTOGRAPHIC COMPARISON OF THE SAKHALIN ISLAND AND KAMCHATKA PENINSULA WITH THE MEXICAN GRAY WHALE CATALOGUES.

J. Urbán R.[1], D. Weller[2], O. Tyurneva[3], S. Swartz[4], A. Bradford[5], Y. Yakovlev[3], O. Sychenko[6], H. Rosales N[1]., S. Martínez A[1]., A. Burdin[6] and A. Gómez-Gallardo U.[1]

[1] *Programa de Investigación de Mamíferos Marinos. Universidad Autónoma de Baja California Sur, La Paz, B.C.S., Mexico*

[2] *Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 3333 North Torrey Pines Court, La Jolla, CA, 92037-1022 USA*

[3] *A.V. Zhirmunsky Institute of Marine Biology, Far Eastern Branch of the Russian Academy of Sciences, Vladivostok, 690041, Russia.*

[4] *Laguna San Ignacio Ecosystem Science Program, Darnestown, MD, USA*

[5] *Protected Species Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Honolulu, HI, USA*

[6] *Kamchatka Branch of Pacific Institute of Geography, Far East Branch - Russian Academy of Sciences, Petropavlovsk, Kamchatka, Russia*

ABSTRACT

Photographs of 382 identified gray whales obtained from summer feeding grounds off Russia (232 from Sakhalin Island 1994-2012; and 150 from Kamchatka Peninsula 2004-2011), were compared with 4,352 photo-identified individuals from winter calving lagoons off the Baja California Peninsula, Mexico between 2006 and 2012. The Sakhalin, Kamchatka and Mexico catalogs comparison resulted in a total of 9 confirmed matches of individuals, including 1 males, three females and five of unknown sex. Two whales were observed in the three places, three in Sakhalin and Mexico and four in Kamchatka and Mexico. Eight of the 9 whales in Mexico were sighted in Laguna San Ignacio and one in Bahía Magdalena. Seven of the 9 whales were photographed in Mexico only in one year, one in two years and one in three years. Five whales were sighted in consecutive seasons. These results offer the first complete migratory information for some gray whales that summer off Russia and provide new information important to the evolving understanding of gray whale population structure in the North Pacific. The matches made between whales sighted off Sakhalin, Kamchatka and the Mexican Pacific are the results of the second year of the multinational collaboration "PACIFIC WIDE STUDY ON POPULATION STRUCTURE AND MOVEMENT PATTERNS OF NORTH PACIFIC GRAY WHALES" initiated under the coordination and support of the International Whaling Commission in 2011.

INTRODUCTION

Recent results of genetic and photographic identification comparisons between western and eastern North Pacific gray whales (Lang *et al*. 2011; Weller *et al*. 2012) suggest a mixing of these populations during the winter reproductive season, and illustrate the great conservation and management importance of a more comprehensive examination of gray whale movement patterns and population structure in the North Pacific. The Scientific Committee recommended that a collaborative Pacific-wide study be developed under the auspices of the IWC, recognising that *inter alia* this will contribute to the Committee-endorsed Conservation Plan for western North Pacific gray whales and incorporate previous recommendations made by the Committee. Such a study will involve collaborative analysis and sharing of existing data as well as the collection of new data. This report summarizes the results of

the comparison of the gray whales photo identified off Sakhalin Island and the Kamchatka Peninsula with the Mexican gray whale catalogue.

METHODS

The comparison was done based on:

1. The combination of two catalogues from Sakhalin Island. **217 individuals**

Burdin, A. M., Weller, D., Sychenko, O., and Bradford, A. 2012. *"WESTERN GRAY WHALES OFF SAKHALIN ISLAND, RUSSIA: A CATALOG OF PHOTO-IDENTIFIED INDIVIDUALS"*.
205 individuals. Period 1994-2011 (Russia-US)

Tyurneva, O. Yu. and Yakovlev, Yu. M. 2010. *"THE WESTERN PACIFIC GRAY WHALES OF SAKHALIN ISLAND 2002-2008, LEARING ABOUT A POPULATION OF WHALES THROUGH PHOTOGRAPHS"*. (IBM)
165 individuals. Period: 2002-2008

2. A catalogue from Kamchatka. **150 individuals**

Tyurneva, O. and V.Vertyankin. 2012. *THE NORTH PACIFIC GRAY WHALES MASTER CATALOGUE 2004-2011*. Kamchatha. Institute of Marine Biology Russian Academy of Sciences

3. New photo-identified whales from Sakhalin from the Institute of Marine Biology Russian Academy of Sciences. **15 individuals**

4. The catalogue from Mexico 2006-2011. **3,405 individuals**

5. The catalogue from México 2012. **947 individuals** (including 670 from Laguna San Ignacio and 272 from Bahía Magdalena).

RESULTS.

The Sakhalin, Kamchatka and Mexico catalogs comparison resulted in a total of 9 confirmed matches of individuals, including 1 male, three females and five of unknown sex. Two whales were observed in the three places, three in Sakhalin and Mexico and four in Kamchatka and Mexico. Eight of the 9 whales in Mexico were sighted in Laguna San Ignacio and one in Bahía Magdalena. Seven of the 9 whales were photographed in Mexico only in one year, one in two years and one in three years. (Table 1).

Five whales were sighted in consecutive seasons. Whale #2, female, was observed in Kamchatka in 2008, in San Ignacio in 2009, with a calf, and again in Kamchatka in the summer 2009. The same whale was observed again in San Ignacio 2012 and Sakhalin 2012.

The whale #4 also a female, was observed in Sakhalin 2007, San Ignacio 2008 and Sakhalin 2008. The same whale was observed in Sakhalin 2009 and San Ignacio 2010 and again Sakhalin 2011 and San Ignacio 2012.

These two whales, #2 and #4 were reported last year (Urbán *et al*. 2012) and they were photographed again during the winter season of 2012 at Laguna san Ignacio.

Table 1. Sighting summary information for 9 gray whales matched between Mexico against Sakhalin and Kamchatka. * = With calf.

#	Sex	Mexico	Sakhalin	Kamchatka
1	U	09-0506-D-LSI	IBM 166	IBM KAMGW 015
Years sighted		09	11	04
2	F	09-0696-D-LSI-M	R-US 42; IBM 90	IBM KAMGM 01
Years sighted		09*,12	97,98,99.00,03,04.05,11,12	08,09
3	M	12-0436-LSI	R-US 47; IBM 9	
Years sighted		12	95,98,9900,01,02,03,04,0507,08,10,11,12	
4	F	08-0051-D-LSI-M	R-US 85; IBM 51	
Years sighted		08*,10,12*	99,01,04,05,07,08,09,11	
5	U	12-0551-LSI	R-US 200; IBM 191	
Years sighted		12	11 (calf)	
6	U	11-0362-LSI		IBM KAMGW 134
Years sighted		11		10
7	U	11-0308-LSI		IBM KAMGW 036
Years sighted		11		07
8	U	12-0272-BM		IBM KAMGW 114
Years sighted		12		09
9	F	12-0229-LSI-M		IBM KAMGW 117
Years sighted		12*		10

In summary the results of this report together with the report from last year (Urban *et al*. 2012) are show in the figure 1:

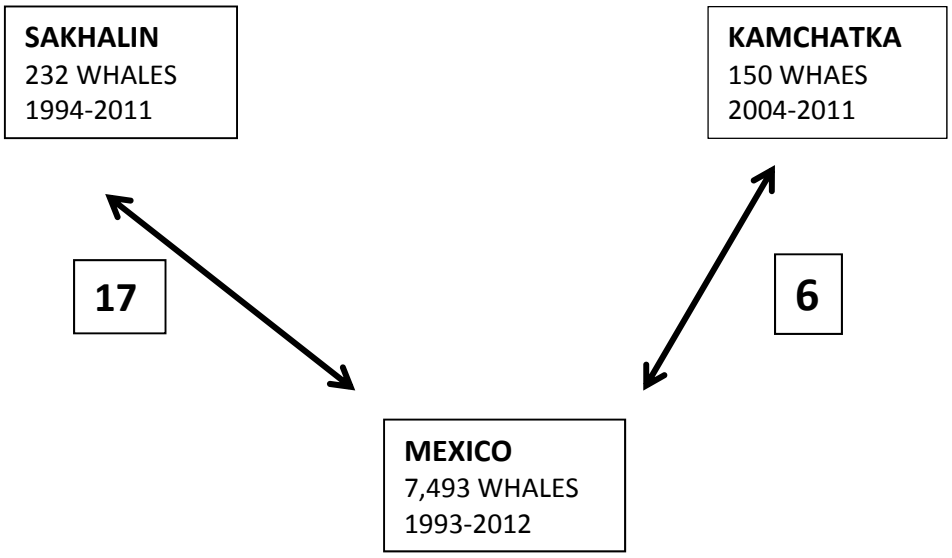

Figure 1. Matches between the two feeding areas: Sakhalin and Kamchatka with Mexico. A total of 21 whales considering that two individuals were observed in the three places. 7 females, 7 males and 7 of unknown sex.

DISCUSSION

Recent results of genetic, telemetry and photographic identification comparisons between western and eastern North Pacific gray whales suggest a mixing of these populations during the winter reproductive season. These findings illustrate the great conservation and management importance of a more comprehensive examination of gray whale movement patterns and population structure in the North Pacific.

These results offer the first complete migratory information for some gray whales that summer off Russia and provide new information important to the evolving understanding of gray whale population structure in the North Pacific.

The matches made between whales sighted off Sakhalin, Kamchatka and the Mexican Pacific are the results of the second year of the multinational collaboration "PACIFIC WIDE STUDY ON POPULATION STRUCTURE AND MOVEMENT PATTERNS OF NORTH PACIFIC GRAY WHALES" initiated under the coordination and support of the International Whaling Commission in 2011 (IWC, 2011)

Acknowledgements

We wish to thank our field researchers and colleagues that assisted with the documentation of the gray whales in Laguna San Ignacio and Laguna Ojo de Liebre. We also thank The Ocean Foundation, and the World Wildlife Fund-Mexico for their support of the field work and analysis of our results. This research was conducted as part of the Laguna San Ignacio Ecosystem Science Program (LSIESP) under special scientific research permits No.SGPA/DGVS/11560/10 and SGPA/DGVS/00640/12from the Subsecretaría de Gestión Para La Protección Ambiental, Dirección General de Vida Silvestre, de Mexico.

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IWC (2011) Report of the 2011 IWC Scientific Committee. Tromso, Norway. [Available from http://www.iwcoffice.org/]

Lang AR, Weller DW, LeDuc R, Burdin AM, Pease VL, Litovka D, Burkanov V, Brownell, RL, Jr. (2011) Genetic analysis of stock structure and movements of gray whales in the eastern and western North Pacific. Paper SC/63/BRG10 presented to the International Whaling Commission Scientific Committee. [Available from http://www.iwcoffice.org/]

Urbán R., J., D. Weller, O. Tyurneva, S. Swartz, A. Bradford, Y. Yakovlev, O. Ivashchenko, H. Rosales N., S. Martínez A., and A. Gómez-Gallardo U. 2012. Report on the photographic comparison of the western and Mexican gray whales catalogues. Paper SC/64/BRG13. presented to the International Whaling Commission Scientific Committee. [Available from http://www.iwcoffice.org/]

Weller, DW, Klimek, A., Bradford, A.L., Calambokidis, J., Lang, A.R., Gisborne, B., Burdin A.M, Szaniszlo, W., J. Urban, A. Gomez-Gallardo, S. Swartz, and Brownell RL, Jr. (2012) Movements of western gray whales between the western and eastern North Pacific. Endangered Species Research 18:193-199

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GRAY WHALES (*ESCHRICHTIUS ROBUSTUS*) OFF SAKHALIN ISLAND, RUSSIA: SEASONAL AND ANNUAL PATTERNS OF OCCURRENCE[1]

DAVID W. WELLER[2]
BERND WÜRSIG
AMANDA L. BRADFORD[2]
Marine Mammal Research Program
Texas A&M University
4700 Avenue U, Building 303,
Galveston, TX 77551, U.S.A.
E-mail: dweller@sgilj.ucsd.edu

ALEXANDER M. BURDIN
Kamchatka Institute of Ecology and Nature Management
Kamchatka, 683000, Russia

SERGEY A. BLOKHIN
Pacific Institute of Fisheries and Oceanography
Vladivostok, 690600, Russia

HIROYA MINAKUCHI
CETUS,
Yokohama 245, Japan

ROBERT L. BROWNELL, JR.
Southwest Fisheries Science Center,
National Marine Fisheries Service,
P. O. Box 271,
La Jolla, California 92038, U.S.A.

ABSTRACT

The annual return, seasonal occurrence, and site fidelity of Korean-Okhotsk or western gray whales on their feeding grounds off northeastern Sakhalin Island, Russia, were assessed by boat-based photo-identification studies in 1994–1998. A total of 262 pods were observed, ranging in size from 1 to 9 whales with an overall mean of 2.0. Sixty-nine whales were individually iden-

[1] We dedicate this paper to Ken Norris, a pioneer and leader of research on the behavioral ecology and conservation-related status of gray whales.

[2] Present address: Southwest Fisheries Science Center, National Marine Fisheries Service, P.O. Box 271, La Jolla, CA 92038, U.S.A.

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tified, and a majority of all whales (71.0%) were observed in multiple years. Annual sighting frequencies ranged from 1 to 18 d, with a mean of 5.4 d. The percentage of whales reidentified from previous years showed a continuous annual increase, reaching 87.0% by the end of the study. Time between first and last sighting of identified individuals within a given year was 1–85 d, with an overall mean of 40.6 d. Annual calf proportions ranged from 4.3% (1997) to 13.2% (1998), and mother-calf separations generally occurred between July and September. The seasonal site fidelity and annual return of whales to this part of the Okhotsk Sea emphasize its importance as a primary feeding ground for this endangered population.

Key words: western gray whale, *Eschrichtius robustus,* Okhotsk Sea, Russia, photo-identification, occurrence patterns, site fidelity.

Gray whales are known to occur as two separate populations along the eastern and western margins of the North Pacific (Rice and Wolman 1971). While both populations were hunted to near extinction, only the eastern North Pacific or California-Chukchi gray whale has returned to pre-exploitation population levels (Reilly 1992, Clapham *et al.* 1999). The western North Pacific or Korean-Okhotsk gray whale was thought to be extinct as recently as the early 1970s (Bowen 1974) but is known to survive today as a remnant population (Brownell and Chun 1977, Blokhin *et al.* 1985, Berzin *et al.* 1990). This western population is presently considered one of the most endangered and little-known large-whale populations in the world (Berzin *et al.* 1995, Brownell *et al.* 1997, Brownell 1999, Clapham *et al.* 1999). The current population size has been reported as 100–250 whales (Vladimirov 1994; Blokhin 1996; Berzin, in press); however, no reliable quantitative data have existed to confirm these assessments.

Basic information regarding the life history and biology of western gray whales is sparse, and only recently has this population come under concerted study (Brownell *et al.* 1997, Würsig *et al.* 1999). Historic sighting data and whaling records suggest that summer feeding grounds are in the Okhotsk Sea and that the whales migrate to presently unknown breeding grounds suspected to be along the coast of southern China (Henderson 1972, 1984, 1990; Yablokov and Bogoslovskaya 1984; Kato and Kasuya, in press). Sighting records from aerial and vessel surveys in the Okhotsk Sea between 1979 and 1989 indicated that feeding gray whales aggregated predominately along the shallow-water shelf of northeastern Sakhalin Island, Russia, and were particularly abundant off the southern portion of a coastal lagoon called Zaliv Pil'tun (Blokhin *et al.* 1985; Berzin *et al.* 1988, 1990, 1991, in press; Blokhin 1996).

Concerns regarding the status of western gray whales have intensified as a result of continued low-level human-related mortality south of the Okhotsk Sea (Brownell 1999) and the onset of large-scale U.S.-Russian oil and gas development programs near the only known gray whale feeding ground within Okhotsk waters (Brownell *et al.* 1997, Würsig *et al.* 1999). In response to these concerns, a joint research project under the U.S.-Russian Environmental Agreement (Marine Mammal Project) was initiated in 1995 to examine the conservation status, occurrence, distribution, behavior, and potential human-

related disturbance of gray whales off the northeastern coast of Sakhalin Island. Principal research components of this project included aerial surveys, shore-based behavioral observations, theodolite tracking, acoustic monitoring, biopsy sampling, and photo-identification (Würsig *et al.* 1998, 1999). Findings presented here represent information from photo-identification studies between 1994 and 1998, and summarize patterns of seasonal and annual occurence of western gray whales on their feeding grounds in the Okhotsk Sea.

Methods

Study Area

Zaliv Pil'tun (referred to here as Piltun Lagoon) is located on the northeastern shore of Sakhalin Island, Russia (Fig. 1). The lagoon is approximately 80 km long and 15 km across at its widest point. A single entrance connecting the inner lagoon with waters of the Okhotsk Sea occurs at 52°50'N, 143°20'E. This channel, approximately 18 km north of the lagoon's southern boundary, served as the base from which studies reported here were conducted. The nearshore marine environment of the study site is predominately sand substrate, characterized by a gradually sloping and broad continental shelf. Water depths within 5 km of shore are almost uniformly less than 20 m (Fig. 1). Sea-surface temperature and salinity, as measured from our research vessel during 1997–1998, were 4°–15°C and 28‰–34‰, respectively. Periods free of sea ice occur mainly between May and December; however, significant interannual variability exists.

Datasets

Data presented here were collected during four years: 1994, 1995, 1997, and 1998. Gray whale photographs from 1994 were taken 7–12 September during the filming of a wildlife documentary by one of the authors (HM). No information other than sighting locations is available for the 1994 sampling period. In 1995 a pilot study to determine the feasibility of conducting systematic research in the Piltun area was completed 14–20 August (Brownell *et al.* 1997). Intensive follow-up work in July–September 1997 and 1998 contributed substantially to the findings presented here. Because of the opportunistic nature of the 1994 season and the brevity of the 1995 season, many analyses detailed here were restricted to only the more comprehensive 1997 and 1998 datasets. However, the 1994 and 1995 samples provided particularly valuable information regarding interannual sightings and general site fidelity patterns for known individuals. The sampling periods used for each respective analysis are defined. For example, the term "1995–1998" is used to define analyses that incorporated data from 1995, 1997, and 1998.

Photo-Identification Surveys

Boat-based photo-identification surveys following nearly identical research protocols were conducted during each of the 1995–1998 field seasons. These

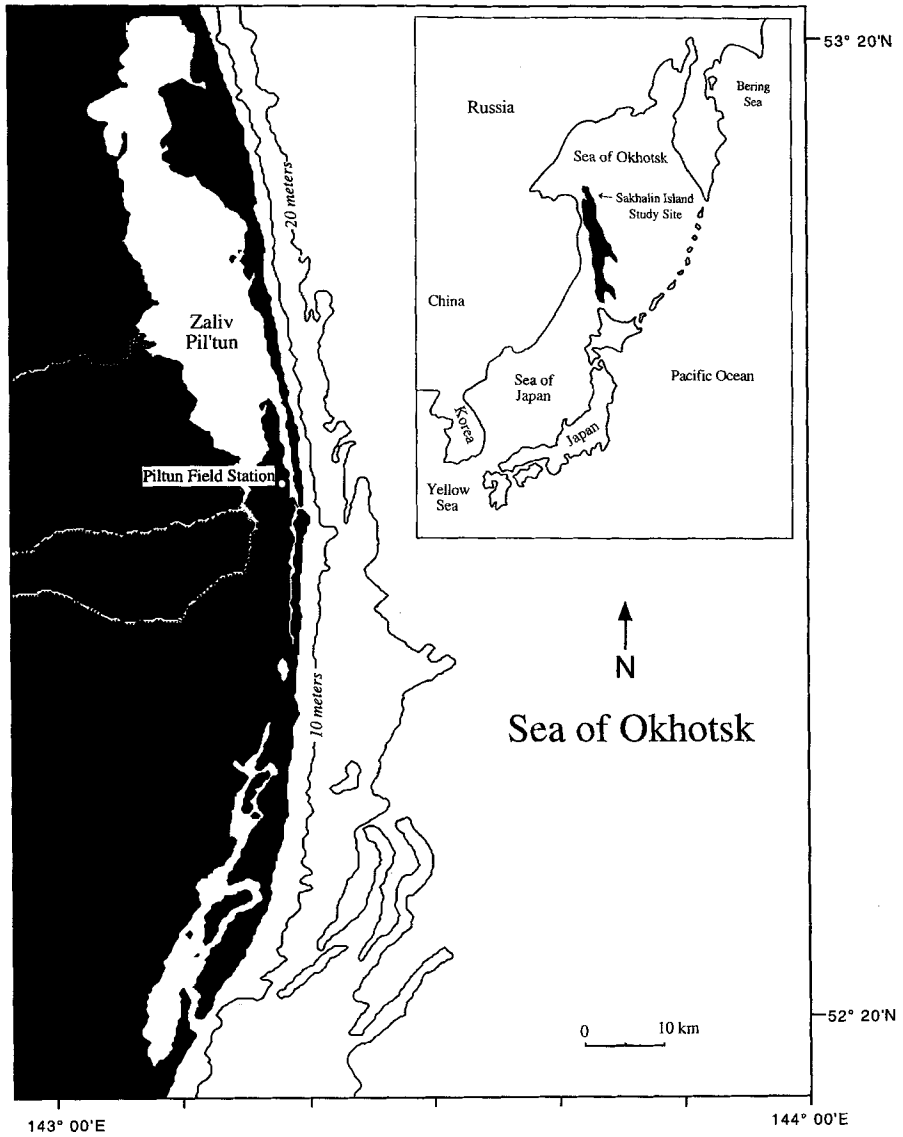

Figure 1. Map of Piltun study area. Inset shows relative location of Sakhalin Island in Sea of Okhotsk.

surveys followed no predetermined systematic vessel track and were conducted in such a manner as to maximize encountering and photographically identifying as many whales as possible. Photographic data from 1994–1995 targeted right-side dorsal flank markings as the primary body aspect for identification purposes (Brownell *et al.* 1997). For the sake of intra- and interannual reliability, this methodological approach was continued in 1997–1998. Photographs from 1997–1998 were taken with a Nikon F5 35-mm camera equipped

with a 100–300-mm zoom telephoto lens, 8 frames per sec motordrive, and databack. Video footage was recorded with a Sony DCR-VX1000 digital camera. Two 35-mm film types were used: Kodachrome 200 ISO color and T-Max 400 ISO black and white.

Photographic surveys involved slow travel in a 4.5-m outboard-powered inflatable boat. The research team consisted of a boat driver, data recorder, digital video camera operator, and 35-mm camera photographer. Systematic search from the survey vessel was maintained until a whale sighting was made. Upon initial sighting of a pod, the survey vessel slowed to idle speed and maneuvered to a vantage point approximately 50 m from the whale(s). From this position observations on pod location (as determined by Global Positioning System), time, behavior, and number of whales were recorded.

The research vessel was then maneuvered within 5–15 m of the pod and individual whales were photographed. During the 1997–1998 photographic efforts, running commentaries regarding film-frame and video-counter number as related to particular whales were recorded on data sheets. Measures of water depth, location, and environmental conditions were documented on average every 3–5 min throughout the entire photographic session. In all cases attempts were made to simultaneously photograph and videotape the right dorsal flank of each whale, followed by the left dorsal flank, and dorsal and ventral aspects of the flukes. Written observations and video footage collected at the time of each photographic session were used to link inter- and intraindividual body aspects whenever possible.

Contact with whale pods was maintained until all individuals encountered had been photographed. The boat then motored away from the pod, where initial estimates of pod size and composition were revised if necessary and all film and written records reviewed for completeness. These procedures were repeated as the research vessel resumed travel and additional whale pods were encountered.

A pod was defined as either a solitary individual, or two or more whales observed in close spatial proximity (within several body lengths of each other) and swimming in close association and generally coordinating their diving or direction of movement (see Clapham 1993). Pod size estimates were based on field observations and represented the product of a consensus among observers on the survey vessel. The term "calf" is used here to refer to young of the year. In all cases calves were initially identified by their small body size (about one-third that of a mature adult) and constant association with a particular adult whale. Calves documented to disaffiliate from their mothers at some point during the field season were termed "newly independent calves."

Photo-Identification Analysis

Photographic identification has proved to be a valuable research tool for gray whale studies (Darling 1984, Swartz 1986, Jones 1990) and served as the primary method for collecting the data presented here. As is true for the eastern population, western gray whales are easily identified by pigmentation

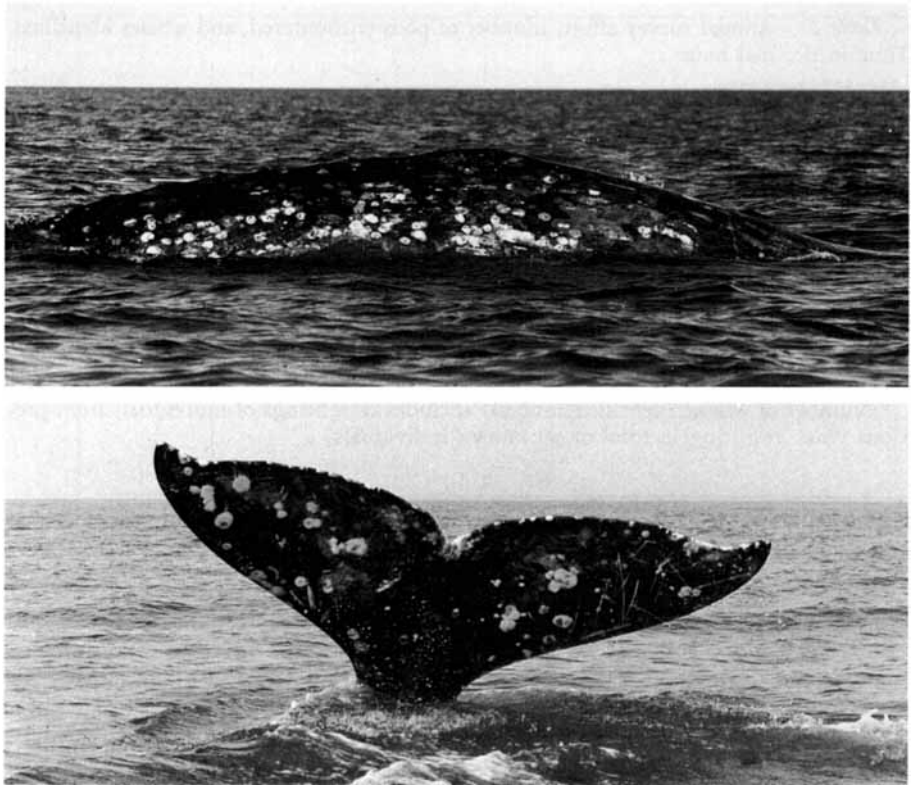

Figure 2. Examples of coloration patterns used for individual recognition of gray whales.

patterns and scars (Fig. 2). Patches of barnacles (*Cryptolepas rhachianceti*) and cyamids (*Cyamus scammoni* and/or *Cyamus ceti*) and occasionally-apparent killer whale (*Orcinus orca*) tooth rakes were not used for long-term recognition.

Images of individual gray whales consisted of various aspects of the body, including the head, back, dorsal flanks, and flukes. To prevent cataloging different aspects of the same whale as more than one individual, the right flank was always used as the basis for initial identification. A whale was not given a subject identification number unless its right dorsal flank was photographed at some point during the field season. Additional aspects of the body were used as identification aids, only if they were first matched with the respective right flank.

Photographic matching was done by comparing new photographs to a catalog of previously identified whales. Once a prospective resighting was located, the current photograph was repeatedly compared to previous images and was required to match before being confirmed as a re-identification of a known individual. If a new photograph could not be matched after comparison to all other cataloged individuals, the whale was considered new and given the next available subject identification number. All images were processed and cata-

Table 1. Annual survey effort, number of pods encountered, and whales identified. Time in decimal hours.

Year	Sampling period	Number of surveys	Hours of observation	Rolls of film used	Pods encountered	Whales identified
1994[a]	09/07–09/12	—	—	—	—	9
1995	08/15–08/19	5	10.1	15	23	26
1997	07/09–09/08	22	33.4	72	114	46
1998	07/06–09/29	35	50.5	91	125	53
Overall		62	94.0	178	262	69[b]

[a] Opportunistic photographs collected during several days in mid-September, 1994. Information other than the number of whales identified not recorded.

[b] Number of whales identified annually includes resightings of individuals from previous years, resulting in total of 69 known individuals.

loged by a single expert operator, with confirmation of both re-identifications and new whales by additional personnel.

Digital video footage was collected simultaneously with still photography during a majority of the photo-identification surveys conducted in 1997 and 1998. Each video session was reviewed frame by frame to verify and enhance the already established 35-mm photographic catalog. If the videographer recorded a previously unphotographed whale or an additional aspect of an identified whale, then a still print was made. Video images of whales not accounted for by 35-mm photographs were systematically matched following the protocol described above. The use of digital video proved especially valuable in increasing sighting frequencies and providing additional aspects of already identified whales.

Results

Observation Effort

Sixty-two photo-identification surveys totaling 94 h spent in direct observation of whale pods were completed in 1995–1998 (Table 1). The greatest amount of observation occurred during 1998 (50.5 h), and the lowest during the pilot study in 1995 (10.1 h). A total of 511 whales in 262 pods were encountered, and 178 rolls of film and nine hours of digital videotape were used for individual identification.

Rate of Discovery

The number of whales identified increased during each of the four annual sampling periods (Fig. 3). Nine whales were identified in 1994 and 21 additional whales (including two calves) in 1995. The number of known individuals increased to 56 (including two calves) in 1997, representing an increase of 26 new whales. With the addition of 13 new whales (including seven calves)

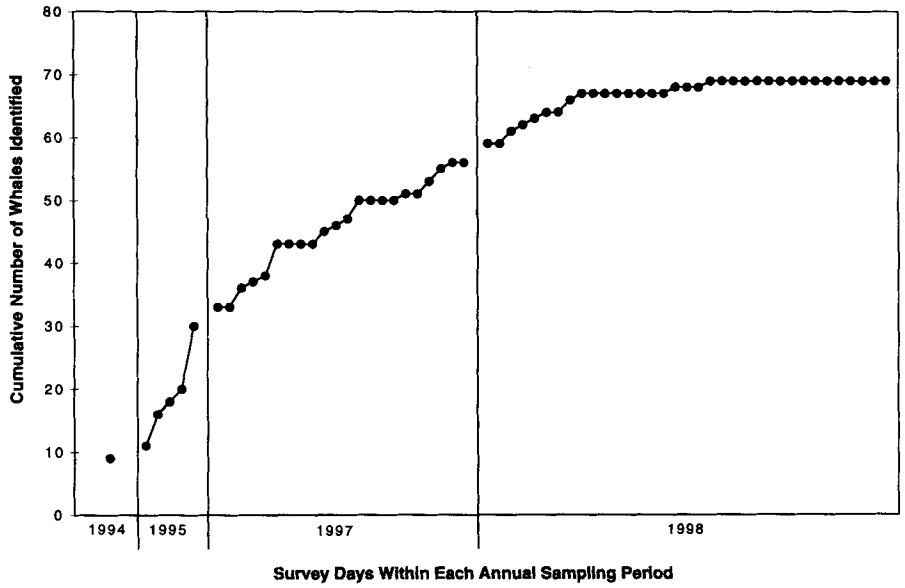

Figure 3. Rate of discovery curve for whales identified 1994–1998. Each solid circle represents one photo-identification survey.

in 1998, a total of 69 individual whales (including 11 calves) were identified during the study. The continuous increase in the number of new identifications through 1997 and into 1998 indicated that at least some previously unidentified whales were present in the study area on a yearly basis. However, the rate at which previously unidentified whales were sighted reached an apparent asymptote by 24 July 1998, with only two new individuals identified in the final 26 surveys of the study.

Occurrence and Resighting Patterns

Sighting frequencies for the 66 whales identified in 1997–1998 are plotted in Figure 4. As some whales were sighted more than once per day, the following analyses were constrained to include only one sighting per day. The number of sightings per individual ranged from 1 to 8 in 1997 and 1 to 18 in 1998, with an overall mean of 5.4 sightings per yr (Fig. 4). The period between the first and last sighting of an individual whale in either 1997 or 1998 ranged from 1 to 85 d. This measure was calculated only for whales photographed on two or more days in a year and does not assume that the individual was absent from or present in the study area for the period between sightings (see Seipt *et al.* 1990, Clapham *et al.* 1993). The mean period between first and last sighting for whales observed in 1997 and 1998 was 35.9 d ± SD 17.74 (n = 34) and 45.2 d ± SD 24.38 (n = 35), respectively, with an overall combined mean of 40.6 d ± SD 21.73 (n = 69).

Monthly occurrence patterns, a partial indicator of site fidelity, were ex-

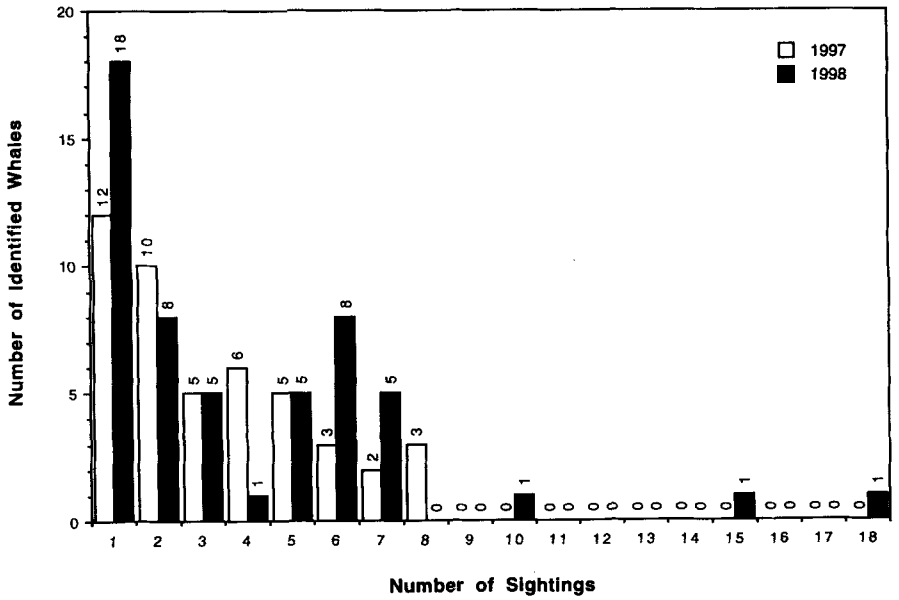

Figure 4. Sighting frequencies for whales identified 1997–1998.

1997

July	August	September	Number of Whales	Percentage
			5	10.9%
			4	8.7%
			6	13.0%
			8	17.4%
			7	15.2%
			3	6.5%
			13	28.3%
		Total	46	100.0%

1998

July	August	September	Number of Whales	Percentage
			13	24.5%
			6	11.3%
			5	9.4%
			9	17.0%
			3	5.7%
			1	1.9%
			16	30.2%
		Total	53	100.0%

Figure 5. Cumulative percentage and number of individuals sighted in each possible monthly combination of 1997 and 1998.

Table 2. Annual return rates of identified whales. Numbers in year columns represent percentage and number of whales identified in given year that were resighted in additional years. For example, 44.4% of whales first identified in 1994 were sighted in all four years of study.

Year first identified	Number of whales identified	1 year	2 years	3 years	4 years
1994	9	—	44.4% (n = 4)	11.1% (n = 1)	44.4% (n = 4)
1995	21	14.3% (n = 3)	33.3% (n = 7)	52.4% (n = 11)	—
1997	26	34.6% (n = 9)	65.4% (n = 17)	—	—

amined for the 1997 and 1998 datasets. The number of individuals occurring in each of seven possible monthly combinations is shown in Figure 5. In 1997, 67.4% (n = 31) of the individuals identified were seen in two or three months. In 1998, 54.7% (n = 29) of the whales identified were sighted in two or three months (Fig. 5). It is likely, however, that the limited number of surveys (n = 4) conducted in the third month of 1997 may have contributed to an underestimate of actual monthly occurrence patterns for that year.

Seasonal sighting patterns were also investigated for intra- and inter-annual consistency (Fig. 5). A majority of the whales sighted in two months during either 1997 or 1998 were sighted in consecutive months (*i.e.,* July–August or August–September) as opposed to an interrupted (*i.e.,* July–September) monthly sighting pattern. Interannual repetition of individual monthly sighting patterns was not apparent. Of 15 whales sighted in only a single month of 1997, 26.7% (n = 4) showed a similar pattern in 1998. None of the whales sighted in 1997 and 1998 had the same two-month occurrence pattern, and of the 13 whales sighted in all three months of 1997, 53.8% (n = 7) were also sighted in all three months of 1998.

Annual sighting frequencies for the 56 whales identified between 1994 and 1997 ranged from one to four years (Table 2 and Fig. 6). Seventy-one percent of all whales identified (excluding seven 1998 calves) were sighted in multiple years. The longest interval between sightings was documented for whales 050 and 068, which were first identified in 1994 and not seen again until 1998 (Fig. 6). Interannual resighting patterns are detailed in Table 3. In 1995, 26 individuals (including two calves) were identified; of the 24 non-calves, 20.8% (n = 5) were first identified in 1994. This resighting trend, albeit greatly amplified, was also apparent for the 1997 sample. During this effort, 46 individuals (including two calves) were identified; of the 44 non-calves, 45.5% (n = 20) were previously identified in either 1994 or 1995. These interannual sighting patterns, based on 1994 and 1995 data, are likely to underrepresent actual return rates due to the limited number of sampling days in those years (see Table 1). In 1998, 53 individuals (including seven calves) were identified; of the 46 non-calves, 87.0% (n = 40) were already known from previous years,

Whale ID number	1994	Aug-95	Jul-97	Aug-97	Sep-97	Jul-98	Aug-98	Sep-98
001								
002								
003								
004								
005						M	M	
006								
007								
008								
009						M	M	
010								
011								
012								
013								
014								
015						M	M	M
016								
017								
018		M				M	M	M
019		M	M	M				
020			C	C	C			
021								
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027								
028								
029								
030								
031			M	M	M			
032			C	C	C			
033								
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037								
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055						M	M	M
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Table 3. Annual sighting trends and resighting percentages of photo-identified whales.

Year	Number of whales identified	Number of calves	Number of new whales identified	Percentage of non-calves identified from previous years	Number of whales seen only in that year
1994	9	—	9	N/A	0
1995	26	2	21	20.8% (n = 5)	3
1997	46	2	26	45.5% (n = 20)	9
1998	53	7	13	87.0% (n = 40)	13[a]

[a] Seven of these 13 whales were "young of the year" calves, and therefore could not have been sighted in any other sampling period.

including one whale recorded as a calf in 1997. Therefore, during the 1998 field effort only six new non-calf individuals were identified, and all but two of the 13 new whales for this year were photographed in the first month of the three-month field effort.

Based on 1998 data alone, the minimum number of gray whales utilizing the study area was 53, consisting of 46 non-calves and seven calves. However, if each whale identified between 1994 and 1998 is assumed to be living, this number can be increased to 69 whales, including a minimum of 11 calves born between 1995 and 1998.

Pod Sizes

A total of 262 whale pods were observed between 1995 and 1998. Pod sizes ranged from 1 to 9 whales, with an overall mean of 2.0 ± SD 1.18 (n = 262), a median of 2, and a mode of 1 (Table 4, Fig. 7). Pods containing a single whale were the most frequently encountered, and accounted for 43.1% (n = 113) of all sightings. Overall, pods of 4 or fewer accounted for 97.7% (n = 256) of all sightings.

The largest pod sizes were documented in 1995 ($\bar{x}$ = 2.3 ± SD 1.18, n = 23) and the smallest in 1997 ($\bar{x}$ = 1.8 ± SD 1.33, n = 114) (Table 4). Between 1997 and 1998 overall pod sizes were larger in July ($\bar{x}$ = 2.1 ± SD 1.29, n = 89) and smaller in August ($\bar{x}$ = 1.8 ± SD 0.92, n = 77) and September ($\bar{x}$ = 1.8 ± SD 1.26, n = 73). Analysis of variance revealed no significant difference in mean pod size by month (F (2,236) = 2.52, P = 0.08) or between years (F (1,237) = 0.86, P = 0.35).

←

Figure 6. Occurrence patterns for whales photographically identified 1994–1998. Shaded cells represent presence in study area, M = mother with calf, and C = calf of that year.

Table 4. Pod size summary statistics.

Year	Number of pods	Mean pod size	Median pod size	Mode pod size	± SD pod size	Range in pod size
1995	23	2.3	2	2	±1.18	1–6
1997	114	1.8	1	1	±1.33	1–9
1998	125	2.0	2	2	±1.02	1–6
Overall	262	2.0	2	1	±1.18	1–9

Pods With and Without Calves

Eleven calves and nine mothers were identified in 1995 and 1998 and ranked among the most frequently sighted whales. The observed crude birth rate, as calculated by dividing the total number of all whales identified (including calves) in a given year by the number of calves observed (see Clapham and Mayo 1990), ranged from 4.3% (1997) to 13.2% (1998). Of the two mothers identified in 1995, one was sighted in four years and one in three years (Fig. 6). The two mothers identified in 1997 were sighted in one and

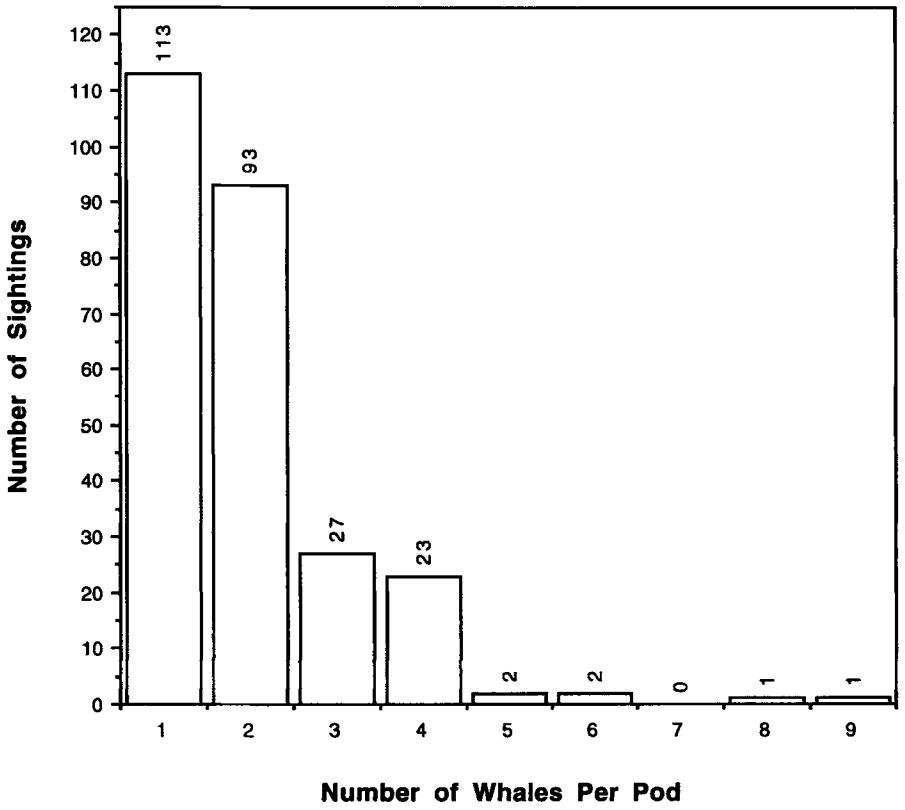

Figure 7. Frequency distribution of pod sizes between 1995 and 1998.

three years, respectively. Finally, of the seven mothers identified in 1998, one was first sighted in that year, while 57.1% (n = 4) were observed in two years and 28.6% (n = 2) were sighted in each of the four years. When accompanying a calf in either 1997 or 1998, 55.6% (n = 5) of these mothers were sighted in all three months of that respective year, 33.3% (n = 3) were observed in two months, and 11.1% (n = 1) in one month (Fig. 6).

Pods containing one or more calves in 1997–1998 ranged in size from 1 to 8 whales, with a mean of 2.6 ± SD 1.19 (n = 63), a median of 2, and a mode of 2. Pods without calves ranged in size from 1–9 whales, with a mean of 1.7 ± SD 1.09 (n = 176), a median of 1, and a mode of 1. The number of calves identified in each field season between 1995 and 1998 was two, two, and seven, respectively (Table 3). Only one of the four calves identified prior to the 1998 season was subsequently resighted. Seven (77.8%) of the nine mothers identified were sighted in at least one year with a calf and one year without a calf. Five (71.4%) of these seven mothers had a higher number of total sightings when accompanying a calf than in years in which they had no calf. None of these mothers were sighted with a calf in sequential years. Of the two mothers identified with calves in 1995, one was subsequently sighted in 1997 with a calf and in 1998 without a calf, and one was sighted in 1997 without a calf and in 1998 with a calf. While no data were collected in 1996, these calving patterns suggest a one to two-year interbirth interval for at least some reproductive females.

Mothers and calves were closely bonded at the onset of each sampling period. However, photographic sighting records indicated that in 1997 one of the two mother-calf pairs had separated sometime between 27 August and 5 September. In 1998 mother-calf disaffiliations were observed for five of the seven pairs. Apparent calf separations occurred between the following dates in 1998: 8 July–13 August, 29 July–13 August, 29 July–18 August, 23 August–28 August, and 3 September–17 September. These dates extend from one day after the last sighting of the mother-calf pair together until the next sighting of either the mother or calf independent from one another. The earliest mother-calf separation may have occurred by 8 July–13 August, while the latest apparent separation occurred sometime between 3 and 17 September. Newly independent calves were occasionally sighted together or in the company of other still affiliated mother-calf pairs.

Discussion

During the study most whales demonstrated high levels of seasonal site fidelity and annual return to the area off the northeastern coast of Sakhalin Island, Russia. These inter- and intra-annual resighting patterns, combined with the continuous occurrence of feeding behavior, suggest that this coastal habitat plays an important role in the feeding ecology of this endangered population.

Pod sizes observed during the present study were primarily small, with most groups composed of 4 or fewer whales. These observed pod sizes closely

correspond with those reported for eastern gray whales feeding in the Bering and Chukchi Seas (Zimushko and Ivashin 1980, Votrogov and Bogoslovskaya 1980, Bogoslovskaya *et al.* 1981, Würsig *et al.* 1986). Variables thought to influence group size include social factors, predation pressure, and prey availability (Krebs and Davies 1993). As social factors related to breeding are presumably relaxed on the feeding grounds (Würsig *et al.* 1986), and predation pressure does not appear to be excessive (as measured by the low number of killer whale sightings during the study), the major determinate of group size during summer feeding is probably related to foraging efficiency.

During the study period a limited number of whales ($n = 69$) were identified. The rate at which previously unidentified whales were photographed reached a pronounced asymptote early into the final year of the study. Only six previously unidentified whales (excluding seven calves) were photographed in 1998, resulting in an overall 87.0% resighting rate. It is intriguing that the reported asymptote was reached in such a short period of time, especially given the limited number of surveys in 1994 and 1995. These findings represent a clear departure from the typical patterns reported from other large-whale studies, and suggest that the western gray whale population is perhaps smaller than previously estimated (Vladimirov 1994; Blokhin 1996; Berzin, in press), or it may be only a discrete subpopulation consistently using the northeastern Sakhalin Island feeding ground.

Gray whales in other parts of the North Pacific are suspected to sometimes segregate by age while on their feeding grounds (Zenkovich 1937, Votrogov and Bogoslovskaya 1980, Bogoslovskaya *et al.* 1981, Darling 1984, Darling *et al.* 1998). One possible explanation for the low number of individuals identified during the present study could be that only an age-specific portion of the population uses the northeastern Sakhalin coast. Age-class segregation was not, however, apparent in our observations. During the course of study we regularly documented the presence of adult reproductive females, their young of the year calves, numerous whales of apparent adult body size, and at least one known two-year-old individual.

An additional alternative explanation for the low number of whales identified during the study is that only a small portion of a larger population migrates to the northeastern Sakhalin Island coast. Small numbers of eastern gray whales have been reported to summer along the North American coast from Alaska to California, never fully migrating to more northern feeding areas (Rice and Wolman 1971). While a similar pattern may occur for the western population, aerial and ship-based surveys in the northern Okhotsk Sea reported finding concentrations of gray whales only in a small area off Piltun Lagoon (including some area outside the boundary typically covered by our research vessel during this study) (Blokhin *et al.* 1985; Berzin *et al.* 1988, 1990, 1991; Blokhin 1996; Berzin, in press). Our lack of photographic effort in other regions along the Sakhalin Island coast, and the virtual absence of data from this population's southern range off China, Korea, and Japan prohibit further speculation regarding potential subpopulation structuring. We are hopeful that a third sampling period equal in effort to 1997–1998 and

covering a broader geographic area will be completed in 1999, allowing the first quantitative mark-recapture population estimate to be calculated (Hammond 1986, Hammond *et al.* 1990).

A majority of the whales identified between 1994 and 1998 displayed high rates of annual return to the study area. The annual return of whales to this region is similar to that reported for eastern gray whales off Vancouver Island (Darling 1984) and may be suggestive of foraging area philopatry as has been hypothesized for humpback whales (*Megaptera novaeangliae*) in the southern Gulf of Maine (Clapham *et al.* 1993). Annual return to the same geographic feeding area has been observed for a variety of other baleen whales (Agler *et al.* 1990, Dorsey *et al.* 1990, Sears *et al.* 1990, Clapham *et al.* 1993), and in the present case emphasizes the significance of the Piltun region as an important feeding ground for at least some portion of the western gray whale population.

Occurrence patterns of the 66 whales identified between 1997 and 1998 suggested a reasonably strong intraseasonal fidelity to the area. The mean period between first and last sighting of whales in the Piltun region was 40.6 d, and over one-half of the whales identified on a yearly basis were sighted in either two or three months. However, even whales demonstrating seemingly strong site fidelity were on occasion apparently absent from the region. It is difficult to determine if breaks in individual resighting patterns represent occasions when whales were in the study area but were missed photographically, or if they were indicative of movements to other regions between sightings. We suggest that whales take short excursions away from the study site, presumably related to foraging, but eventually return. Support for this idea comes from several survey days on which we sampled 20–25 km north and up to 10 km offshore of our typical search area. In each case whales found at the periphery of the study site were feeding, and all identified individuals (including one mother-calf pair) had previous and subsequent sightings within the more typical survey area.

Darling *et al.* (1998) characterized gray whales off Vancouver Island as having "foraging ranges" that in some cases extend over hundreds of kilometers. While existing data are insufficient to allow us to reliably assess movement patterns outside the current study area, we suggest that the unique habitat structure and infaunal prey ecology characteristic of our study site favors seasonal site fidelity as opposed to the coastal ranging behavior described by Darling *et al.* (1998). Our photographic resighting data showing seasonal and annual fidelity appear to support this hypothesis, as do findings from over 200 shore-based whale counts conducted between 1997 and 1998 from a 35-m lighthouse near the mouth of Piltun Lagoon (Würsig *et al.* 1999). Theodolite-determined pod locations during these counts indicated that the highest concentrations of feeding gray whales were usually within 10 km of the lagoon mouth and less than 5 km offshore (Würsig *et al.* 1999). Similarly, aerial and ship-based surveys of the Okhotsk Sea found only limited numbers of gray whales away from the northeastern Sakhalin Island coast (Blokhin *et al.* 1985; Berzin *et al.* 1988, 1990, 1991; Blokhin 1996; Würsig *et al.* 1998;

Berzin, in press). This apparent distributional fidelity to the coastal waters near the channel opening of Piltun Lagoon may reflect a particular biological richness of the region, perhaps related to enrichment of nearshore marine waters by tidal effluent from the lagoon. While further information regarding the benthic ecology of the region is needed, this explanation may at least partially account for the high annual return and intraseasonal site fidelity observed.

Eleven mother-calf pairs and nine mothers were identified during the study. Calves separated from their mothers between July and mid-September. Using a mean birth date of 10 January as calculated for eastern gray whales (Rice and Wolman 1971), it appears that calves off Sakhalin Island separate from their mothers at 6–8 mo. This age at separation closely corresponds with the 7-mo lactation period estimated for the species (Rice and Wolman 1971). Thus, if August is used to estimate the typical period of separation for western gray whale mother-calf pairs, January may represent the peak calving period, as is true for the eastern population (Rice and Wolman 1971).

Mother-calf pairs ranked among the most commonly sighted individuals on an intraseasonal basis, and 77.8% of these known mothers were sighted in multiple years of the study. Of the seven mothers identified in 1998, six were sighted in 1997 when they were newly pregnant. Both lactating and pregnant females are under especially high energy demands (Rice and Wolman 1971, Lockyer 1984). Therefore, it is imperative that they feed in regions capable of meeting their elevated energy requirements. The seasonal site fidelity and annual return of reproductive females reported here, combined with their need for high-quality habitat, suggests that the northeastern Sakhalin Island coast is of particular biological importance to this endangered whale population.

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The western gray whale: a review of past exploitation, current status and potential threats

DAVID W. WELLER*†, ALEXANDER M. BURDIN+, BERND WÜRSIG†, BARBARA L. TAYLOR* and ROBERT L. BROWNELL, JR.*

Contact e-mail: dave.weller@noaa.gov

ABSTRACT

Gray whales (*Eschrichtius robustus*) occur along the eastern and western coastlines of the North Pacific as two geographically isolated populations and have traditionally been divided into the eastern (California-Chukchi) and western (Korean-Okhotsk) populations. Recent molecular comparisons confirm, based on differences in haplotypic frequencies, that these populations are genetically separated at the population-level. Both populations were commercially hunted, but only the eastern gray whale has returned to near pre-exploitation numbers. In contrast, the western population remains highly depleted, shows no apparent signs of recovery and its future survival remains uncertain. Research off Sakhalin Island, Russia between 1995 and 1999 has produced important new information on the present day conservation status of western gray whales and provided the basis for the World Conservation Union (IUCN) to list the population as 'Critically Endangered' in 2000. The information presented here, in combination with potential impacts from anthropogenic threats throughout the range of this population, raises strong concerns about the recovery and continued survival of the western gray whale.

KEYWORDS: GRAY WHALE; PACIFIC OCEAN; NORTHERN HEMISPHERE; CONSERVATION; OKHOTSK SEA; EXPLOITATION; POPULATION STATUS

INTRODUCTION

Gray whales (*Eschrichtius robustus*) are known to occur along the eastern and western margins of the North Pacific (Andrews, 1914; Rice and Wolman, 1971); they have been extinct in the North Atlantic for several hundred years (Mead and Mitchell, 1984). Recent genetic studies show that animals from the eastern (California-Chukchi) and the western (Korean-Okhotsk) Pacific should be recognised as geographically and genetically separated at the population level (LeDuc *et al.*, 2002). Although both populations were greatly reduced by commercial whaling, only the eastern gray whale has returned to numbers approaching the suspected pre-exploitation population size (IWC, 1998). In contrast, the western gray whale was thought to be extinct as recently as the early 1970s (Bowen, 1974), but later published reports confirmed that the population was extant (Berzin, 1974; Brownell and Chun, 1977). Today, the western gray whale population remains highly depleted and shows no apparent signs of recovery (e.g. Weller *et al.*, 1999; IWC, 2002b). Information regarding the life history and biology of the western population is sparse (Andrews, 1914; Rice and Wolman, 1971) and only recently has it come under concerted study (e.g. Brownell *et al.*, 1997; Weller *et al.*, 1999).

Historic records and recent data suggest that summer feeding grounds for the western population are in the Okhotsk Sea, but the location(s) of the winter breeding grounds, suspected to be along the coast of southern China, remain unknown (Wang, 1984; Henderson, 1990). Contemporary findings from an ongoing US-Russia mark-recapture photo-identification project between 1995 and 2001 suggest that the total population size is < 100 individuals (e.g. Weller *et al.*, 1999; IWC, 2002b). Low-level human-related mortality south of the Okhotsk Sea (Brownell and Kasuya, 1999; Baker *et al.*, 2002), and the onset of large-scale multinational oil and gas development programmes within Okhotsk waters, pose potential new threats to the continued survival of this population.

Serious concern over the status of this population has been expressed by the World Conservation Union (by assigning it 'Critically Endangered' - Hilton-Taylor, 2000) and by the International Whaling Commission (IWC, 2002b).

RANGE AND DISTRIBUTION

Western gray whales occur off Russia, Japan, the Democratic People's Republic of Korea (North Korea), Republic of Korea (South Korea) and People's Republic of China (China). Although historic sighting and whaling records indicate that gray whales occurred in areas north of the presently described Okhotsk Sea feeding ground, the present day population range appears to be largely confined to the region between the west central Okhotsk Sea off the northeastern coast of Sakhalin Island (summer-autumn) and the South China Sea (winter). Individuals remain in shallow, mainly nearshore waters, year-round; except when crossing the La Perouse and Tartarskiy Straits off the southern end of Sakhalin Island or during north-south migrations in the Sea of Japan, and the Yellow and East China Seas. Although few records of gray whales are available south of Hong Kong (Wang, 1984; Zhu, 1998), it is presumed that they maintain a nearshore affinity throughout the southern portion of their range.

Main habitat

Gray whales are known for their long-distance migrations between sub-tropical calving and mating grounds near continental coasts and high-latitude feeding grounds in the Arctic and sub-Arctic (e.g. Rice and Wolman, 1971; Swartz, 1986). As bottom-feeding specialists, gray whales aggregate during summer and autumn in shallow shelf waters and offshore banks where benthic and epibenthic invertebrate communities are concentrated (Nerini, 1984; Oliver *et al.*, 1984; Kim and Oliver, 1989). Traditional nearshore migratory routes connect high-latitude feeding areas with warm-water coastal and inshore wintering grounds. Today, the primary summer-autumn feeding habitat for western

* *Southwest Fisheries Science Center, National Marine Fisheries Service, 8604 La Jolla Shores Drive, La Jolla, CA 92037-0271, USA.*
+ *Kamchatka Institute of Ecology and Nature Management, Russian Academy of Sciences, Kamchatka, 683000, Russia.*
† *Texas A&M University, Marine Mammal Research Program, 4700 Avenue U, Building 303, Galveston, TX 77551, USA.*

gray whales is located off the northeastern coast of Sakhalin Island (Weller *et al.*, 1999; 2002). The calving and mating grounds for this population are unknown, but records from sightings, strandings and whaling catches from 1933-1996 indicate that at least some western gray whales occur in coastal waters off China in the South China Sea (Wang, 1984; Zhu, 1998).

Distribution

Key areas of distribution include the summer feeding grounds off northeastern Sakhalin Island (~52°50'N 143°20'E). Known portions of the north-south migratory route include regions off the eastern shore of Sakhalin Island in the Okhotsk Sea and along the eastern shores of mainland Russia near Peter the Great Bay and along the Korean peninsula in the Sea of Japan (Andrews, 1914; Brownell and Chun, 1977; Berzin, 1990). It is thought that prior to the 20th century, two groups of gray whales may have migrated to coastal waters off Japan (Omura, 1984). One of these groups was thought to travel along the eastern (Pacific) shore of Honshu during their southbound migration while en route for a supposed calving ground in the Seto Inland Sea (Omura, 1984). The other group was suspected to migrate along the eastern shore of Korea, cross the Korean Strait near Ulsan, and ultimately arrive at southwest Honshu and northwest Kyushu (Omura, 1984). Although gray whales were once hunted by net fishermen off the eastern shore of Honshu (Omura, 1984), present-day sightings of the species off Japan are very rare (Kato and Tokuhiro, 1997).

The winter distribution of this population is unknown. Whaling records indicate that peak gray whale numbers off southern Korea occurred in two seasonal pulses, one during the southward migration between December and January, and the other between March and April during the northward migration (Andrews, 1914; Kato and Kasuya, 2002). Whalers working off Ulsan, South Korea found that a majority of adult females taken between December-January were carrying near-term foetuses and were thought to be within two to three weeks of parturition (Andrews, 1914). Based on these observations, and his own measurement of one 4.76m foetus, Andrews suggested that calves were probably born somewhere off the southern end of the Korean Peninsula, and that this region represented the probable southern terminus of the winter migration (Andrews, 1914).

The idea that western gray whales overwinter off the southern coast of Korea, as suggested by Andrews (1914), was largely speculative (Rice, 1998). Several lines of evidence suggest that Andrews miscalculated the true position of the wintering grounds. Rice and Wolman (1971) reported an average near-term foetus size of 4.62m for eastern gray whales taken off central California between December and January. Thus, the observed foetus size, seasonal timing and latitudinal position (about 34°N) reported for Korea and central California closely corresponded. However, eastern gray whales migrate to breeding areas as far south as 20°-27°N off Baja California (Rice and Wolman, 1971; Swartz, 1986). Although Andrews suspected that western gray whales terminated their southern migration off southern Korea, a location approximately 7°-14° north of the eastern gray whale wintering grounds, historical records indicate that they occur as far south as the Yellow Sea, East China Sea and South China Sea (Henderson, 1972; 1984; 1990; Wang, 1978; 1984; Omura, 1988; Zhu, 1998; Kato and Kasuya, In press). Some evidence is available that western gray whales range at least as far south as 20°N off Hainan Island in southeastern China (Wang, 1984; Zhu, 1998). In addition, several unverified sighting reports led Omura (1974) to suggest that an alternative or additional calving and mating area was in the Seto Inland Sea (34°-35°N) off southern Japan, but little direct evidence is available to support this idea.

EXPLOITATION

Groups of Koryak natives (Kamentsy, Parentsy and Itkantsy) living along the northeastern shores of the Okhotsk Sea hunted whales, although the particular species killed by these aboriginal whalers were not well documented (Krupnik, 1984); the author, however, believed that gray whales were hunted until the early 20th century. Whaling by Japanese hand-harpoon whalers was underway by at least the 16th century and Japanese net-whalers continued to take whales during the 17th-19th centuries (Omura, 1984). European and American whalers operating in the western North Pacific (mainly in the Okhotsk Sea) took gray whales from the late 1840s to perhaps the start of the 20th century (Henderson, 1984; 1990). Russian steam whalers took gray whales in the coastal waters of the Far East at the end of the 19th century (Andrews, 1914; Brownell, unpublished data). Japanese and Korean whalers continued to hunt gray whales until as recently as 1966 (Kasahara, 1950; Mizue, 1951; Brownell and Chun, 1977; Omura, 1984).

The reduction in the western Pacific gray whale population can be attributed largely to modern commercial whaling off Korea and Japan between the 1890s and 1960s. The population has been protected from commercial whaling since 1946, under the International Convention for the Regulation of Whaling. The Soviet Union and Japan joined the International Whaling Commission (IWC) in 1948 and 1951, respectively. The Republic of Korea and China, however, did not join until 1978 and 1980, respectively. Prior to their IWC membership, at least 67 gray whales were killed in the period 1948-1966 off the Republic of Korea (Brownell and Chun, 1977). Although no capture records are available from 1967 to the time that either the Republic of Korea or China joined the IWC, it cannot be assumed that gray whale catches did not occur during this period. Kasahara (1950) summarised whaling operations off northern Korea prior to 1945. Today, the Democratic People's Republic of Korea is not a member of the IWC and nothing is known about whaling in its waters since the end of World War II.

Western gray whales were probably never as numerous as their eastern counterparts. While pre-exploitation numbers for the western population are unknown, it has been speculated that they once may have numbered between 1,500-10,000 individuals (Yablokov and Bogoslovskaya, 1984). Berzin and Vladimirov (1981) estimated that only 1,000-1,500 gray whales remained in the population by 1910, after some commercial exploitation had already occurred. However, details of how these pre-exploitation and 1910 estimates were derived are not provided.

Kato and Kasuya (In press) estimated that some 1,800-2,000 whales (including 44 individuals killed by net whaling in the 1890s) were taken in the period 1891-1966, mostly off Korea and Japan. Peak annual catches of 100-200 whales began as early as 1907, but occurred primarily between 1911 and 1919 (no data were available for 1910) during which time at least 1,034 whales were killed, with a mean annual take of 115 whales. In the period 1920-1929, 289 whales were killed, with a mean annual take of 29 whales. By the 1930s, gray whale captures had greatly declined, with only 48 whales killed between 1930 and 1934

for a mean annual take of 10. No known additional catches occurred until 1942. Based on these catch data, it is apparent that by the early 1930s gray whales were far less abundant off the coasts of Korea and Japan and had likely reached commercial extinction. Continued low-level hunting between the 1940s and 1966, including the 67 whales captured in waters off South Korea, resulted in at least 71 whales killed. Kato and Kasuya (In press) hypothesise that the continued, albeit low-level, whaling pressure during this time is responsible for hindering the recovery of the western population. If the projected population size in 1910 was between 1,000-1,500, as estimated by Berzin and Vladimirov (1981), the removal of at least 1,442 whales recorded in the period 1911-1966 lends support to the above hypothesis offered by Kato and Kasuya (In press).

By the 1930s, the western gray whale was considered by many to be extinct (Mizue, 1951; Bowen, 1974). Nishiwaki and Kasuya (1970), believing the western population to be extinct and unaware of the Korean catches and sightings in the 1960s, suggested that sightings of two gray whales, one in about 1959 and one in 1968 off the coast of Japan, represented strays from the eastern population. However, Brownell and Chun (1977) described the probable existence of the western population based on catch records from the Korean coast during a nearly 20-year period between 1948 and 1966. These catch records, combined with the observation of four gray whales in the western Okhotsk Sea in 1967 (Berzin, 1974) and the sighting of a female gray whale and her calf in Korean waters in May 1968 (Brownell and Chun, 1977) indicated that western gray whales continued to survive in small numbers and that the observations reported by Nishiwaki and Kasuya (1970) were likely to be of western rather than eastern gray whales.

CURRENT POPULATION STATUS

The western gray whale population survives as a small remnant population (Blokhin *et al.*, 1985; Weller *et al.*, 1999). Aerial and ship-based sighting records in the Okhotsk Sea between 1979 and 1989 indicated that gray whales aggregated predominantly along the shallow-water shelf of northeastern Sakhalin Island and were most common offshore of the southern portion of Piltun Lagoon (Blokhin *et al.*, 1985; Berzin *et al.*, 1988; 1990; 1991; Berzin, 1990; Blokhin, 1996). Two non-quantitative population estimates have been reported in the Russian literature (Vladimirov, 1994; Blokhin, 1996). An estimate of 250 by Vladimirov (1994) was derived from cetacean sighting records collected between 1979 and 1992 in the Okhotsk Sea; these records were collected from a variety of observation platforms, during different seasons, and employed mostly non-systematic sampling strategies. Although counts may be inflated by repeated observations of the same individuals, the highest number reported by Vladimirov (1994) during any sampling period was 34 gray whales observed in 1989 off northeastern Sakhalin Island. The author does not explain the origin of the estimate 250. An estimate of 100 by Blokhin (1996) was based on eight shore counts and one helicopter survey conducted between July and August of 1995 along the northeastern Sakhalin Island coast. The highest number of whales counted on any one day during that period was 42 but again, the author did not explain the origin of the estimate of 100. Therefore, both of these estimates must be considered unreliable.

Recent photo-identification studies conducted between 1994 and 1999 on the primary feeding ground off northeastern Sakhalin Island (Weller *et al.*, 1999; 2000; Würsig *et al.*, 1999; 2000) have identified a total of 88 individual whales (Table 1). These photo-identification data indicate high levels of annual return and pronounced seasonal site fidelity for most whales (Table 2). While new individuals continue to be identified annually, the rate at which this is occurring is low. Only 18 previously unidentified whales (excluding calves) were photographed during 91 days of effort between 1998 and 1999. This finding suggests that a majority of the population had been identified in the period 1994-1997 (Weller *et al.*, 2000). Between 1995 and 1999, 11 reproductive females and their

Table 1

Annual survey effort, number of groups encountered and whales identified in the period 1994-1999.

Year	Sampling period	No. of surveys	Hours of direct observation	Rolls of film used	Groups encountered	Whales identified
1994	7 Sep. - 12 Sep.					10
1995	15 Aug. - 19 Aug.	5	10.1	15	23	27
1997	9 Jul. - 8 Sep.	22	33.4	72	114	47
1998	6 Jul. - 29 Sep.	35	50.5	91	125	54
1999	29 Jun. - 13 Oct.	56	122.0	160	434	70
Overall		118	216.0	338	696	88*

*The number of whales identified annually includes resightings of individuals from previous years, resulting in a total of 88.

Table 2

Annual sighting trends and resighting percentages of whales photo-identified in the period 1994-1999.

Year	Whales identified	Calves/non-calves identified (crude birth rate)	New non-calves	Non-calves identified from previous years
1994	10		10	
1995	27	2/25*	20	20.0% ($n = 5$)
1997	47	2/45 (4.3%)	25	44.4% ($n = 20$)
1998	54	8/46 (14.8%)	5	89.1% ($n = 41$)
1999	70	3/67 (4.3%)	13	80.6% ($n = 54$)

* Insufficient data available to calculate crude birth rate.

15 calves were observed (Weller *et al.*, 2000). Two calves were observed in each of 1995 and 1997, eight in 1998 and three in 1999. Crude birth rates ranged between a low of 4.3% in 1997 and 1999, to a high of 14.8% in 1998. Of the 12 calves identified between 1995-1998, seven (58.3%) have not been resighted on the Sakhalin feeding grounds subsequent to their birth year.

Mature population size[1]

Estimating the number of whales inferred to be capable of reproduction or 'number mature' is problematic for western gray whales because there are limited direct data, and demographic estimates depend on the population growth rate, which is currently unknown. Two approaches are used here to estimate plausible, albeit conservative, numbers mature. The first uses information from Rice and Wolman (1971), who found that 24% of the eastern gray whales in their sample were sexually immature and from this suggested that the total proportion of immature animals in the population was more likely to be 44%-61%. Using the minimum estimate of 88 western gray whales (Weller *et al.*, 1999; 2000) and using the estimated proportion immature from Rice and Wolman (1971), the number of mature whales in the western population ranges between 34 and 49.

However, the eastern gray whale population was growing at the time Rice and Wolman conducted their study and would therefore be expected to consist primarily of immature animals; this would not be the case for a stable population. The second method used here is based on the premise that the proportion mature for a stable population can be estimated using age-specific birth and mortality rates. Rice and Wolman (1971) reported the mean age of sexual maturity for eastern gray whales to be eight years (range = 5-11 years). Reilly (1992) estimated adult survival to be 0.95. Although there are no data for first year survival in gray whales, it is assumed here that survival does not differ strongly from that for humpback whales (*Megaptera novaeangliae*), which is 0.875 (Barlow and Clapham, 1997). For a stable population, therefore, the estimated proportion mature is 63%, which for the estimate of 88 whales in the present case results in 55 mature animals.

In addition to the uncertainty surrounding the estimated values of the population parameters, this estimate assumes that all mature adults are capable of reproduction. If, as suspected, the western population is not growing, then it is plausible that reproduction has been compromised because the population is so small. Data from another small population that has failed to recover provide a pessimistic comparative scenario. Only 70% of North Atlantic right whale (*Eubalaena glacialis*) females known to be mature are reproductively active (IWC, 2001). If it is assumed that all males reproduce but only 70% of the females do, then 85% of the sexually mature animals are capable of reproduction. Thus, of the 55 mature western gray whales estimated using this approach, only 47 would meet the IUCN definition of mature (see below).

Clearly, both these approaches are somewhat crude and are based on assumptions that may not be valid. However, both suggest a mature population size of less than 50 mature individuals, including only 11 known calf-bearing females documented between 1995 and 1999.

[1] In terms of evaluating the western gray whale population under 'Criterion D' (population estimated to number less than 50 mature individuals) of the World Conservation Union (IUCN), the definition of 'mature individuals' in this context is defined as 'the number of individuals known, estimated or inferred to be capable of reproduction' – see section on 'International concern and conservation measures'.

Potential threats to the population

Although there is some evidence that an undetermined level of hunting may occur (e.g. Brownell and Kasuya, 1999; Baker *et al.*, 2002), it seems likely that the major threats for this population may stem from indirect mortality (e.g. bycatches and ship strikes) and habitat pollution and degredation.

Gray whales are known to be vulnerable to incidental catches in fisheries (e.g. IWC, 1994) and there are extensive coastal net fisheries off southern China, Korea and Japan (Zhou and Wang, 1994; Kato, 1998; Kim, 2000). The substantial nearshore industrialisation and shipping congestion throughout the migratory corridor(s) of this population also represent potential threats by increasing the likelihood of exposure to chemical pollution and ship strikes. Present and planned large-scale offshore gas and oil development in the South China Sea and in close proximity to the only known feeding ground for western gray whales off northeast Sakhalin Island in the Okhotsk Sea is of particular concern (e.g. see Brownell *et al.*, 1997; Brownell and Yablokov, 2001; IWC, 2002b). Activities related to oil and gas exploration, including high-intensity geophysical seismic surveying, drilling operations, increased ship and air traffic, and oil spills all pose potential threats to gray whales (e.g. Moore and Clarke, 2002). Disturbance from underwater industrial noise may displace whales from critical feeding, migratory and breeding habitat (e.g. Bryant *et al.*, 1984; Richardson *et al.*, 1995; Brownell and Yablokov, 2001). Physical habitat damage from drilling and dredging operations, combined with possible impacts of oil and chemical spills on benthic prey communities, also warrant concern.

A recent concern is the deterioration in physical condition of numerous individuals; during 1999, 2000 and 2001 whales have been observed that appeared to be unusually thin ('skinny') while on the summer feeding grounds (Weller *et al.*, 2000; authors' data). Morphological attributes correlated with this description varied among individuals, but consisted of at least one of the following: (1) an obvious sub-dermal protrusion of the top edge of the scapula from the body with associated thoracic depressions at the anterior and posterior insertion points of the flipper; (2) the presence of depressions near and posterior to the blowholes and head; and (3) a pronounced depression along the neural/dorsal spine of the lumbar and caudal vertebrae resulting in the appearance of a 'bulge' along the lateral flank.

While the causal mechanism(s) for the observed deterioration in physical condition and apparent health status of some whales is unknown, any of the following alone or in combination may be contributing factors: (1) natural or human produced changes in prey availability or habitat quality; (2) physiological changes related to stress; or (3) disease. Regardless of the cause, the loss of even a few whales (especially reproductive females) due to this deterioration in physical condition will greatly hinder population growth and ultimately prevent its recovery. Therefore, it is essential that this situation is carefully monitored and that all anthropogenic activities be reduced to an absolute minimum.

Although a natural occurrence, predation by killer whales (*Orcinus orca*) may also pose an additional threat to the recovery of this population at its currently reduced number. Killer whales are known to kill eastern gray whales, especially calves, off central and northern California (Rice and Wolman, 1971; Baldridge, 1972). Andrews (1914) found killer whale tooth raking on the flukes and flippers of a majority of the gray whales killed off Korea and

documented numerous accounts of killer whales attacking both living and already captured gray whales. Although killer whales are somewhat common off the Sakhalin Island gray whale feeding ground, no aggressive interactions between the two species have been observed (Weller *et al.*, 2000). However, of 69 gray whales photographically identified between 1997 and 1998 on the feeding ground off Sakhalin, over 33% had tooth rakes from killer whales on their flukes, flippers or bodies (authors' data). This finding suggests that killer whales are at least threatening, and perhaps killing, western gray whales somewhere within their range but any associated mortality related to these observations is currently unknown.

Other factors, for which the cause is unknown but which give rise to concern for this population include low calf survival estimates (< 42%) between 1995 and 1998; a male bias (59.4% males, 40.6% females; $n = 64$) in the [biopsy] sampled population and a more pronounced male bias (77.8% males, 22.2% females; $n = 9$) in sampled calves.

INTERNATIONAL CONCERN AND CONSERVATION MEASURES

Largely on the basis of the recent information provided by the joint USA-Russia research programme (1995-2001) initiative and summarised here, the World Conservation Union (IUCN) listed the western gray whale population as 'Critically Endangered' in 2000 (Hilton-Taylor, 2000). In particular, this was due to the criterion that the population is estimated to have less than 50 mature individuals.

Serious concern over the status of the population has also been expressed by the Scientific Committee of the International Whaling Commission (IWC, 2002b). As a result of this, the Commission itself passed a Resolution in 2001 calling for concerted action by range states and others to pursue actions to eliminate anthropogenic mortality and disturbances on this population (IWC, 2002a). The IWC also strongly endorsed a continuation and expansion of the current research programme.

CONCLUSION

It is apparent that long-term research and monitoring efforts of the western gray whale population need to be continued and expanded. The extensive past exploitation of this population, in combination with potential new threats from anthropogenic activities throughout its range, raises questions about the potential recovery and continued survival of the western gray whale. Future measures to protect this population will require international research collaboration between all range state countries and development of effective conservation measures and dedicated cooperation between science, industry and government.

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A photographic match of a western gray whale between Sakhalin Island, Russia, and Honshu, Japan: the first link between the feeding ground and a migratory corridor

DAVID W. WELLER*, AMANDA L. BRADFORD+, HIDEHIRO KATO#, TAKEHARU BANDO^, SEIJI OTANI^, ALEXANDER M. BURDIN++, ~ AND ROBERT. L. BROWNELL, JR.*

Contact e-mail: dave.weller@noaa.gov

ABSTRACT

Between 2005 and 2007, four female western gray whales were accidentally entrapped and died in Japanese set nets while migrating along the Pacific coast of Honshu, Japan. Photographs of these animals were compared to a photo-identification catalogue of western gray whales from their feeding ground off Sakhalin Island, Russia, to look for matches of individuals between the two areas. Although useable quality photographs were available for only one of the four whales from Japan, a confirmed match was made to a whale photographed off Sakhalin Island. This match represents the first link between the feeding ground and a migratory corridor and highlights the importance of multi-national research collaboration in the formation of range-wide conservation measures to protect this critically endangered population.

KEYWORDS: GRAY WHALE; PHOTO-IDENTIFICATION; ENTRAPMENT; BYCATCH; CONSERVATION; NORTHERN HEMISPHERE; INCIDENTAL CATCHES; FEEDING GROUNDS; MIGRATION; PACIFIC OCEAN

INTRODUCTION

The western North Pacific population of gray whales (*Eschrichtius robustus*) is critically endangered (Baillie *et al*., 2004; Weller *et al*., 2002). The population is estimated to contain about 130 individuals of age one or older, of which only 23 are known to be reproductive females (Cooke *et al*., 2008; Weller *et al*., 2008). The population faces a number of potential anthropogenic threats throughout its range, primarily as a result of oil and gas development on its feeding ground off Sakhalin Island (Reeves *et al*., 2005) and fishing activities in much of its range. These threats include: collisions with ships, exposure to underwater noise (e.g. seismic surveys); modifications to physical habitat; and entrapment or entanglement in fishing gear (Brownell *et al*., 2007; Reeves *et al*., 2005; Weller *et al*., 2002).

Western gray whales migrate to summer feeding grounds off the northeastern coast of Sakhalin Island, Russia, from winter breeding grounds suspected to be in the South China Sea. While the coastal waters of eastern Russia, the Korean Peninsula and Japan have all been recorded as migratory corridors historically, the current migration route(s) of the population is not well understood (e.g. see review in Weller *et al*., 2002). Although western gray whales were hunted centuries ago by net fishermen off the eastern shores of Japan (Omura, 1984), present-day sightings in that country are uncommon (Kato *et al*., 2007). Of the 17 records since 1955 that exist in Japan, 76% (*n*=13) were reported from the Pacific (east) coast while 24% (*n*=4) came from the Sea of Japan (west) coast. Eleven (65%) of these records are from the period 1990 to 2007, with none reported between 1970 and 1982, suggesting that occurrence patterns, sighting effort or both have recently increased. All occurrences took place between January and July with the highest number of records (*n*=11) reported between March and May. Six (35%) of the 17 observations were reported as 'entanglements' by Kato *et al*. (2007). The importance of these records is two-fold in that they: (1) provide recent evidence for use of the eastern and western shores of Japan as migration corridors for at least some whales; and (2) identify and highlight the problem of interactions with coastal fishing gear during migration.

Between 2005 and 2007, four female western gray whales were unintentionally entrapped and died in Japanese set nets (i.e. trap nets) while migrating off the Pacific coast of Honshu, Japan (Kato *et al*., 2006; Kato *et al*., 2007; 2005). These four animals included: (1) a 7.8m female found in the southeastern part of Tokyo Bay on 11 May 2005; (2) a large 12.7m female and a smaller 7.7m female (considered a mother-calf pair) found about 340km northeast of Tokyo (near Enoshima, Onagawa Peninsula, Miyagi Prefecture) on 15 July 2005; and (3) a 9.1m female found approximately 430km northeast of Tokyo (in Yoshihama Bay, Ofunato City, Iwate Prefecture) on 18 January 2007 (Fig. 1). Photographs of these entrapped animals were compared to a photo-identification catalogue of western gray whales (Weller *et al*., 2006; 1999) from their feeding ground in the Okhotsk Sea off Sakhalin Island, Russia, to look for matches of individuals between the two areas. The results of this comparison are presented herein.

METHODS AND RESULTS

Since 1995, a collaborative Russia-US photo-identification study of western gray whales on their summer feeding ground off the northeastern coast of Sakhalin Island, Russia, has been ongoing (Weller *et al*., 2008; Weller *et al*., 1999). Through 2006, 158 individually identified whales have been catalogued, including 59 whales first identified as calves

* *Southwest Fisheries Science Center, NOAA Fisheries, 8604 La Jolla Shores Drive, La Jolla, CA 92037-0271, USA.*
+ *School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195-5020, USA.*
# *Tokyo University of Marine Science and Technology, 4-5-7 Konan, Minato-ku, Tokyo 108-8477, Japan.*
^ *Institute of Cetacean Research, 4-5 Toyomi-cho, Chuo-ku, Tokyo 104-0055, Japan.*
++ *Kamchatka Branch of Pacific Institute of Geography, Far East Branch of the Russian Academy of Sciences, Pr. Rybakov, 19-a, Petropavlovsk-Kamchatsky, 683024, Russia.*
~ *Alaska Sea Life Center, 301 Railway Avenue, Seward, AK 99664, USA.*

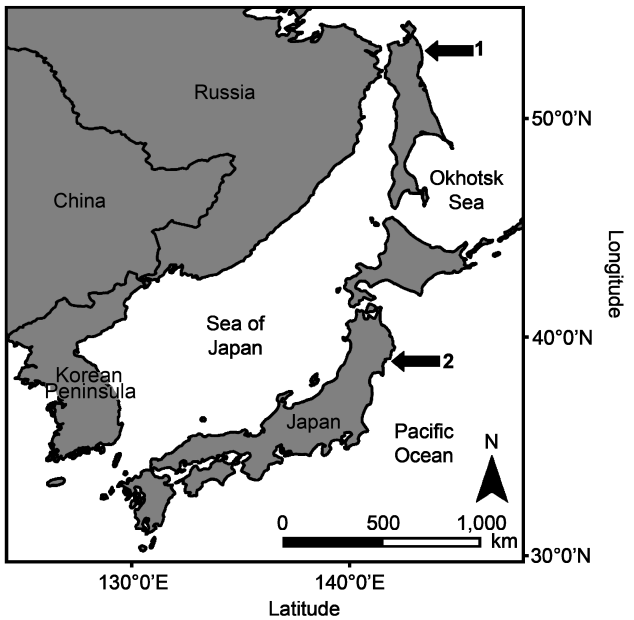

Fig. 1. Map of western North Pacific region showing where western gray whale no. 151 was sighted on the feeding ground off Sakhalin Island, Russia (52°50'N, 143°20'E) on 23 July 2006 (Arrow 1) and found in a trap net off Honshu, Japan (39°08'N, 141°54'E) on 18 January 2007 (Arrow 2).

(Weller *et al*., 2008). This catalogue of known individuals served as the basis for comparison to images collected from the whales entrapped off Japan. Upon initial inspection of the available photographs of the four whales taken in set nets between 2005 and 2007, it was found that the only images of suitable quality for comparison to the Sakhalin Island catalogue were those of the Yoshihama Bay whale. Left and right dorsal flank images of this whale were examined and found to match whale no. 151 from the Russia-US catalogue.

Whale no. 151 was first sighted off northeastern Sakhalin Island on 23 July 2006. It was sighted again two days later, when a biopsy sample was taken. The final sighting of whale no. 151 occurred on 24 August 2006. During each encounter, this whale was observed in close association with a known reproductive female who was last observed to have a calf in 2002. Based on this relationship and the size difference of the two animals, these whales were recorded as a mother-calf pair, one of four such pairs observed during the 2006 field season (Weller *et al*., 2008). This mother-calf designation was subsequently confirmed by genetic analysis (A.R. Lang, pers. comm.). Whale no. 151 would have been weaned on the Sakhalin feeding ground in the late summer or early autumn of 2006 before migrating southward along the eastern coast of Japan. Based on the mean birth date of mid-January (Rice, 1983; Rice and Wolman, 1971) and southbound migratory timing (Rugh *et al*., 2001) reported for eastern gray whales, whale no. 151 was approximately one year old and migrating south when entrapped in a set net off Japan in January 2007.

DISCUSSION

The photographic match reported here is the first to link the feeding ground of western gray whales to a location more than 1,500km to the south within a migratory corridor. This finding, when combined with other data on gray whales off Japan (see Kato *et al*., 2007), adds useful contemporary information on when and where gray whales might be found during their migration as well as the pathways being used. Omura (1984) hypothesised that gray whales occurring off the Pacific coast of Japan could comprise a distinct stock or substock of the western population and Park (2001) went on to suggest that this supposed substock might summer off the coast of southern Kamchatka and migrate along the Kuril Islands. The evidence presented herein does not support the reasoning offered by Omura (1984) and Park (2001). In a broader context, this match highlights the importance of obtaining photographs (and genetic samples) from western gray whales outside of the Sakhalin Island feeding ground whenever possible and emphasises how multi-national research collaboration can benefit range-wide conservation measures designed to best protect this critically endangered population.

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Movements of western gray whales from the Okhotsk Sea to the eastern North Pacific

D.W. WELLER [1], A. KLIMEK [2], A.L. BRADFORD [3], J. CALAMBOKIDIS [2], A.R. LANG [1], B. GISBORNE [4], A.M. BURDIN [5], W. SZANISZLO [6] AND R.L. BROWNELL, JR. [1]

Contact e-mail: dave.weller@noaa.gov

[1] *Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, CA, USA*

[2] *Cascadia Research Collective, Olympia, WA, USA*

[3] *Protected Species Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Honolulu, HI, USA*

[4] *Juan de Fuca Express, Victoria, BC*

[5] *Kamchatka Branch of Pacific Institute of Geography, Far East Branch - Russian Academy of Sciences, Petropavlovsk, Kamchatka, RUSSIA*

[6] *P.O. Box 486, Ucluelet, BC V0R 3A0*

ABSTRACT

The western North Pacific (WNP) population of gray whales (*Eschrichtius robustus*) is listed as critically endangered by the IUCN and its continued ability to survive is of concern. As part of a long-term study on WNP whales off Sakhalin Island, Russia, a photo-catalog comparison to eastern North Pacific (ENP) gray whales was undertaken to detect possible population mixing. The WNP/ENP catalog comparison involved 181 and 1,200 individuals, respectively, and resulted in six matches (three males, two females, and one whale of unknown sex). Three of the six whales were first identified as calves (with their mothers) off Sakhalin. All ENP sightings of Sakhalin whales occurred off southern Vancouver Island, BC, and were collected during only two days of effort. Three whales were identified on 02 May 2004 and 25 April 2008, respectively. The three whales in 2004 were together in a single group, while the three whales in 2008 were in two groups in close proximity. All six whales were sighted off Sakhalin prior to their ENP sightings and five were observed off Sakhalin subsequent to being sighted in the ENP. Four whales were sighted in both the ENP and WNP in the same year, three in 2004 and one in 2008. As the ENP catalog represents only a fraction of the total number of individuals in the ENP population (~19,000), it is likely that more WNP/ENP exchange has occurred than was detected during this comparison. Although these matches provide new records of WNP to ENP movements, winter/spring observations of gray whales off Japan, including a 2006/2007 photo-match from Honshu to Sakhalin, indicate that not all gray whales identified off Sakhalin share a common wintering ground. Thus, it is possible that the number of whales in the WNP population is smaller than previously estimated and therefore of increased conservation concern.

KEYWORDS: GRAY WHALE; PACIFIC OCEAN; MOVEMENT PATTERNS; CONSERVATION

INTRODUCTION

The western gray whale (*Eschrichtius robustus*) population is listed as critically endangered by the IUCN and its continued ability to survive is of concern. The most recent population assessment by Cooke *et al.* (2008), using a Bayesian individually-based stage structured model, reported a median 1+ (non-calf) estimate of 130 individuals (90% Bayesian CI = 120-142). Research on this population has been ongoing since 1995, primarily on the feeding ground off northeastern Sakhalin Island, Russia (Weller *et al*., 1999; Bradford *et al*., 2008; Lang *et al*., 2010) but also, recently, off southeastern Kamchatka (Vertyankin *et al*., 2004; Tyurneva *et al*., 2010; Burdin *et al*., 2011).

Our photo-identification studies on the Sakhalin feeding ground have documented (1) pronounced seasonal site fidelity and annual return of known individuals, (2) utilization of the area by reproductive females when pregnant, resting and accompanying their calves and (3) return to the area by many individuals first identified as calves (Weller *et al.*, 1999, 2002; Bradford *et al*., 2008). Genetic studies utilizing both mitochondrial and nuclear markers have observed significant levels of differentiation between western North Pacific (WNP) and eastern North Pacific (ENP) gray whales, indicating that some degree of reproductive isolation occurs (Lang, 2010; Lang *et al.,* 2011).

Some of the whales identified feeding in the coastal waters off Sakhalin, including reproductive females and calves, have also been documented off the southern and eastern coast of Kamchatka (Tyurneva *et al*., 2010; Burdin *et al*., 2011). Further, sightings of whales observed off Sakhalin have been recorded off the northern Kuril Islands in the eastern Okhotsk Sea and Bering Island in the western Bering Sea (Weller *et al*., 2003).

While information regarding the summer feeding areas of gray whales in the WNP has become increasingly available in the past decade, little is known about the current migratory routes and wintering areas of these animals. Historic evidence suggests that the coastal waters of eastern Russia, the Korean Peninsula and Japan were part of the migratory route at one point in time and that areas in the South China Sea may have been used as wintering grounds (see review in Weller *et al.*, 2002). Observations of gray whales off Japan have been made for hundreds of years (Omura, 1984), including 13 records since 1990 (Kato *et al*. 2010). Between 2005 and 2007, four female gray whales were fatally entrapped in set nets while migrating along the Pacific coast of Honshu. One of these females, entrapped in January 2007, was matched to an earlier photograph of it as a calf (with its mother) while on the Sakhalin feeding ground in 2006 (Weller *et al*., 2008). This match provided the most contemporary link between the Sakhalin feeding ground and a winter migratory route in WNP.

In an effort to obtain more information about the southern migration route(s) and wintering area(s) of WNP gray whales, a collaborative satellite telemetry project was undertaken in 2010 by a team of Russian and American scientists[1]. A 13-year old male gray whale named "Flex" was tagged on the Sakhalin feeding ground in October 2010 and tracked to the ENP off the west coast of the U.S.[2,3] While the objective of this tagging study was to document gray whale movements in the WNP, the tracking of "Flex" to the ENP provided the impetus for the WNP/ENP photo-identification catalog comparison described herein.

METHODS

Photo-identification images of 181 individual western gray whales (called the WNP catalog herein[4]) collected off Sakhalin between 1994-2009 by a Russia-U.S. joint research program were compared to a catalog of nearly 1200 eastern gray whales (called the ENP catalog) identified by Cascadia Research Collective and its collaborators working in U.S. and Canadian waters from California to Alaska (Calambokidis *et al*., 2002; 2010). The ENP catalog focuses on several hundred gray whales called the Pacific Coast Feeding Group (PCFG) that feed during summer and fall in coastal waters between northern California and the Gulf of Alaska but also includes a small number (n=247) of migrating gray whales identified in the spring (March to May) during their northward passage to the Bering, Beaufort and Chukchi Seas.

RESULTS

The WNP/ENP catalog comparison resulted in a total of six confirmed matches, including three males, two females, and one whale of unknown sex (Table 1). None of these six whales are known PCFG animals and, to date, have only ever been sighted a single time during either May or April.

Table 1
Sighting summary information for six whales matched between the WNP and ENP.

Whale ID	Sex	Years Sighted WNP	Date Sighted ENP	ENP Sighting Coordinates
RUS-U.S. 002 / CRC 0817	M	94-95, 97, 99-01, 04-09	02 May 2004	48°41.41'N 124°58.06'W
RUS-U.S. 032 / CRC 1045 [1]	M	97-98, 01-05, 07-10	25 April 2008	48°53.81'N 125°24.54'W
RUS-U.S. 035 / CRC 0809 [2]	M	95, 97, 98-07, 09-10	02 May 2004	48°41.41'N 124°58.06'W
RUS-U.S. 078 / CRC 0825	U	97, 99, 02-04, 06-10	02 May 2004	48°41.41'N 124°58.06'W
RUS-U.S. 119 / CRC 1040 [3]	F	03, 10	25 April 2008	48°44.01'N 125°07.70'W
RUS-U.S. 135 / CRC 1042 [4]	F	04	25 April 2008	48°44.01'N 125°07.70'W

[1] *RUS-U.S. 032 / CRC 1045 – "Flex". First identified off Sakhalin as a calf in 1997.*

[2] *RUS-U.S. 035 / CRC 0809 – Putative father of 2 (strict criterion) or 4 (relaxed criterion) Sakhalin calves (for definitions see Lang, 2010). Years that these calves were first identified are: 1998, 2001, 2002 and 2003.*

[3] *RUS-U.S. 119 / CRC 1040 – First identified off Sakhalin in 2003 as a calf.*

[4] *RUS-U.S. 135 / CRC 1042 – First identified off Sakhalin in 2004 as a calf.*

[1] http://www.iucn.org/wgwap/?6614/International-scientists-track-endangered-whale-to-discover-breeding-grounds

[2] http://mmi.oregonstate.edu/Sakhalin2010

[3] http://www.sevin.ru/menues1/index_rus.html?../ExpeditionsRAS/Gray_whale/Gray_whale.html

[4] The number of whales in this catalog (n=181) does not correspond to the estimated size of the population.

Remarkably, all six of the matches were from only two days of effort in the ENP, with three whales identified on 02 May 2004 and three on 25 April 2008. The three whales identified on 02 May 2004 were together in a single group while the three whales recorded on 25 April 2008 were in two separate groups but in close proximity. All of the sightings of WNP gray whales in the ENP occurred off the west coast of southern Vancouver Island, BC (near Barkley Sound).

Three of the six whales were first identified as calves (with their mothers) on the Sakhalin feeding ground during 1997 (no. 032/1045), 2003 (no. 119/1040) and 2004 (no. 135/1042), respectively. All six whales had sightings off Sakhalin prior to their respective sightings in the ENP and five (83%) had sightings off Sakhalin subsequent to their ENP sightings. Four whales were sighted in the ENP and WNP in the same year, three in 2004 and one in 2008. Of the three whales identified off Vancouver Island on 02 May 2004, two were sighted off Sakhalin on 31 July 2004 while the third was first sighted on 6 August 2004. "Flex" (no. 032/1045) was sighted off Sakhalin in 2007 during July (29th), August (4,18,25th) and September (7,8,9th), off southern Vancouver Island on 25 April 2008 and then back off Sakhalin on 19 July 2008. The movements of "Flex" detailed here were all prior to the telemetry derived track showing him moving from the WNP off Sakhalin in October 2010 to the ENP off the U.S. west coast in February 2011[1]. Thus, "Flex" has made the trip from the WNP to the ENP more than once.

DISCUSSION

The six photographic matches reported here provide new information that is of broad significance to understanding the population structure and mixing of gray whales in the Pacific (see Lang *et al*., 2011). Particularly intriguing is the high number of matches made given that the ENP catalog used for comparison focuses on PCFG whales and has only a small number (n=247) of the approximately 19,000 gray whales (Laake *et al*., 2009) that pass the Pacific Northwest during the spring migration (March to May). Even smaller numbers of whales in the ENP catalog have been identified during the spring off the coast of Vancouver Island where the six whales matched were observed (n=26 for southern Vancouver Island; n=48 for all of western Vancouver Island). Given that the ENP catalog contains only a small fraction (1,200) of the total number of individuals (~19,000) in the ENP population, it is likely that more WNP/ENP exchange has occurred than was detected during this comparison.

The high match rate observed in this study suggests there is a spatio-temporal behavioral factor that makes WNP whales more likely to have been identified in the small ENP spring sample. That all the matches came from sightings on only two days, mostly in the same groups and in localized areas, indicates that whales from the Sakhalin feeding ground remain associated, at least to some degree, even when in the ENP. These six whales were sighted in an area where some whales tend to linger and feed during the northbound migration. Feeding whales are often found in more nearshore waters and over extended periods of time, potentially making them more likely to be photographed than animals rapidly migrating pass the area. The long distance and potential open water crossing required for transit from the ENP to the WNP may make it advantageous for whales to spend time feeding in the Pacific Northwest (e.g. Vancouver Island) prior to undertaking a westerly passage to Sakhalin.

Although the high number of matches reported here was somewhat surprising, WNP to ENP movements were not completely unexpected. Lang (2010) reported that two adult individuals from the WNP, sampled off Sakhalin in 1998 and 2004, matched the microsatellite genotypes, mtDNA haplotypes, and sexes (one male, one female) of two whales sampled off central California on 20 and 23 March 1995. When these two genetic matches are combined with the six photographic matches reported herein, a total of eight adult WNP gray whales have been matched to the ENP. These eight matches include four males and three females, providing evidence that both sexes, in approximately equal numbers, move between the WNP and the ENP. Interestingly, one of the males (no. 035/0809) matched in this study was determined to be the father of two and possibly four claves identified off Sakhalin (Lang, 2010). Despite this level of mixing, significant mtDNA and nuclear genetic differences between whales utilizing the Sakhalin feeding ground and those summering in the ENP support the continued recognition of Sakhalin animals as a distinct unit (Lang *et al*., 2011).

Adding to the complexity of mixing between the WNP and ENP are contemporary records of gray whales off Japan. There have been 13 reports of gray whales in Japanese waters since 1990 (Kato *et al*., 2010). One of these reports includes a whale first identified as a calf accompanied by her mother off Sakhalin Island in 2006 that was later fatally entrapped in a set net off the Pacific coast of Honshu in January 2007

Weller *et al*., 2008). While observations of gray whales in Japan have been made between November and August, a majority of these records are concentrated between March and May. This March to May period coincides with when the six matched whales described here were sighted in the ENP. These findings indicate that not all gray whales identified off Sakhalin share a common wintering ground and suggest that the number of whales estimated to be in the WNP population may possibly be lower than previously thought.

The use of photo-identification methods, in combination with genetic and telemetry techniques, are essential to furthering our understanding of gray whale population structure. It is recommended that other existing photo collections and tissue samples of WNP and ENP gray whales (e.g. those from Sakhalin, Kamchatka, Chukotka, Mexico and Japan) be used to further examine gray whale movement patterns and population structure within the Pacific. Ideally, a collaborative Pacific wide study should be undertaken, similar in scope to what has been done for humpback whales in the Atlantic and Pacific.

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FEATURE ARTICLE

OPEN ACCESS

Movements of gray whales between the western and eastern North Pacific

David W. Weller[1,*], Amber Klimek[2], Amanda L. Bradford[3], John Calambokidis[2], Aimee R. Lang[1], Brian Gisborne[4], Alexander M. Burdin[5], Wendy Szaniszlo[6], Jorge Urbán[7], Alejandro Gómez-Gallardo Unzueta [7], Steven Swartz[8], Robert L. Brownell Jr.[1]

[1]Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 3333 North Torrey Pines Court, La Jolla, California 92037-1022, USA
[2]Cascadia Research Collective, Olympia, Washington 98501, USA
[3]Protected Species Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Honolulu, Hawaii 96814, USA
[4]Juan de Fuca Express, Victoria, British Columbia, Canada
[5]Kamchatka Branch of Pacific Institute of Geography, Far East Branch - Russian Academy of Sciences, Petropavlovsk, Kamchatka, Russia
[6]PO Box 486, Ucluelet, British Columbia, Canada
[7]Programa de Investigación de Mamíferos Marinos, Universidad Autónoma de Baja California Sur, La Paz, B.C.S., Mexico
[8]Cetacean Research Associates, Darnestown, Maryland 20874, USA

ABSTRACT: The western North Pacific (WNP) population of gray whales *Eschrichtius robustus* is redlisted by the IUCN as Critically Endangered. As part of a long-term study on whales off Sakhalin Island, Russia, photo-catalog comparisons of gray whales in the western and eastern North Pacific (ENP) were undertaken to assess population mixing. These comparisons involved 2 approaches: (1) a systematic comparison of the WNP 'Sakhalin Catalog' to an ENP 'Pacific Northwest Catalog' that consisted of images from the northwest coast of North America and (2) a non-systematic comparison of the WNP 'Sakhalin Catalog' to an ENP 'Laguna San Ignacio Catalog' that consisted of images from central Baja California, Mexico. The Sakhalin to Pacific Northwest comparison consisted of 181 and 1064 whales, respectively, and resulted in 6 matches (3 males, 2 females, and 1 whale of unknown sex). All sightings of 'Sakhalin whales' in the Pacific Northwest occurred off southern Vancouver Island, British Columbia, Canada. The Sakhalin to Laguna San Ignacio comparison consisted of 181 and 2514 whales, respectively, and resulted in 4 matches (2 males and 2 females). As the Pacific Northwest and Laguna San Ignacio catalogs represent only a small fraction of the total estimated number of individuals in the ENP population (~19 000), it is likely that more WNP/ENP exchange has occurred than was detected by these photo-catalog comparisons. Although these matches provide new records of movements between the WNP and ENP, recent observations of gray whales off Japan and China suggest that not all gray whales identified in the WNP share a common wintering ground.



Once thought to be extinct, an endangered western North Pacific gray whale breaches off Sakhalin Island, Russia.
Image: David W. Weller

KEY WORDS: Gray whale · Pacific Ocean · Movement patterns · Conservation

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INTRODUCTION

Gray whales *Eschrichtius robustus* are presently recognized as 2 populations in the North Pacific Ocean. Recent genetic studies using both mitochondrial and nuclear markers have demonstrated significant differentiation between the western North

*Email: dave.weller@noaa.gov

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Pacific (WNP) and eastern North Pacific (ENP) populations (LeDuc et al. 2002, Lang 2010, Lang et al. 2011). The ENP population ranges from calving areas off Baja California, Mexico, to feeding areas in the Bering, Beaufort, and Chukchi Seas. The WNP population feeds in the Okhotsk Sea off Sakhalin Island, Russia, and in nearshore waters of the southeastern Kamchatka Peninsula (southwestern Bering Sea). Little is known about the current migratory routes and wintering areas of the WNP population, but historic evidence indicates that the coastal waters of eastern Russia, the Korean Peninsula, and Japan were part of the migratory route and that areas in the South China Sea were used as wintering grounds (see review by Weller et al. 2002).

Both populations were dramatically reduced by commercial whaling during the 19th and 20th centuries (Henderson 1984, Weller et al. 2002, Reeves et al. 2010). The ENP population was removed from the U.S. List of Endangered and Threatened Wildlife in 1994 and is currently estimated to number approximately 19 000 individuals (Laake et al. 2009). At the single species-level unit, gray whales are redlisted by the International Union for Conservation of Nature (IUCN) as being of Least Concern (Reilly et al. 2008). The WNP subpopulation, however, is redlisted by the IUCN as Critically Endangered (Reilly et al. 2008). The most recent assessment of the Sakhalin population, using a Bayesian individual-based stage-structured model, resulted in a median 1+ (non-calf) estimate of 130 individuals (90% Bayesian CI = 120–142) in 2008 (Cooke et al. 2008).

Research on gray whales in the WNP has been ongoing since 1995, predominantly on the primary feeding ground off northeastern Sakhalin Island (Weller et al. 1999, Bradford et al. 2008, Lang et al. 2011), and more recently off southeastern Kamchatka (Vertyankin et al. 2004, Tyurneva et al. 2010, Burdin et al. 2011). These studies monitor gray whales using photo-identification methods, as gray whales are individually identifiable based on unique, permanent pigmentation features (Darling 1984). Such monitoring on the Sakhalin feeding ground has documented (1) pronounced seasonal site fidelity and inter-annual return of known individuals, (2) consistent use of the area by adult females when pregnant, resting (i.e. when not pregnant or lactating), and accompanied by calves, and (3) annual return by many individuals that were first identified there as young-of-the-year (Weller et al. 1999, 2002, Bradford et al. 2008, Bradford 2011).

Whales associated with the Sakhalin feeding area can be absent for all or part of a given feeding season (Bradford et al. 2008), indicating that they probably use other areas during the summer and fall feeding period. Some of the whales identified feeding in the coastal waters off Sakhalin, including reproductive females and calves, have also been documented off the southern and eastern coast of Kamchatka (Tyurneva et al. 2010, Burdin et al. 2011). Further, whales observed off Sakhalin have been sighted off the northern Kuril Islands in the eastern Okhotsk Sea and Bering Island in the western Bering Sea (Weller et al. 2003). Finally, Lang (2010) reported that 2 adult individuals from the WNP, sampled off Sakhalin in 1998 and 2004, matched the microsatellite genotypes, mtDNA haplotypes, and sexes (1 male, 1 female) of 2 whales sampled off Santa Barbara, California, USA (Area 3 in Fig. 1) on 20 and 23 March 1995. The study by Lang (2010) was the first to suggest that some level of interchange might be occurring between the WNP and ENP.

While information regarding the summer feeding areas of gray whales in the WNP has become increasingly available in the past decade, current data from the historic migratory corridor(s) are limited and data from the presumed wintering area(s) are essentially unavailable. There have been only 13 known sightings or strandings in Japanese waters since 1990 (Nambu et al. 2010). Between 2005 and 2007, 4 female gray whales were fatally entrapped in set nets along the Pacific coast of Honshu, Japan. One of these females, entrapped in January 2007, was matched to earlier photographs of it as a calf (with its mother) while on the Sakhalin feeding ground in July and August 2006 (Weller et al. 2008). This match provided the most contemporary link between the summer feeding ground off Sakhalin and a winter location along the coast of Asia.

In an effort to obtain more information about the southern migration route(s) and wintering area(s) of gray whales in the WNP, a satellite telemetry project was undertaken in 2010 by a team of Russian and American scientists (Mate et al. 2011). While the objective of that study was to document gray whale movements in the WNP, the only whale tagged was tracked from the WNP to the ENP. The result of this telemetry study, together with the genetic matches reported by Lang (2010), provided the impetus for WNP/ENP photo-identification catalog comparisons, which we conducted to further assess population mixing.

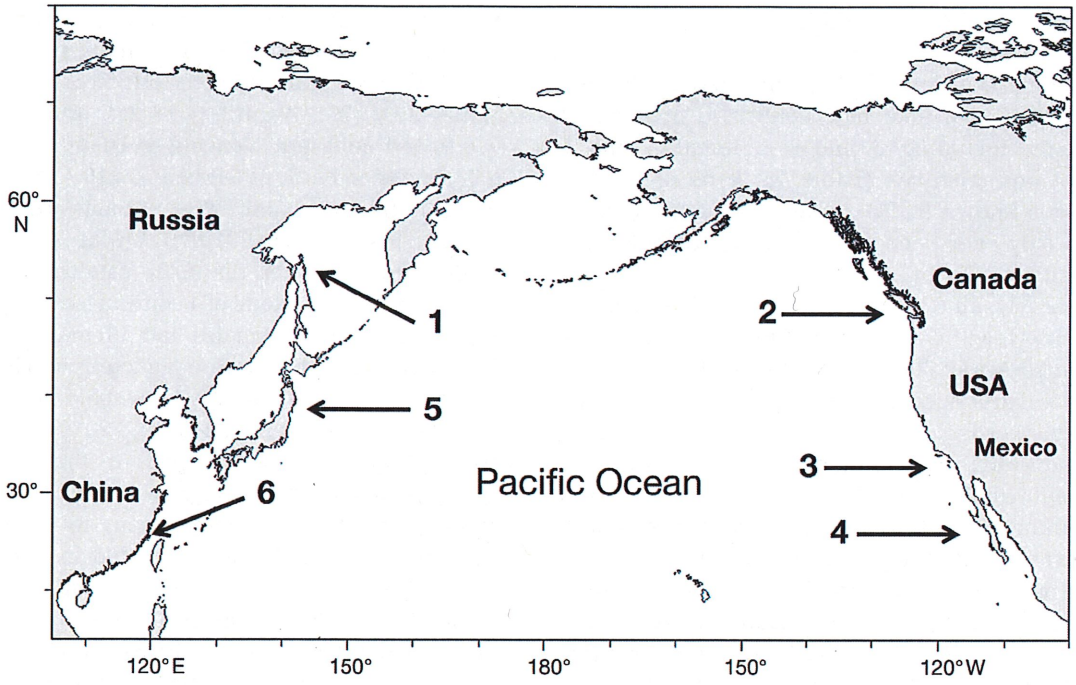

Fig. 1. *Eschrichtius robustus*. North Pacific Ocean, showing: (1) Western North Pacific (WNP) feeding ground off Sakhalin Island, (2) Eastern North Pacific (ENP) region off Vancouver Island where 6 photographic matches to Sakhalin individuals were found, (3) ENP region off California where 2 genetic matches were found (Lang 2010), (4) ENP region off Baja California where 4 photographic matches to Sakhalin individuals were found, (5) WNP region of Japan where a photographic match was found (Weller et al. 2008), and (6) WNP region of China where a gray whale stranded in November 2011 (Zhu 2012)

MATERIALS AND METHODS

Photo-identification images of 181 Sakhalin gray whales (the Sakhalin catalog, hereafter SAK catalog) collected off Sakhalin Island (Area 1 in Fig. 1) between 1994 and 2009 by a joint Russia-U.S. research program (Weller et al. 1999, 2002) were compared to a catalog of 1064 'Pacific Northwest gray whales' (hereafter, PNW catalog) identified by Cascadia Research Collective and collaborators working in U.S. and Canadian waters from California to Alaska (Area 2 in Fig. 1) primarily between 1998 and 2009 (Calambokidis et al. 2002, 2010). The PNW catalog focuses on gray whales that feed during summer and fall in coastal waters between northern California and the Gulf of Alaska, referred to as the Pacific Coast Feeding Group (PCFG), but also includes some migrating whales identified in the spring (March to May) during their northward passage to high-latitude feeding grounds.

Of the 181 whales in the SAK catalog, all were represented by a right-side dorsal flank image, and 179 were associated with a left-side dorsal flank image. Of the 1064 whales in the PNW catalog, 845 were represented by a right-side dorsal flank image, and 898 were associated with a left-side dorsal flank image. Each individual in the SAK catalog was compared in numerical order to all individuals in the PNW catalog as follows. First, the left-side dorsal flank of each individual in the SAK catalog was compared to the left-side dorsal flank of all individuals in the PNW catalog. This process was then repeated using the right-side dorsal flank and ventral aspect of the tail flukes. Comparisons were made by a single analyst (A.K.), but resulting matches were confirmed by 3 independent researchers skilled in gray whale photo-identification (including A.L.B. and J.C.).

Similarly, photo-identification images of 181 whales in the SAK catalog were compared to an online catalog of 2514 'Laguna San Ignacio gray whales' (hereafter, the LSI catalog) identified between 2006 and 2010 in Baja California, Mexico (Area 4 in Fig. 1). This assessment was not comprehensive or systematic, as was the case for the PNW catalog, because the LSI catalog represented a collection of 'annual working catalogs' rather than a single multi-year catalog of known individuals. Thus, the comparison to the SAK catalog reported herein was undertaken opportunistically. A single analyst (A.L.B.) conducted the appraisal, with identified matches confirmed by 2 additional observers (including D.W.W.).

RESULTS

The comparison of the SAK catalog to the PNW catalog resulted in a total of 6 confirmed matches of individuals, including 3 males, 2 females, and 1 whale of unknown sex (Table 1). None of these 6 whales is a known PCFG animal, and, to date, each one has only ever been photographed a single time during either April or May.

Remarkably, all 6 of the matches were from only 2 days of effort, with 3 whales identified on 2 May 2004 and 3 on 25 April 2008. The 3 whales identified on 2 May 2004 were together in a single group, while the 3 whales recorded on 25 April 2008 were in 2 separate groups but in close proximity. All of the sightings of Sakhalin whales in the Pacific Northwest occurred near Barkley Sound off the west coast of southern Vancouver Island, British Columbia, Canada.

Three of the 6 whales were first identified as calves (with their mothers) on the Sakhalin feeding ground during 1997 (no. RUS-U.S. 032/CRC 1045), 2003 (no. RUS-U.S. 119/CRC 1040), and 2004 (no. RUS-U.S. 135/CRC 1042; Table 1). Interestingly, a genetic analysis of paternity classified one of the matched males (no. RUS-U.S. 035/CRC 0809) as the putative father of 2, or possibly 4, calves identified off Sakhalin (Lang 2010). All 6 whales had sightings off Sakhalin prior to their respective sightings off Vancouver Island, and 5 (83%) had sightings off Sakhalin subsequent to their Vancouver sightings. Four whales were sighted off Vancouver Island and Sakhalin in the same year: 3 in 2004 and 1 in 2008. Of the 3 whales identified off Vancouver Island on 2 May 2004, 2 were resighted off Sakhalin on 31 July 2004, while the third was first resighted on 6 August 2004. Whale no. RUS-U.S. 032/CRC 1045 was sighted off Sakhalin in 2007 during July (29), August (4,18,25), and September (7,8,9), off southern Vancouver Island on 25 April 2008, and then back off Sakhalin on 19 July 2008. This whale is the same individual satellite-tracked from Sakhalin to the ENP in 2010/2011 (Mate et al. 2011).

The comparison of the SAK catalog to the LSI catalog resulted in a total of 4 confirmed matches of individuals, including 2 males and 2 females (Table 2). Three of these 4 whales were photographed in Laguna San Ignacio in only 1 year, while whale no. RUS-U.S. 052 was identified in both 2007 and 2010. All 4 whales had sightings off Sakhalin prior to their respective sightings in Laguna San Ignacio, and 3 (75%) had sightings off Sakhalin subsequent to their lagoon sightings. Two whales were sighted in Laguna San Ignacio and Sakhalin in the same year: one in 2008 (no. RUS-U.S. 063) and one in 2010 (no. RUS-U.S. 052).

One of the 4 whales (no. RUS-U.S. 020) was first identified as a calf on the Sakhalin feeding ground

Table 2. *Eschrichtius robustus.* Sighting summary information for 4 gray whales matched between Sakhalin Island, Russia (SAK), and Laguna San Ignacio (LSI), Baja California, Mexico. Years shown with a dash (–) are inclusive. RUS-U.S.: joint Russia-U.S. research program; M: male; F: female

Whale ID	Sex	Years sighted in SAK	Years sighted in LSI
RUS-U.S. 020[a]	M	97, 02–04, 07–09	2006
RUS-U.S. 042[b]	F	97–00, 03–05	2009
RUS-U.S. 052[c]	M	98–03, 05–06, 08–10	2007, 2010
RUS-U.S. 063[d]	F	97–98, 00–02, 05, 07, 08, 10	2008

[a]First identified off Sakhalin in 1997 as a calf. Photo-matched to Bering Island in June 2000 (Weller et al. 2003). [b]Identified as a mother with calf in LSI 2009. Never seen with calf off Sakhalin. [c]Putative father of a 1998 Sakhalin calf (Lang 2010). [d]Identified as a mother with calf in LSI 2008. Known mother from Sakhalin in 1998

Table 1. *Eschrichtius robustus.* Sighting summary information for 6 gray whales matched between Sakhalin Island, Russia (SAK), and the Pacific Northwest coast of North America (PNW). Years shown with a dash (–) are inclusive. RUS-U.S.: joint Russia-U.S. research programm; CRC: Cascadia Research Collective; M: male; U: unknown; F: female

Whale ID	Sex	Years sighted in SAK	PNW sighting	PNW sighting coordinates
RUS-U.S. 002 / CRC 0817	M	94–95, 97, 99–01, 04–09	02 May 2004	48° 41.41' N, 124° 58.06' W
RUS-U.S. 032 / CRC 1045[a]	M	97–98, 01–05, 07–10	25 April 2008	48° 53.81' N, 125° 24.54' W
RUS-U.S. 035 / CRC 0809[b]	M	95, 97, 98–07, 09–10	02 May 2004	48° 41.41' N, 124° 58.06' W
RUS-U.S. 078 / CRC 0825	U	97, 99, 02–04, 06–10	02 May 2004	48° 41.41' N, 124° 58.06' W
RUS-U.S. 119 / CRC 1040[c]	F	03, 10	25 April 2008	48° 44.01' N, 125° 07.70' W
RUS-U.S. 135 / CRC 1042[d]	F	04	25 April 2008	48° 44.01' N, 125° 07.70' W

[a]Same whale satellite-tagged in 2010 (Mate et al. 2011). First identified off Sakhalin as a calf in 1997. [b]Putative father of 2 (strict criterion) or 4 (relaxed criterion) Sakhalin calves (for definitions see Lang 2010). Years that these calves were first identified are: 1998, 2001, 2002, and 2003. [c]First identified off Sakhalin in 2003 as a calf. [d]First identified off Sakhalin in 2004 as a calf

during 1997 (Table 2) and photographically matched to the Commander Islands in June 2000 (Weller et al. 2003). A genetic analysis of paternity classified 1 of the matched males (no. RUS-U.S. 052) as the putative father of a calf identified in 1998 off Sakhalin (Lang 2010). Both of the matched females were identified as mothers with calves while in Laguna San Ignacio. Whale no. RUS-U.S. 042 was identified as a mother with a calf in 2009 but has never been seen with a calf off Sakhalin. Whale no. RUS-U.S. 063 was identified as a mother with a calf in 2008 and was also observed with a calf off Sakhalin (in 1998).

DISCUSSION

The photographic matches reported here provide new information that is of broad significance to understanding the migration patterns and mixing of gray whales in the North Pacific. The high number of matches made between the SAK and PNW catalogs is particularly intriguing given that the PNW catalog used for comparison focuses on PCFG whales and thus greatly underrepresents individuals that pass off the Pacific Northwest during the spring migration. Limited numbers of whales in the PNW catalog have been photographed during the spring off the coast of Vancouver Island where the 6 matched whales were observed (n = 26 for southern Vancouver Island; n = 48 for all of western Vancouver Island). Thus, 6 of the 74 (8.1%) whales identified off Vancouver Island in the PNW catalog were known Sakhalin individuals. Given that the PNW catalog contains only a small fraction (1064) of the estimated total number of individuals (~19 000) in the ENP population, it is likely that more WNP/ENP exchange has occurred than was detected during this comparison.

The high match rate observed between the SAK and PNW catalogs suggests a spatio-temporal behavioral factor that makes Sakhalin whales more likely to have been identified in the small PNW spring sample. The fact that all the matches came from sightings made on only 2 days, mostly in the same groups and in localized areas, indicates that whales from the Sakhalin feeding ground associate, at least to some degree, even when utilizing migratory routes in the ENP. These 6 whales were sighted in an area where some whales tend to linger and feed during the northbound migration (Darling et al. 1998). Feeding whales are often found in more nearshore waters and over extended periods of time, potentially making them more likely to be photographed than animals rapidly migrating past the area (Darling et al. 1998, Calambokidis et al. 2010). The long distance and potential open water crossing required for transit from the ENP to the WNP may make it advantageous for whales to spend time feeding in the Pacific Northwest (e.g. Vancouver Island) prior to undertaking a westerly passage to Sakhalin.

The preliminary comparison of the SAK and LSI catalogs revealed 4 additional matches. Since the SAK to LSI catalog comparison was conducted in a non-comprehensive manner, relying on long-term familiarity with whales in the WNP catalog, it is probable that additional matches exist. Given the importance of conducting further comparisons to the wintering lagoons of Baja California, Mexico, a systematic and comprehensive comparison of the SAK catalog to a recently compiled multi-year catalog from LSI and Laguna Ojo de Liebre (Scammon's Lagoon) is presently underway (see IWC 2011).

When the 10 WNP/ENP photo-identification matches reported here are combined with the 2 genetic matches noted by Lang (2010), a total of 12 gray whales (6 males, 5 females and 1 whale of unknown sex) identified in the WNP off Sakhalin Island have been matched to 3 locations in the ENP (Vancouver Island, Southern California, Laguna San Ignacio), providing evidence that both sexes, in approximately equal numbers, move between the WNP and the ENP. Despite this level of mixing, significant mtDNA and nuclear genetic differences between whales utilizing the Sakhalin feeding ground and those summering in the ENP support the continued recognition of Sakhalin animals as a distinct genetic unit (Lang et al. 2011).

Adding to the complexity of mixing between the WNP and ENP are contemporary records of gray whales off Japan and, to a lesser degree, China. As previously mentioned, there have been only 13 records of gray whales in Japanese waters since 1990 (Nambu et al. 2010). One of these reports includes a whale first identified as a calf accompanied by her mother on the Sakhalin Island feeding ground in July and August 2006 that was later fatally entrapped in a set net off the Pacific coast of Honshu (Area 5 in Fig. 1) in January 2007 (Weller et al. 2008). While observations of gray whales in Japan have been made between November and August, most of these records are concentrated between March and May. This March to May period coincides with the sightings in the ENP of the 10 matched whales described here. Observations of gray whales in China are exceptionally rare. Only 24 sightings and/or strandings have been recorded since 1933, including obser-

vations of 2 mother–calf pairs (Wang 1984, Zhu 2002). However, a 13 m female gray whale stranded in the Taiwan Strait near the town of Baiqingxiang (Pingtan County), China (Area 6 in Fig. 1), in November 2011 (Zhu 2012). These findings, in combination, suggest that not all gray whales identified in the WNP share a common wintering ground.

The use of photo-identification methods, together with genetic and telemetry techniques, is essential to furthering our understanding of gray whale population structure. We recommend that other existing photo collections and tissue samples of gray whales in the WNP and ENP (e.g. those from Sakhalin, Kamchatka, Chukotka, Mexico, and Japan) be used to further examine gray whale movement patterns and population mixing within the Pacific. Ideally, a collaborative Pacific-wide study should be undertaken, similar in scope to those conducted for humpback whales in the Atlantic and Pacific (Smith et al. 1999, Calambokidis et al. 2008).

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A re-evaluation of gray whale records in the western North Pacific

DAVID W. WELLER AND ROBERT L. BROWNELL, JR.

Contact e-mail: dave.weller@noaa.gov

Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 3333 North Torrey Pines Court, La Jolla, CA, 92037-1022 USA

ABSTRACT

While recent observations have documented gray whales (*Eschrichtius robustus*) identified in the western North Pacific migrating to areas off the coast of North America (Vancouver, California, Mexico) during the winter/spring, the past and present occurrence of gray whales off Japan and China (and the Korean Peninsula historically) suggest that not all gray whales identified in the WNP off Sakhalin share a common wintering ground. Observed genetic differentiation between western and eastern gray whales, in combination with sighting/stranding records from Japan and China during the winter/spring cause us to believe that a relic WNP gray whale population still exists. Thus, the number of whales in the WNP population is substantially smaller than currently estimated and is therefore of increased conservation concern.

KEYWORDS: GRAY WHALE; PACIFIC OCEAN; POPULATION STRUCTURE; MIGRATION

INTRODUCTION

Gray whales (*Eschrichtius robustus*) are recognized as comprising two populations in the North Pacific Ocean. Significant mitochondrial and nuclear genetic differences have been found between whales in the western North Pacific (WNP) and those in the eastern North Pacific (ENP) (Lang *et al*., 2011). The ENP population ranges from calving areas in Baja California, Mexico, to feeding areas in the Bering, Beaufort, and Chukchi Seas. The WNP population feeds in the Okhotsk Sea off Sakhalin Island, Russia, and in nearshore waters of the southeastern Kamchatka Peninsula (southwestern Bering Sea).

The historical distribution of gray whales in the Okhotsk Sea greatly exceeded what is found today (Reeves *et al*., 2008). Whales associated with the Sakhalin feeding area can be absent for all or part of a given feeding season (Bradford *et al*., 2008), indicating they probably use other areas during the summer and fall feeding period. Some of the whales identified feeding in the coastal waters off Sakhalin, including reproductive females and calves, have also been documented off the southern and eastern coast of Kamchatka (Tyurneva *et al*., 2010). Further, whales observed off Sakhalin have been sighted off the northern Kuril Islands in the eastern Okhotsk Sea and Bering Island in the western Bering Sea (Weller *et al*., 2003).

Recently, mixing of whales identified in the WNP and ENP has been observed. Lang (2010) reported that two adult individuals from the WNP, sampled off Sakhalin in 1998 and 2004, matched the microsatellite genotypes, mtDNA haplotypes, and sexes (one male, one female) of two whales sampled off Santa Barbara, California in March 1995. Mate and colleagues (Mate *et al*., 2011) satellite-tracked a whale from the WNP to the ENP in 2010/2011. Finally, photographic matches between the WNP and ENP, including resightings between Sakhalin and Vancouver Island and Laguna San Ignacio, have further confirmed use of areas in the ENP by whales identified in the WNP (Weller *et al*., 2011; Urban *et al*. 2012). Despite this level of mixing, significant mitochondrial and nuclear genetic differences between whales in the WNP and ENP have been found (Lang *et al*., 2011).

Although it is clear that some whales feeding off Sakhalin Island during the summer/fall migrate to the west coast of North America during the winter/spring, observations of gray whales in the WNP off Japan, Korea and China during the winter/spring suggest that not all gray whales in the WNP share a common wintering ground. Little is known about the current migratory routes and wintering areas in the WNP, but historical evidence indicates that the coastal waters of eastern Russia, the Korean Peninsula and Japan were part of the migratory route and that areas in the South China Sea were used as wintering grounds (see review in Weller *et al*., 2002). Summarized herein are relevant gray whale records from the WNP,

including two recent sightings from China in 2011 and Japan in 2012.

DATA RECORDS

Japan

Nambu *et al*. (2010) reported only 13 known sighting or stranding records in Japanese waters between 1990 and 2007. Between 2005 and 2007, four female gray whales were fatally entrapped in set nets along the Pacific coast of Honshu, Japan. One of these females, entrapped in January 2007, was matched to earlier photographs of it as a calf (with its mother) while on the Sakhalin feeding ground in July and August 2006 (Weller *et al*., 2008). This match provided the most contemporary link between the summer feeding ground off Sakhalin and a winter location along the coast of Asia. More recently, the Japan Times (3 May 2012) reported that in March 2012 a gray whale was sighted and photographed in Mikawa Bay (Aichi Prefecture), east of Ise Bay near Nagoya on the Pacific coast of Honshu.[1]

While observations of gray whales in Japan have been made between November and August, most records are concentrated between March and May. This March to May period coincides with when a majority of the whales matched between the WNP and ENP have been sighted in the ENP (Weller *et al*., 2011), suggesting that not all gray whales identified in the WNP off Sakhalin share a common wintering ground.

China

Observations of gray whales in China are also exceptionally rare. Although 24 capture, sighting or stranding records exist since 1933 (Wang, 1984; Zhu, 2002), including observations of two mother-calf pairs, some of these (especially the sightings) have not been reported in sufficient detail to validate species identification. More recently, an 11.5 m female stranded live at Zhuanghe (Bohai Sea *ca*. 39˚N) in December 1996 (Zhao, 1997) and a 13 m female gray whale was taken in fishing gear offshore of Baiqingxiang (Pingtan County), in the Taiwan Strait in November 2011 (Zhu, 2012). Henderson (1990) summarized information from the 1869 logbooks of the New Bedford whaleships *Cornelius Howland* and *Onward* while they were on the "Chinese whale grounds" (also see Reeves *et al*., 2008). The *Cornelius Howland* reported gray whales being sighted in February at nearly an identical location (Pingtan County) as the aforementioned November 2011 Baiqingxiang specimen. The *Onward* reported gray whales off the northern coast of Taiwan, but no subsequent records are known from Taiwanese waters (Yang, 1964).

While the 2011 gray whale specimen confirms the continued occurrence of gray whales off China, the low latitude location (~25°30'N 119°47'E) of this record in November 2011 (equivalent to the latitude of the ENP wintering lagoons in Baja California, Mexico), is early for the southbound migration. In his summary of whaling in Chinese waters, Henderson (1990) noted that whalers recorded gray whales arriving to waters south of Hailing Island (near Yangjang, Guangdong Province), China (north end of the island at 21°51'N 111°58'E) in January and February (before 1874). Wang (1984) reported fishermen noting a small number of gray whale sightings in June and July, but the method of species identification was not mentioned. Based on the varied timing of these observations, Henderson (1990) hypothesized that some gray whales may remain in Chinese waters all year and that the southern most whales occurred as far south as Hainan Island (between 18°30'N and 20° N).

Korea

Gray whales were once common and hunted off the coast of South Korea (Andrews, 1914; Mizue, 1951) and off Yushin (ca. 40°N 129°E), North Korea (Tago, 1922). The last reported commercial catches were in 1966 off Ulsan, South Korea (Brownell and Chun, 1977). Despite systematic annual sighting surveys conducted since 1999 during May and June when gray whales would be expected to be present off South Korea, no sightings have been reported (Kim *et al*., 2002). In fact, there is no recent evidence from any source (stranding, sighting, bycatch) to confirm the occurrence of gray whales off the Korean Peninsula in the past 35 years. The last known sighting of a gray whale off Korea was in 1977 (Park, 1995; Kim, 2007). Given the absence of gray whales off the coast of Korea in recent times, we suggest that WNP gray whales have abandoned the once heavily used migration corridor along the Korean Peninsula or that the gray whale subpopulation using the Korean Peninsula is extinct.

[1] http://www.japantimes.co.jp/text/nn20120503a7.html

CONCLUSIONS

The past and present occurrence of gray whales off Japan and China (and the Korea Peninsula historically) suggest that not all gray whales identified in the WNP off Sakhalin share a common wintering ground. Despite the recently documented interchange of whales between the WNP and ENP, showing that some whales identified off Sakhalin migrate to the ENP during the winter/spring, the observed genetic differentiation between western and eastern gray whales (Lang *et al*., 2011) in combination with sighting/stranding records from Japan and China during the winter/spring migratory period leads us to conclude that a relic WNP gray whale population still exists. That being said, the number of whales in the WNP population is probably substantially smaller than the currently estimated ~150 whales that use the Sakhalin summer feeding area. Thus, the status of gray whales in the WNP may be of greater conservation concern than is currently recognized.

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David W. Weller
Shannon Bettridge
Robert L. Brownell, Jr.
Jeffrey L. Laake
Jeffrey E. Moore
Patricia E. Rosel
Barbara L. Taylor
Paul R. Wade

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REPORT OF THE NATIONAL MARINE FISHERIES SERVICE GRAY WHALE STOCK IDENTIFICATION WORKSHOP

David W. Weller [1], Shannon Bettridge [2], Robert L. Brownell [1], Jr., Jeffrey L. Laake [3], Jeffrey E. Moore [1], Patricia E. Rosel [4], Barbara L. Taylor [1], Paul R. Wade [3]

[1] NOAA National Marine Fisheries Service
Southwest Fisheries Science Center
8901 La Jolla Shores Drive
La Jolla, CA 92037

[2] NOAA National Marine Fisheries Service
Office of Protected Resources
1315 East-West Highway, 13th Floor
Silver Spring, MD 20910

[3] NOAA National Marine Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way Northeast
Seattle, WA 98115

[4] NOAA National Marine Fisheries Service
Southeast Fisheries Science Center
646 Cajundome Blvd.
Lafyette, LA 70506

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National Marine Fisheries Service
Southwest Fisheries Science Center

NOAA Technical Memorandum NMFS

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Executive Summary

The Marine Mammal Protection Act of 1972 (MMPA) requires that the National Marine Fisheries Service (NMFS) and the Fish and Wildlife Service develop stock assessment reports for all marine mammal stocks in waters under U.S. jurisdiction. NMFS considers stock structure as part of these assessments and has developed guidance for delineating separate population stocks under the MMPA. A single population stock of gray whales (*Eschrichtius robustus*), referred to as the eastern North Pacific (ENP) stock, is presently recognized in U.S. waters (Carretta *et al*. 2013). New information, however, suggests the possibility of recognizing two additional stocks of gray whales in U.S. waters: the Pacific Coast Feeding Group (PCFG) and the western North Pacific (WNP) stock. To evaluate the currently recognized and potentially emerging characterization of gray whale stock structure, NMFS established a scientific Task Force (TF). The overarching objective of this TF was to provide an objective scientific evaluation of gray whale stock structure as defined under the MMPA and implemented through the NMFS Guidelines for Assessing Marine Mammal Stocks (GAMMS; NMFS 2005). More specifically, the TF was convened to provide advice on the primary question – "*Is the PCFG a "population stock" under the MMPA and GAMMS guidelines"?* In addition, the TF was asked to provide advice on a question of developing importance – "*Is the WNP stock a "population stock" under the MMPA and GAMMS guidelines"?*

Both of these questions have immediate management implications, including: (1) how future NMFS stock assessment reports will address gray whale stock structure in the North Pacific, and (2) how to interpret any new information in the context of the Makah Indian Tribe's MMPA waiver request to resume hunting gray whales off Washington State, USA.

As the agency lead for gray whale science, the Southwest Fisheries Science Center convened a meeting of the aforementioned TF from 31 July to 2 August 2012. Using the best scientific information available at the time of the workshop, the TF worked to: (1) review new information relevant to gray whale stock structure, and (2) provide advice on revisions to stock structure so as to be available for management consideration. The TF conducted its work as an advisory rather than prescriptive body and therefore its conclusions should viewed as scientific advice based on review and discussion of the available science.

The implications of new data pertinent to stock structure, including considerable information related to the PCFG and WNP gray whales, were thoroughly reviewed during the workshop. Evaluating the new findings relevant to the status of the PCFG proved particularly complex. After review of results from photo-identification, genetics, tagging, and other studies within the context of the GAMMS guidelines (NMFS 2005) there remains a substantial level of uncertainty in the strength of the lines of evidence supporting demographic independence of the PCFG. Consequently, the TF was unable to provide definitive advice as to whether the PCFG is a population stock under the MMPA and the GAMMS guidelines. Members of the TF ranged in their opinions from strongly agreeing to strongly disagreeing about whether the PCFG should be recognized as a separate stock.

In the case of WNP gray whales, the work of the TF was more straightforward. The mitochondrial DNA and nuclear DNA genetic differentiation found between the WNP and ENP stocks provided convincing evidence that resulted in the TF providing unambiguous advice that the WNP stock should be recognized as a population stock pursuant to the GAMMS guidelines and the MMPA.

Additional research may narrow the uncertainty associated with the question of whether the PCFG should be recognized as a population stock. To work towards this objective, the TF recommended further investigation of recruitment into the PCFG. Presently, both the photo-identification and genetics data indicate that the levels of internal versus external recruitment are comparable, but these are not quantified well enough to determine if the population dynamics of the PCFG are more a consequence of births and deaths within the group (internal dynamics) rather than related to immigration and/or emigration (external dynamics). The TF offered a number of research recommendations, using the existing photo-identification and genetics datasets, that could provide increased resolution on the issue of recruitment and, in turn, the question of stock identification.

While the need for additional data collection was apparent, especially with regard to recruitment into the PCFG, the purpose of the workshop was for the TF to determine whether the *existing* best available science was sufficient to advise that the PCFG be recognized as a population stock under the language of the MMPA and GAMMS guidelines. Therefore, the advice of the TF offered in this report should be viewed as a contemporary "snapshot" taken from an emerging and ever-changing body of knowledge regarding the PCFG.

The TF emphasizes that the PCFG is relatively small in number and utilizes a largely different ecosystem from that of the main ENP stock. While the status of the PCFG as a population stock has yet to be resolved, continued research on these whales should be undertaken with particular attention dedicated to collecting data relevant to the question of stock identification.

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List of Acronyms

AFSC	Alaska Fisheries Science Center
ALJ	Administrative Law Judge
AWMP	Aboriginal Whaling Management Procedure
BRT	Biological Review Team
DIPs	Demographically Independent Units
DPSs	Distinct Population Segments
EIS	Environmental Impact Statement
ENP	Eastern North Pacific
ESA	Endangered Species Act
FEMAT	Forest Ecosystem Management Assessment Team
GAMMS	Guidelines for Assessing Marine Mammal Stocks
HCM	Human Caused Mortality
HWE	Hardy-Weinberg equilibrium
IR	Implementation Review
IUCN	International Union for Conservation of Nature
IWC	International Whaling Commission
K	Carrying Capacity
Makah U&A	Makah Usual and Accustomed (Fishing Ground)
MMC	Marine Mammal Commission
MMPA	Marine Mammal Protection Act
MNPL	Maximum Net Productivity Level
MSA	Magnuson-Stevens Act
MSYR	Maximum Sustained Yield Rate
mtDNA	Mitochondrial DNA
nDNA	Nuclear DNA
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
NPS	Northern Puget Sound
NWR	Northwest Regional Office
OPR	Office of Protected Resources
OSP	Optimum Sustainable Population
PBR	Potential Biological Removal
PCFG	Pacific Coast Feeding Group
SAR	Stock Assessment Report(s)
SEFSC	Southeast Fisheries Science Center
SJF	Strait of Juan de Fuca
SRG	Scientific Review Group
SWFSC	Southwest Fisheries Science Center
SVI	Southern Vancouver Island
TF	Task Force
UME	Unusual Mortality Event
WNP	Western North Pacific

1. Introductory Remarks

Dr. Lisa Ballance, Director of the Marine Mammal and Turtle Division at Southwest Fisheries Science Center (SWFSC), welcomed the workshop participants. She noted that this workshop represented a significant event, in that it: (1) brings agency scientists together to review research that continues to evolve and reveal unexpected patterns, (2) provides results that will be relevant to management activities for the National Marine Fisheries Service (NMFS), and (3) typifies the ideal model for how NMFS works, illustrating science addressing management actions and highlighting the collaboration between NMFS scientists, regional offices, and headquarters.

The technical and scientific expertise required on the Task Force (TF) was determined by SWFSC in consultation with the NMFS Northwest Regional Office (NWR) and the NMFS Office of Protected Resources (OPR). TF members were experts in their respective fields with ample experience and ability to bridge scientific and policy issues related to marine mammal stock structure. Members of the TF included the following eight NMFS scientists:

Dr. Shannon Bettridge	NMFS – Office of Protected Resources
Dr. Robert L. Brownell, Jr.	NMFS – Southwest Fisheries Science Center
Dr. Jeffrey L. Laake	NMFS – Alaska Fisheries Science Center
Dr. Jeffrey E. Moore	NMFS – Southwest Fisheries Science Center
Dr. Patricia E. Rosel	NMFS – Southeast Fisheries Science Center
Dr. Barbara L. Taylor	NMFS – Southwest Fisheries Science Center
Dr. Paul R. Wade	NMFS – Alaska Fisheries Science Center
Dr. David W. Weller (Chairman)	NMFS – Southwest Fisheries Science Center

In addition to the TF, a number of agency scientists and NMFS affiliates (e.g., post-docs, contractors, etc.) attended the workshop to observe and provide information. These participants included: Eric Archer (SWFSC), Lisa Ballance (SWFSC), Laurie Beale (NOAA General Counsel), Jim Carretta (SWFSC), Donna Darm (NWR), Kirsten Erickson (NOAA General Counsel - by phone), Jason Foreman (NOAA General Counsel), Annette Henry (SWFSC), Aimee Lang (SWFSC), Karen Martien (SWFSC), Sarah Mesnick (SWFSC), Phil Morin (SWFSC), Vicki Pease (SWFSC), Bill Perrin (SWFSC), Wayne Perryman (SWFSC) and Steve Stone (NWR). At the request of the TF, several of these participants provided valuable information to the workshop in the form of expert knowledge, presentations and/or written documents. Aimee Lang and Annette Henry generously agreed to serve as workshop rapporteurs.

The agenda for the workshop was circulated amongst the TF for input in advance of the meeting (Appendix 1). It was agreed, however, that the agenda would serve to guide the workshop proceedings but be viewed as flexible so as not to constrain discussion. Documents for the workshop were made available on a file sharing website. Appendix 2 provides a list of the workshop documents available for review and consideration by the TF in preparation for the workshop.

1.1 Workshop objectives

NMFS presently recognizes a single stock of gray whales (*Eschrichtius robustus*) in U.S. waters that is referred to as the eastern North Pacific (ENP) stock (Carretta *et al*. 2013). New information, however, suggests the possibility of recognizing two additional stocks of gray whales in U.S. waters, including: (1) the Pacific Coast Feeding Group (PCFG) - defined as whales observed between 1 June to 30 November within the region between northern California and northern Vancouver Island (from 41°N to 52°N) and photo-identified within this area during

two or more years (see section 3.3), and (2) western North Pacific (WNP) gray whales - defined as whales observed feeding during summer and fall off Sakhalin Island, Russia, and other areas in the WNP (see section 3.2). The main objective of the TF was to provide scientific advice regarding gray whale stock structure using the definitions given in the GAMMS guidelines (NMFS 2005; see also Moore and Merrick 2011). More specifically, the TF was convened to provide advice on two questions: (1) *Is the PCFG a "population stock" under the MMPA and GAMMS guidelines?*, and (2) *Is the WNP stock a "population stock" under the MMPA and GAMMS guidelines?* Both of these questions have immediate management implications, including: (1) how future NMFS stock assessment reports (SAR) will address gray whale stock structure in the North Pacific, and (2) how to interpret any new information in the context of the Makah Indian Tribe's MMPA waiver request to resume hunting gray whales off Washington State, USA.

1.2 Workshop relationship to stock assessment reports

At the request of the TF, Carretta (SWFSC) summarized the relationship of the workshop to future gray whale stock assessment reports (SARs). The current eastern North Pacific gray whale SAR (Carretta *et al*. 2013) provides a summary of present knowledge but is expected to evolve based on the input received at this workshop as well as from input from the scientific review groups (SRG)[1], NWR and OPR. The TF expected that the outcome of the workshop would influence how the SAR is structured in the future, including how various data sources (i.e., genetics, movements, distribution) are evaluated for future stock designation. The workshop report will also serve as a useful SRG background document on gray whale stock structure.

1.3 Workshop relationship to Makah waiver request

Newly available information from genetic, photo-identification and tagging studies suggests that more than one stock of gray whales may occur in U.S. waters (Lang *et al*. 2010; Frasier *et al.* 2011; Lang *et al.* 2011a; Lang *et al*. 2011b; Mate *et al*. 2011; Calambokidis *et al.* 2012; Weller *et al*. 2012). With that in mind, the TF requested that Darm (NWR) present a summary of the Makah Indian Tribe's request to hunt gray whales off northwest Washington State, USA.

The Makah's right to hunt whales is secured by the 1855 Treaty of Neah Bay, where the Makah ceded lands to the U.S. government but reserved the right to hunt, fish, seal and whale. The Ninth Circuit Court of Appeals decision in 2004 (Anderson v. Evans) held that for the Makah to exercise their right to hunt whales they must comply with the requirements of the MMPA. In 2005, the Makah requested authorization from NOAA/NMFS, under the MMPA and the Whaling Convention Act, to resume limited hunting of gray whales for ceremonial and subsistence purposes in the coastal portion of their usual and accustomed (U&A) fishing grounds off the coast of Washington State (NMFS 2008). The spatial overlap of the Makah U&A with the summer distribution of PCFG whales has management implications. The proposal by the Makah Tribe includes time/area restrictions designed to reduce the probability of killing a PCFG whale and to focus the hunt on whales migrating to/from feeding areas to the north.

The NWR was assigned responsibility for evaluating the Tribe's request under the MMPA and National Environmental Policy Act (NEPA) process. Section 101(a) of the MMPA imposes a

[1] Pursuant to Sec. 117 of the MMPA, independent scientific review groups, representing Alaska, and the Pacific and Atlantic coasts, were established in 1994. These groups consist of individuals with expertise in marine mammal biology and ecology, population dynamics and modeling, commercial fishing technology and practices, and stocks taken under section 101(b).

moratorium on the take of all marine mammals, although the statute provides for certain exemptions allowing the take of marine mammals. Section 101(a)(3)(A) allows for a waiver of the take prohibition; this exemption applies to a specific stock and is only authorized to the extent provided for in the waiver. Determination of whether the waiver will be granted must be made based on the best scientific information, in consultation with the Marine Mammal Commission, and with due regard to the distribution, abundance, breeding habits, and movements of the stock in question. For the waiver to be granted there must also be a finding that the requested take is in accord with sound principles of resources protection and conservation as provided for in the MMPA.

Unlike most rulemaking by the agency, this determination will entail a formal rulemaking process in which the agency presents evidence before an administrative law judge (ALJ) to support the rule. This process may involve presenting evidence on the status of relevant stocks, including their optimum sustainable population level (OSP)[2], and whether the stocks are at or below that level (i.e., depleted).

Although the NWR made substantial progress in evaluating the waiver request during the past few years, this progress had been slowed by: (1) new information pertinent to the question of whether the PCFG is a separate stock, and (2) the potential implications of movements of whales between the WNP and ENP. Therefore, the advice of the TF will provide a collective "best professional judgment" useful to the ongoing evaluation of the waiver by the NWR.

In discussion, the TF asked Darm if there would be a potential need to get more than one waiver to the MMPA if it was determined that three stocks of gray whales occur in U.S. waters (i.e., ENP, PCFG and WNP stocks). In that case, Darm replied that there would be some possibility of needing to request multiple exemptions (waivers). However, the need for a waiver would be informed by the likelihood of take and obtaining a waiver for WNP gray whales (if the group is recognized as a stock) is highly unlikely given that they are listed as endangered under the Endangered Species Act (ESA) and as such, would be considered depleted under the MMPA.

2. Overview of MMPA Language, GAMMS Guidelines and Related Key Concepts

From the outset of the workshop, the TF concurred that it was important to review the existing language of the MMPA and GAMMS with regard to the definition of "population stock". In addition, it was also agreed important to discuss three key concepts inherent to defining a population stock, including: (1) "demographic independence", (2) "interbreed when mature", and (3) "functioning element of the ecosystem".

Under the MMPA, population stock (used interchangeably with "stock" and "population" hereafter) is the fundamental conservation unit. The MMPA (Sec. 3) defines population stock as: "*a group of marine mammals of the same species or smaller taxa in a common spatial arrangement, that interbreed when mature.*" The purposes and polices underlying the stated definition, as follows, are found in Sec. 2(2) and Sec. 2(6) of the MMPA:

[2] The maximum net productivity level is described in the National Marine Fisheries Service's definition of "optimum sustainable population" (OSP) (50 CFR 216.3) as the abundance level that results in the greatest net annual increment in population numbers or biomass resulting from additions to the population due to reproduction and/or growth less losses due to natural mortality. Under the U.S. Marine Mammal Protection Act, populations above MNPL are considered to be at OSP; populations below MNPL can be designated as 'depleted' and are afforded a greater level of protection.

(1)*"[marine mammal] species and population stocks should not be permitted to diminish beyond the point at which they cease to be a significant functioning element in the ecosystem of which they are a part, and, consistent with this major objective, they should not be permitted to diminish below their optimum sustainable population."*

(2)*"… the primary objective of their management should be to maintain the health and stability of the marine ecosystem."*

Acknowledging the above definitions and objectives of the MMPA, the TF then considered the related guidelines contained in the "Definition of Stock" section of the GAMMS guidelines (NMFS 2005):

(1) *"For the purposes of management under the MMPA, a stock is recognized as being a management unit that identifies a demographically isolated biological population."*

(2) *"Demographic isolation means that the population dynamics of the affected group is more a consequence of births and deaths within the group (internal dynamics) rather than immigration or emigration (external dynamics). Thus, the exchange of individuals between population stocks is not great enough to prevent the depletion of one of the populations as a result of increased mortality or lower birth rates."*

The TF noted that within the broader field of population biology, the term "isolation" generally implies little or no exchange (emigration or immigration of individuals) between stocks and is a criterion commonly used to distinguish taxonomic units higher than that of a population (e.g., species, subspecies). In contrast, the GAMMS guidelines and definition of stock clearly allow for the "*exchange of individuals between population stocks"* (NMFS 2005), a distinction more in line with use of the term "demographic independence" rather than "demographic isolation". The use of the term "independence" as opposed to "isolation" is potentially confusing and has been noted by a number of NMFS reviewers and workshops (Eagle *et al*. 2008). To avoid this confusion, Eagle *et al*. (2008) suggested that the term "demographic isolation" be replaced by "demographic independence".

Moore (SWFSC) provided the TF with an overview of the GAMMS III workshop, convened by NMFS in February 2011, which also noted the potential confusion over the use of "isolation" as opposed to "independence". The GAMMS III workshop recommended revising the SAR guidelines to reflect that the intent of the GAMMS II guidelines (NMFS 2005) was to base stock identification on demographic independence as noted in Eagle *et al.* (2008) and proposed that the term demographic isolation be replaced with "demographic independence" as follows:

(1) *"For the purposes of management under the MMPA, a stock is recognized as being a management unit that identifies a demographically independent biological population."*

(2) *"Demographic independence means that the population dynamics of the affected group is more a consequence of births and deaths within the group (internal dynamics) rather than immigration or emigration (external dynamics). Thus, the exchange of individuals between population stocks is not great enough to prevent the depletion of one of the populations as a result of increased mortality or lower birth rates."*

In other words, the participants at the GAMMS III workshop viewed this as a semantic issue where the term demographic independence is a better description for the current GAMMS guidelines definition than is the term demographic isolation.

2.1 Discussion of "demographic independence"

This interpretation of "isolation" differs substantively from how it is used within the GAMMS guidelines definition above, wherein allowance is made for some level of exchange of individuals between stocks. The TF concurred that in spite of using the term "isolation", the actual definitions under the current GAMMS guidelines (see above) are more consistent with MMPA objectives to protect population stocks than with the objective of protecting just subspecies and species.

Given that the draft GAMMS guideline revisions from the GAMMS III workshop have not yet been formally approved, the TF agreed to use the current GAMMS guidelines definition (NMFS 2005) for the purposes of their discussions and deliberations but noted that the actual definition used in the two versions (for demographic isolation and demographic independence) is essentially the same in that neither implies true "isolation" within the context of the MMPA.

2.2 Discussion of "interbreed when mature"

Bettridge (OPR) presented a brief overview of relevant language under the MMPA and GAMMS guidelines pertaining to NMFS interpretation of "interbreed when mature". She explained that the draft second revision to the SAR guidelines (from the GAMMS II workshop held in Seattle in 2003) included a definition of interbreed when mature. This term was interpreted to mean cases in which either:

(1) "*mating occurs primarily among members of the same demographically isolated group*"

or

(2) "*the group migrates seasonally to a breeding ground where its members breed with members of the same group as well as with members of other demographically distinct groups which have migrated to the same breeding ground from a different feeding ground."*

When comments were solicited on the draft GAMMS II guidelines (69 FR 67541, 18 November 2004), the Marine Mammal Commission (MMC) supported the aforementioned interpretations, but suggested that a more rigorous analysis was needed of how the revisions fit with the language of the MMPA. Additionally, the MMC stated that NMFS should develop criteria for applying the modified guidelines to determine when a population is demographically isolated to an extent that it is a discrete group that warrants recognition as a separate stock.

In its response to comments on this issue (70 FR 35397, 20 June 2005), NMFS stated that public comments were sufficient to raise questions about the proposed interpretation, and the agency removed the proposed text pertaining to "interbreed when mature" from the final GAMMS II guidelines.

Subsequent NMFS review and consultation with MMC staff and NOAA General Counsel suggest that the GAMMS II workshop definition of "interbreed when mature" is consistent with NMFS GAMMS guidelines and the review undertaken in Eagle *et al.* (2008, see below). In those forums NMFS has consistently interpreted a population stock not as one that is completely reproductively isolated but rather as something less restrictive.

Regarding the MMC request for scientific criteria for how much interbreeding would be consistent with the proposed GAMMS II guidelines definition, the TF noted that specific quantitative criteria would be impractical to apply consistently across all contexts of uncertain stock definition and that determining whether a population is demographically independent or an isolated unit would likely have to be conducted on a case-specific basis. Some TF members felt

that the "interbreed when mature" component of the MMPA definition of stock should merely be viewed as a necessary but not sufficient criterion for defining a stock. In other words, individuals "in a common spatial arrangement" would not constitute a stock unless there is some interbreeding (satisfying the need criterion), but this would not preclude individuals of a stock from also breeding with members of other stocks.

For the purposes of the workshop, the TF agreed they would continue to interpret "interbreed when mature" consistent with "demographic independence" as suggested by Eagle *et al*. (2008) and GAMMS II (NMFS 2005), with the minor change of "isolation" being replaced with "independence".

2.3 Discussion of "functioning element of the ecosystem"

Sec. 2 of the MMPA states that marine mammals are "resources of great international significance, esthetic and recreational as well as economic" and "that the primary objective of their management should be to maintain the health and stability of the marine ecosystem". The TF therefore considered whether the functioning element of the ecosystem criteria is aesthetically or ecologically based (or both) but no clear resolution on how to best define functioning element of the ecosystem was reached by the TF.

The TF then focused its discussion on defining the ecosystem and appropriate scale of management with respect to gray whales. The TF agreed the matter was complex given the species' seasonal use of different ecosystems. In general, the TF agreed that the Chukotka Peninsula/Bering Strait feeding areas were not part of the same ecosystem as that found off the Pacific Northwest and used by the PCFG. In discussion of this concept, it was noted by some TF members that even for the largest-scale classification system for marine ecosystems (Longhurst 1998, discussed in Moore and Merrick 2011), it could be argued that the PCFG is in a different ecosystem than other gray whales. Other TF members pointed out, however, that this was only true for part of the year, and that the interpretation was complicated because non-PCFG animals migrate through the area defined for PCFG whales and, in some cases, may feed there in a given year but not return in a subsequent year.

2.4 Additional information on the definition of "population" for marine mammals

In addition to applying the MMPA language and GAMMS guidelines definitions, the TF considered two documents relevant to the question of stock definition under the MMPA. In the first (Taylor 1997), simulation analyses were used to explore the potential consequences, in terms of the risk of violating MMPA ecosystem function objectives, of defining a population stock as a unit akin to an evolutionarily significant unit or reproductively isolated group. Briefly, this analysis considered scenarios in which a single reproductively isolated population was distributed as a network of discrete groups occupying distinct habitat areas throughout its range, with some level of dispersal between discrete groups. The major analytical finding was that, if allowable human caused mortality (HCM) for the entire population (i.e., sum of all discrete groups) were to act disproportionately on certain groups, those groups could be extirpated, depending on whether the amount of immigration from other groups was below a certain dispersal rate threshold (which varied with simulation conditions). In conclusion, to achieve MMPA objectives of maintaining marine mammals as "functioning elements of their ecosystem", distinct groups should be managed as separate stocks if their connectivity to other groups via dispersal is low, although how low is context specific.

Taylor (1997) provides several examples (Figure 1) where localized removals lead to local extirpation which arguably violates the ecosystem goals of the MMPA. For all of the models tested, when dispersal fell below a few percentage of the population per year, recruitment into the population with HCM was insufficient to compensate for removal, and population levels declined below those sought by management objectives. Therefore, populations should be managed separately if dispersal between them is less than several percent per year.

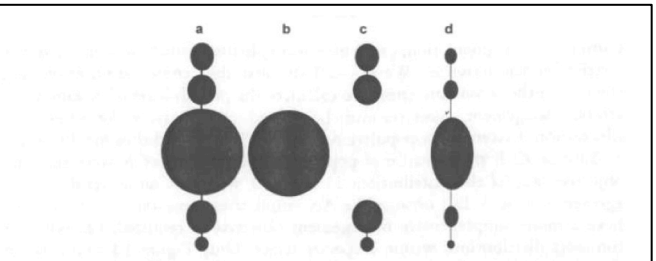

Figure 1. Distribution of pristine populations (a), versus potential distributions after 50% of the total abundance is removed (b–d). Width represents abundance; length represents distance.

Figure 1. Original figure from Taylor (1997).

Taylor (SWFSC) cautioned the TF, however, that it is impossible to have a "one number fits all" criterion and that a better approach would be to have an objective that states what is important in terms of maintaining the extent and connectivity of the range. There are some cases where it is obvious that a stock is no longer a functioning element of its ecosystem, such as example C in Figure 1 where the large central group is extirpated. Extirpation of the PCFG would be more analogous to removing one of the smaller groups outside of the main group (e.g., example B). Further discussion is needed to better define the intent of the MMPA with respect to maintaining marine mammals within different parts of their range.

The second document discussed by the TF, as pertains to the agency's definition of population stock, was the report of a 2006 workshop entitled "Conservation Units of Managed Fish, Threatened or Endangered Species, and Marine Mammals" (Eagle *et al.* 2008). This workshop was convened by NMFS with the objective of bringing together scientists, managers and policy advisers to discuss differences and recommend revisions to how NMFS defines units to conserve under three statutes – the MMPA, ESA and Magnuson-Stevens Act (MSA). The workshop sought to address two overarching questions: (1) why are conservation units different under the three statutes? and (2) is there a biological paradigm that can be used to explain the differences?

In brief, it was agreed by the participants of the 2006 workshop that the differences in how NMFS defines conservation units under the three statutes are appropriate given the differing objectives of the three laws. Under the ESA, major objectives are to prevent *species* extinction and preserve evolutionary potential. Thus, conservation units under this Act should be substantially reproductively isolated. Under the MMPA, objectives correspond to maintaining population and ecosystem goals. Therefore, conservation units align with demographically independent units (DIPs), which are demographically discrete from other populations but not necessarily genetically discrete due to a low but sufficient degree of interbreeding between them. Participants of the 2006 workshop concluded that while the GAMMS guidelines "*…clearly support the use of DIPs as stocks of marine mammals […] the MMPA does not indicate to what extent breeding should occur within a stock instead of among stocks*" and that future revisions to the GAMMS guidelines "*should, therefore, include a rationalization for recognizing DIPs as stocks in cases where males from one stock may breed with females from the same and other stocks*".

There was discussion amongst the TF regarding where to reasonably draw the line in defining small stocks, given that for some marine mammal species very small groups of animals could be

considered DIPs. For example, individual pods of killer whales (*Orcinus orca*) could potentially be considered demographically independent. However, other TF members noted that the intent of the GAMMS guidelines was not to recognize very small population units – such as individual killer whale pods or a small group of animals occupying a small habitat fragment – as population stocks. It was similarly suggested that other criteria besides demographic independence, such as whether the unit can be considered a significant functioning element of the ecosystem, should also be considered in defining stocks. The TF understood that most biological "populations" and "stocks" do not exist as truly distinct groups, nor are individuals within the same population typically part of a truly panmictic group (Waples and Gaggiotti 2006). Rather, population differentiation occurs along a continuum, and placing discrete boundaries along this continuum for management purposes is a challenge. The TF acknowledged that marine mammal social structure can further complicate determining whether a unit should be considered demographically independent. In these areas of uncertainty, decisions will likely be case specific, and ultimately rely on scientific judgment and the factors identified for consideration in the MMPA and GAMMS guidelines.

The TF considered the report by Eagle *et al.* (2008) and the recommendations from that workshop as support for the NMFS interpretation of "interbreed when mature" as one that includes cases where individuals interbreed primarily within their stock but occasional interbreeding amongst stocks may occur and agreed to use such as the operational definition for the purposes of their work.

3. Overview of Eastern, Western and Pacific Coast Feeding Group Gray Whales

Like many species of baleen whales, gray whales exhibit seasonal movements between high-latitude summer feeding grounds and low- latitude wintering areas. The current distribution of this species is limited to the North Pacific, where a small western population (<150 individuals) and a much larger eastern population (~19,000 individuals) are recognized.(Reilly *et al.* 2008).

Lang (SWFSC) presented a brief overview of information on the biology of ENP, WNP, and PCFG gray whales. The purpose of this overview was not to discuss gray whale stock structure in detail but rather to provide a summary of relevant background information.

3.1 Eastern North Pacific (ENP) gray whales

During summer and fall most ENP whales feed in the Chukchi, Beaufort and northwestern Bering Seas (Figure 2). An exception is the relatively small number (100s) of whales that summer and feed along the Pacific coast between Kodiak Island, Alaska and northern California (Darling 1984; Calambokidis *et al.* 2002; 2012; Gosho *et al.* 2011). By late November, the southbound migration of the ENP stock is underway as whales begin to travel from summer feeding areas to winter calving areas off the west coast of Baja California, Mexico (Rugh *et al.* 2001; Swartz *et al.* 2006). The southbound migration is segregated by age, sex and reproductive condition (Rice and Wolman 1971). The northbound migration begins about mid-February and is also segregated by age, sex and reproductive condition.

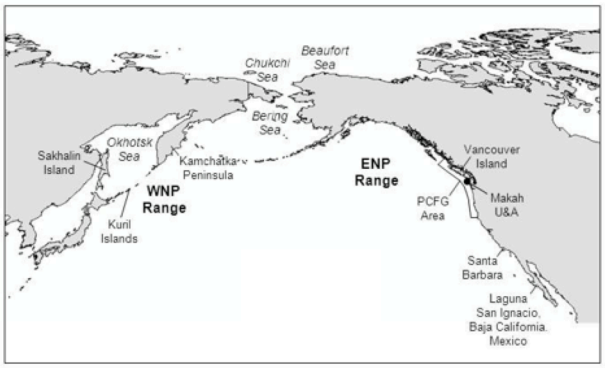

Figure 2. Geographic range of ENP, WNP and PCFG whales. In summer, WNP whales are typically found in feeding areas off the coasts of Sakhalin Island and the Kamchatka Peninsula, in Russia. Most ENP whales are typically found in summer north of St. Lawrence Island (in the northern Bering Sea), including the Bering Strait, the Chukotka Peninsula in Russia, the Chukchi Sea, and along the Beaufort Sea coast (north slope) of Alaska. Additional summer ENP feeding areas include Kodiak, AK, and areas between Southeast Alaska and Northern California. ENP whales migrate to the Baja Peninsula, Mexico in the autumn and return to feeding areas in the spring. The region used by the PCFG is defined to be the area between northern California and northern Vancouver Island (from 41°N to 52°N).

Gray whale breeding and calving are seasonal and closely synchronized with migratory timing. Sexual maturity is attained between 6 and 12 years of age (Rice 1990; Rice and Wolman 1971). Gestation is estimated to be 13 months, with calving beginning in late December and continuing to early February (Rice and Wolman 1971). Some calves are born during the southbound migration while others are born near or on the wintering grounds (Shelden *et al.* 2004). Females produce a single calf, on average, every 2 years (Jones 1990). Calves are weaned and become independent by six to eight months of age while on the summer feeding ground (Rice and Wolman 1971). Three primary calving lagoons in the ENP are utilized during winter, and some females are known to make repeated returns to specific lagoons (Jones 1990).

The abundance of the ENP population, which includes the PCFG, is presently estimated to be about 19,000 whales (Laake *et al.* 2012). The potential biological removal (PBR) level for the ENP stock of gray whales is calculated as the minimum (20th percentile) estimate of population size, times one-half of the maximum theoretical net population growth rate (½ x 6.2% = 3.1%), times a recovery factor of 1.0 for a stock above its maximum net productivity level (MNPL) (Punt and Wade 2012). The minimum population estimate (N_{MIN}) for the ENP stock is calculated from Equation 1 from the PBR Guidelines (Wade and Angliss 1997): $N_{MIN} = N/\exp(0.842\times[\ln(1 +[CV(N)]^2)]^{½})$. Using the 2006/07 abundance estimate of 19,126 and its associated CV of 0.071, N_{MIN} for this stock is 18,017. Therefore, PBR is 558 animals. A recent analysis conducted by Punt and Wade (2012) estimated a probability of 0.884 that the ENP gray whale stock is above its MNPL, which means there is a 0.884 probability that it is at its OSP as defined by the MMPA.

Genetic studies suggest some sub-structuring may occur on the wintering grounds, with significant differences in mitochondrial DNA (mtDNA) haplotype frequencies found between females (mothers with calves) utilizing two of the primary calving lagoons and females sampled in other areas (Goerlitz *et al.* 2003). Other research, employing both mtDNA and microsatellites, identified significant departure from panmixia between two of the lagoons using nuclear data, although no significant differences using mtDNA were observed (Alter *et al.* 2009). Significant mtDNA and nuclear (nDNA) genetic differences have been found between whales in the WNP and those in the ENP (LeDuc *et al*. 2002; Lang *et al.*, 2011b).

In discussion, the TF agreed that the information presented by Lang represented an up to date overview of the ENP population and had no follow up questions.

3.2 Western North Pacific (WNP) gray whales

Information on the distribution and migration patterns of gray whales in the WNP is incomplete. There is no doubt that the historical distribution of gray whales in the Okhotsk Sea once greatly exceeded what is found at present (Reeves *et al*. 2008). Today, the main feeding ground is in the Okhotsk Sea off the northeastern coast of Sakhalin Island, Russia (Figure 2) but some animals also occur off eastern Kamchatka and in other coastal waters of the northern Okhotsk Sea (Weller *et al.* 2002; Vertyankin *et al.* 2004; Tyurneva *et al.* 2010). Whales associated with the Sakhalin feeding area can be absent for all or part of a given feeding season (Bradford *et al*. 2008), indicating they probably use other areas during the summer and fall feeding period. For example, some whales observed off Sakhalin have been sighted off the northern Kuril Islands in the eastern Okhotsk Sea and Bering Island in the western Bering Sea (Weller *et al*. 2003).

The WNP migration route(s) and winter breeding ground(s) are poorly known (Weller *et al*. 2002; Weller and Brownell 2012). Information collected over the past century indicates that whales migrated along the coasts of Japan and South Korea (Andrews 1914; Mizue 1951; Omura 1984) to wintering areas somewhere in the South China Sea, possibly near Hainan Island (Wang 1984). At present, observations of gray whales off Japan are rare. Nambu *et al*. (2010) reported 13 known sighting or stranding records in Japanese waters between 1990 and 2007. Between 2005 and 2007, four female gray whales were fatally entrapped in set nets along the Pacific coast of Honshu, Japan. One of these females, entrapped in January 2007, was matched to earlier photographs of it as a calf (with its mother) while on the Sakhalin feeding ground in July and August 2006 (Weller *et al*. 2008). This match provided the most contemporary link between the summer feeding ground off Sakhalin and a winter location along the coast of Asia. More recently, in March 2012 a gray whale was sighted and photographed in Mikawa Bay (Aichi Prefecture), east of Ise Bay near Nagoya on the Pacific coast of Honshu (Japan Times, 3 May 2012).

Observations of gray whales in China are also exceptionally rare. Although 24 capture, sighting or stranding records exist since 1933 (Wang 1984; Zhu 2002), including observations of two mother-calf pairs, some of these (especially the sightings) have not been reported in sufficient detail to validate species identification. More recently, an 11.5 m female stranded live at Zhuanghe (Bohai Sea ca. 39˚N) in December 1996 (Zhao 1997) and a 13 m female gray whale was taken in fishing gear offshore of Baiqingxiang (Pingtan County), in the Taiwan Strait in November 2011 (Zhu 2012). The last known sighting of a gray whale off Korea was in 1977 (Park 1995).

The WNP gray whale population is redlisted by the IUCN as Critically Endangered. The most recent population assessment (for 2012), using a Bayesian individually-based stage- structured model, resulted in a median 1+ (non-calf) estimate of 155 individuals, with 95% CI = 142-165 (IUCN 2012). A collaborative Russia-U.S. research program on WNP gray whales summering off northeastern Sakhalin Island, Russia, has been ongoing since the mid-1990s. When data collected between 1994-2011 are combined, a catalog of 200 photo-identified individuals has been compiled. Beginning in 2002, photo-identification studies off Sakhalin have also been conducted by Russia scientists working with oil and gas companies (Tyurneva *et al*. 2010). This research largely corroborates the work of the Russia-U.S. team and in some cases collaborative analyses utilizing combined datasets have been conducted.

Recently, results from photo-identification (Urbán *et al.* 2012; Weller *et al.* 2012), genetic (Lang 2010; Lang *et al.* 2011b), and telemetry studies (Mate *et al.* 2011) have documented spatial and

temporal overlap between WNP and ENP gray whales. Observations of such overlap include: (1) six whales photographically matched from Sakhalin Island to southern Vancouver Island, (2) two whales genetically matched from Sakhalin to Santa Barbara, California, (3) 13 whales photographically matched from Sakhalin Island to San Ignacio Lagoon, Mexico, and (4) 2 satellite tagged whales that migrated from Sakhalin Island to the west coast of North America. In combination, these studies have recorded a total of 23 gray whales observed in both the WNP and ENP. Despite this overlap, significant mtDNA and nDNA differences are found between whales in the WNP and those summering in the ENP (Lang *et al.* 2011b). Although it is clear that some whales feeding off Sakhalin Island during the summer/fall migrate to the west coast of North America during the winter/spring, past and present observations of gray whales in the WNP off Japan, Korea and China during the winter/spring suggest that not all gray whales in the WNP share a common wintering ground (Weller and Brownell 2012).

In discussion, the TF agreed that the occurrence of WNP gray whales in U.S. waters presented previously unexpected implications with respect to the SAR process and the Makah waiver request. More specifically, two questions were discussed at length, including: (1) given the occurrence of WNP gray whales in U.S. waters, is a WNP gray whale SAR required? and (2) given the potential occurrence of WNP gray whales in the proposed Makah hunt area, what are the implications regarding the existing wavier request?

TF members also noted that these new findings of gray whales moving between Sakhalin Island and the ENP had significance to our understanding of the status of gray whales in the WNP. That is, given that some of the whales sighted off Sakhalin appear to overwinter in the ENP, the number of animals remaining in the WNP year-round may be much smaller and of greater conservation concern than is currently recognized (Weller and Brownell 2012).

3.3 Pacific Coast Feeding Group (PCFG)

Gray whales using the Pacific Northwest area during summer and autumn include two components: (1) whales that return frequently and account for most of the sightings between 1 June and 30 November, and (2) whales that are sighted only in one year, tend to be seen for shorter time periods in that year, and are encountered in more limited areas. For the purposes of their work to evaluate the proposed Makah Indian Tribe gray whale hunt, the International Whaling Commission (IWC) defined PCFG gray whales as: whales observed between 1 June to 30 November within the region between northern California and northern Vancouver Island (from 41°N to 52°N) and photo-identified within this area during two or more years (IWC 2011; IWC 2012a). This same definition has been adopted in the analyses of Calambokidis *et al*. (2012). In this report, the TF defines "PCFG whales" following the IWC definition.

Recent research has provided new information on movements and habitat utilization of PCFG whales (for example Frasier *et al.* 2011; Lang *et al.* 2011a; Calambokidis *et al.* 2012). While PCFG whales are known to feed during summer and fall off the Pacific coast between northern California and southeastern Alaska, they also occasionally occur as far north as Kodiak (Gosho *et al.* 2011) and Barrow, Alaska (Calambokidis *et al.* 2012). The sighting from Barrow suggests that some PCFG whales (meaning whales seen in summer in the defined area used by the PCFG and in more than one year), at least occasionally occur in one of the most northern gray whale feeding areas in the ENP (Calambokidis *et al.* 2012). Similarly, of the 121 whales identified off Kodiak from 1998-2010, there have been 30 sightings of 17 individuals between June-November in areas extending from northern California to northern British Columbia (Table 9, Calambokidis

et al. 2012). These observations indicate that at least some PCFG whales have used both the Kodiak feeding area in addition to the 41°N to 52°N area defined for the PCFG.

Satellite tagging studies between 3 September and 4 December 2009 off Oregon and California provide additional movement data for whales considered to be part of the PCFG (Mate *et al.* 2010). While duration of tag attachment differed between individuals, some whales remained in relatively small areas within the larger PCFG seasonal range while others traveled more widely. All six individuals whose tags continued to transmit through the southbound migration utilized the wintering area within and adjacent to Laguna Ojo de Liebre (Scammon´s lagoon). Three whales were tracked north from Ojo de Liebre and displayed the following movement patterns: (1) one whale traveled at least as far as Icy Bay, Alaska, and (2) two whales were tracked to coastal waters off Washington (Olympic Peninsula) and California (Cape Mendocino). In combination, satellite tag and photo-identification data suggest that the range of the PCFG may, at least for some individuals, exceed the pre-defined 41°N to 52°N boundaries that have been used in a number of PCFG-related analyses (e.g., abundance estimation).

Further support of the PCFG range extending beyond the pre-defined 41°N to 52°N boundaries comes from a study of six whales satellite tagged off the central west coast of Vancouver Island in March. This study was designed to determine northern migration routes in the greater Vancouver Island area (Ford *et al.* 2012). Three of the tagged whales had been previously sighted within the seasonal range used by PCFG whales (41°N to 52°N) and two had multi-year sighting histories there. These three whales moved north to between ~55°N to 57° N before their tags stopped transmitting. One of these whales was later observed in the seasonal range of the PCFG off southern Vancouver Island. These findings suggest that in the spring at least some PCFG whales may migrate northward, past the defined seasonal range used by the PCFG, along with the larger ENP stock before "circling back" to within the range of the PCFG summer feeding area.

It is unknown how long gray whales have used the PCFG area in summer and autumn; it may have been colonized as recently as the last century or during the Little Ice Age (~1540-1850) or other glacial periods when it was difficult or impossible for gray whales to feed further north. Records of gray whales feeding between northern California and Alaska during summer/fall date back to at least 1926 (Howell and Huey 1930), including reports of whales feeding on the southern feeding ground during the 1940s, 1950s, and 1960s (Gilmore 1960; Pike and MacAskie 1969; Rice and Wolman 1971). The consistent return of individuals to the southwestern coast of Vancouver Island, British Columbia, was first documented in the early 1970s (Hatler and Darling 1974).

A unique characteristic of PCFG whales is an apparent flexibility in their feeding habits. That is, whales summering in the seasonal range of the PCFG consume a varied diet including mysids, amphipods, crab larvae, and herring eggs/larvae. This is in contrast (generally speaking) to gray whales feeding in the arctic where they seem to be more focused on an amphipod food base (Nerini 1984). That being said, whales that utilize the seasonal range of the PCFG in only a single year (i.e., non-PCFG whales) must also be flexible, at least to some degree, in their feeding habits.

Abundance estimates of PCFG gray whales reported by Calambokidis *et al.* (2012) show a high rate of increase in the late 1990s and early 2000s, but have been relatively stable, albeit with some decline, since about 2003. No statistical analysis of trends in abundance is currently

available for this population. The PCFG is estimated to contain about 200 individuals (Calambokidis *et al*. 2012). As stated in the 2012 gray whale SAR "because the PCFG appears to be a distinct feeding aggregation and may warrant consideration as a distinct stock in the future, a separate PBR was calculated" (Carretta *et al*. 2013). Calculation of a PBR for the PCFG allows NMFS to assess whether levels of HCM are likely to cause local depletion of this group. In keeping with that management objective, NMFS used the 2008 abundance estimate of 194 (SE = 17.0)[3] from Calambokidis *et al*. (2010) and the range of the PCFG (between 41°N to 52°N) as defined by the IWC to calculate a potential PBR for PCFG whales (Carretta *et al*. 2013). This calculation used the minimum population size (180 animals), times one half the maximum theoretical net population growth rate (½ x 6.2% = 3.1%), times a recovery factor of 0.5 (for a population of unknown status), resulting in a PBR of 2.8 animals (NMFS 2012). Further, a review of annual HCM in the PCFG between 2006 and 2010 was estimated and averaged 0.6 animals/year known deaths (Carretta *et al*. 2013).

In discussion, the TF asked Lang if there was any evidence that oceanographic changes have influenced the abundance or recruitment of whales into the PCFG. Lang replied that Calambokidis *et al.* (2012) reported a higher than usual "pulse" of animals recruited into the PCFG in the years following the 1999-2000 gray whale Unusual Mortality Event (UME). This UME has been theorized to be the result of limited food resources on the northern feeding grounds (see Gulland *et al.* 2005), and as such, this "pulse" of gray whale immigration[4] into the PCFG could potentially be considered a response to oceanographic changes. Given that the photo-identification effort on PCFG whales expanded greatly in 1998 (data from years prior to 1998 exist but not at the same level of effort), coinciding closely in time with the UME, it makes it impossible to resolve with certainty the occurrence or magnitude of the hypothesized pulse recruitment.

In response to the observations of PCFG whales in northern areas such as Kodiak and Barrow, Alaska, some members of the TF asked why the boundaries of the PCFG area defined by the IWC were not extended further north? The TF noted that the IWC definition was not intended to define the stock but rather to provide a conservative basis on which to evaluate the gray whale hunt proposed by the Makah Indian Tribe. With respect to low survey effort north of 52°N, the TF agreed that the PCFG could have a higher abundance than currently estimated and that this might affect a number of analyses including determination of annual sighting patterns of individual whales (e.g., a PCFG whale may have been present in a larger area but not photographed because it was located in an region not surveyed). The TF concurred that these issues are important to assignments of PCFG whales (i.e., those seen in two or more years between 41°N and 52°N) and highlighted the importance of expanding the spatial and temporal coverage of the photo-identification effort. In addition, further satellite tagging of known PCFG whales would also help to better define habitat use and delineate the seasonal feeding range.

Additional discussion was devoted to addressing the possibility that HCM (e.g., ship strikes and commercial fisheries bycatch) for whales in the PCFG area could be higher than for whales that migrate through the area. That is, PCFG whales spend more time near shore where ship traffic and fishing gear are concentrated. Despite this concern, little information is available on where

[3] This estimate will be updated in the 2013 SAR to include the now available 1999-2010 time series presented in Calambokidis *et al*. (2012).

[4] Immigration, as used here, means a permanent change of feeding ground fidelity and is considered interchangeable with "external recruitment".

HCM actually occurs. The TF asked Carretta how whales were classified as being PCFG in his analysis. He replied that the estimate was based on NMFS stranding data for the most recent 5-year period and included whales that stranded within the defined PCFG time period (1 June and 30 November) and range (41°N to 52°N). Carretta noted that his estimate of 0.6 animals/year, based on only the most current 5-year period (as per protocol of the SAR guidelines), is lower than the 20-year average of 1.5 animals/year reported elsewhere (IWC 2012a). The TF agreed that both of these estimates of HCM for the PCFG were likely to represent minimum estimates because there is no correction for incidents that go unobserved or unreported.

Related to the issue of HCM, the TF also discussed the results presented in Connor *et al.* (2011), which found that PCFG whales had higher rates of scarring than other gray whales. It was noted that crab pots are common off the Washington and Oregon coasts and as such may pose an increased threat in some parts of the PCFG range. Carretta noted that when looking through the HCM records, a fair number of southern California crab pot interactions were reported, which suggests that fisheries interactions of this nature could be a pervasive issue along the coast. The TF noted that PCFG animals could have more interactions (compared to non-PCFG whales) with crab pots and coastal fishing gear given their extended residency in nearshore areas. Therefore, the TF recommended that the existing photo-identification time series be used to examine scarring patterns of PCFG whales to possibly provide a better assessment of their interactions with fishing gear.

4. Population Dynamics of the Pacific Coast Feeding Group

Laake (AFSC) provided a summary of information regarding the PCFG (following the IWC definition) based on photo-identification research as described in Calambokidis *et al.* (2012). Photo-identification studies from 1998 to 2010 between northern California and northern British Columbia have categorized gray whales using that region during summer and autumn in two components: (1) whales that frequently return to the area, are seen in more than one year between 1 June and 30 November, and account for most of the sightings during that time period, and (2) whales that are sighted only in one year, tend to be seen for shorter time periods in that year, and are encountered in more limited areas.

4.1 Definition of Pacific Coast Feeding Group whales based on timing and area

Defining the PCFG involves analysis that spans both time and space. The temporal component of the PCFG range is better defined than the spatial component, but neither can be considered absolute. As mentioned previously, the IWC defines the PCFG as: gray whales observed between 1 June to 30 November within the region between northern California and northern Vancouver Island (from 41°N to 52°N) and photo-identified within this area during two or more years (IWC 2012a). The spatial boundaries of the PCFG range under the IWC definition were chosen for the following reasons: (1) samples used for the genetic analyses were taken from whales across this range, (2) the work of Calambokidis *et al.* (2012) showed movements of whales throughout the area (Figure 3), (3) only a small number of PCFG whales have been observed north or south of the area during the 1 June to 30 November time period, and (4) few if any whales are still migrating north through the 41°N to 52° N region from 1 June to 30 November. The temporal definition (1 June to 30 November) was based, in part, on the disparity in sighting rates across months. Whales observed after 1 June were more likely to be sighted (i.e., photographed) more than one time, in more than one year, and in more than one region (Figure 4).

In discussion, the TF asked whether the results presented in Figure 3 were effort-corrected. Laake explained that the proportions are only dependent on the effort in the region from the Makah U&A to Southern Vancouver Island (SVI) and not in the other areas. Variation in effort in areas outside of the Makah U&A-SVI region will change the sample size that could be detected in the Makah U&A-SVI but not the proportion of individuals resighted in the Makah U&A-SVI.

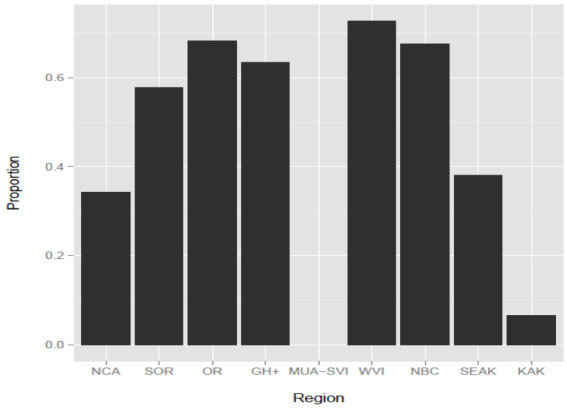

Figure 3. Proportion of whales sighted in the MUA-SVI region of whales seen in the identified areas. MUA and SVI were collapsed due to their proximity and high exchange rate. NCA = Northern California, SOR = Southern Oregon, OR = Central Oregon, GH+ = Gray's Harbor and surrounding coastal waters, MUA-SVI – Makah Usual and Accustomed Area to Southern Vancouver Island, WVI = West Vancouver Island, NBC = Northen Vancouver Island and coastal areas of British Columbia, SEAK = Southeast Alaska, KAK = Kodiak, Alaska.

The spatial range of PCFG whales was then discussed by the TF, including apparent gaps in survey coverage. Surveys in the seasonal range of the PCFG tend to focus on regions where gray whales have been seen and so the surveys are not randomly designed to cover the entire possible range. There is a large gap in survey effort north of 52° N (i.e., between northern Vancouver Island and Kodiak, Alaska). Because only a limited amount of gray whale survey effort has been undertaken in this region, it is unknown whether this area represents a true distributional gap. Even with this limitation, it is nevertheless possible to document observed movements of known individuals and estimate a related minimum range. Figure 5 presents the observed range of maximum distances between sighting locations for individual whales. Overall, approximately 40% of PCFG whales are known to have utilized areas spanning at least one degree of latitude. Further, there are documented movements of PCFG whales to Kodiak (Gosho *et al.* 2011) and Point Barrow, Alaska (Calambokidis *et al.* 2012), in years they were not seen in the PCFG area. Finally, information from tagging (see section above) also supports the idea that the range of some PCFG whales extends outside of the presently defined boundaries.

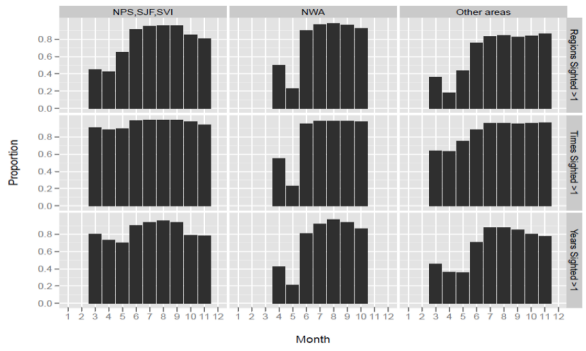

Figure 4. Proportion of whales sighted in more than one region (top), on more than one day (center) and in more than one year (bottom) as defined by the region and month they were seen. NPS = Northern Puget Sound, SJF = Strait of Juan de Fuca, SVI = Southern Vancouver Island, NWA = Northern Washington Coast.

It was noted by the TF that site fidelity of known reproductive mothers to the WNP Sakhalin Island feeding area is very strong (Weller *et al.* 2002). The TF therefore recommended that the existing PCFG photo-identification data be examined to see if moms/calves demonstrate higher levels of fidelity than other whales.

4.2 Pacific Coast Feeding Group abundance and survival

The photo-identification data collected annually in the seasonal range of PCFG whales (following the IWC definition) between 1998 and 2010 have been used to estimate abundance. In these analyses, the term "transient whale" was used to refer to whales seen in only one year and never seen again in any other year, and "non-transient whale" was used to refer to whales seen in at least two years, such that an estimate of the number of non-transient whales would be equivalent to an estimate of the number of whales defined to be in the area used by the PCFG. The total number of gray whales in the area used by the PCFG in summer would include both transient and non-transient whales, and is therefore higher than the number of defined PCFG whales in the area. In the following discussion of abundance estimates, whether an estimate is biased or not is relative to the true number of defined PCFG whales (not to the total number of gray whales in the area).

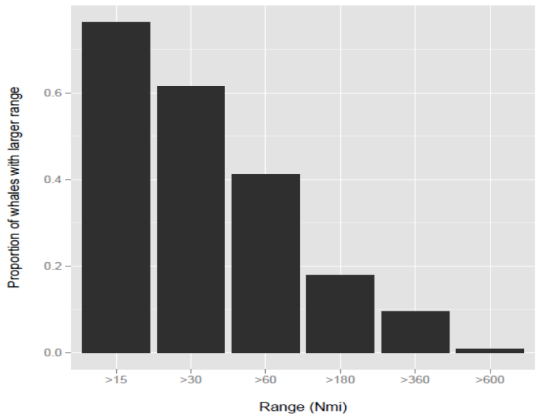

Figure 5. Distribution of maximum distance, in nautical miles, between photo-id locations for PCFG gray whales during 1 June – 30 November 1998-2010. The distance for 40% of the whales exceeded 1 degree latitude (60 nautical miles).

A number of different estimators were used including: (1) Lincoln-Peterson (LP), (2) Limited Lincoln-Peterson (LLP), and (3) Modified Jolly-Seber (JS1). The first two estimators constructed estimates from consecutive years of data. The LP estimator assumes a closed population and is unbiased if there are only losses or only gains. There are both losses and gains to the PCFG due to transient whales and therefore induces a positive bias. The LLP estimator removes the positive bias of the LP estimator by restricting the data to whales seen during the 2-year period but also in another year prior or after the 2-year period. This restriction eliminates whales that were transients in either of the years. The JS1 estimator is an open population model that estimates the abundance of non-transient whales. A fourth estimator, JS2, is an alternate JS modification that produced similar results except at the end of the time series (Calambokidis *et al*. 2012).

Calambokidis *et al.* (2012) considered the JS1 estimator to be the best suited for analysis of the PCFG (Figure 6). The Jolly Seber 1 (JS1) estimator assumes that any gray whale joining the PCFG is seen the first year it enters. The assumption is made to model the data adequately with the strong relationship between minimum tenure (time between first and last sighting in the year) and the probability it remains in the PCFG. The magnitude and trend of the LP abundance estimates do not match up well with the limited LP and the JS1 estimates; this is due to the fact that the LP

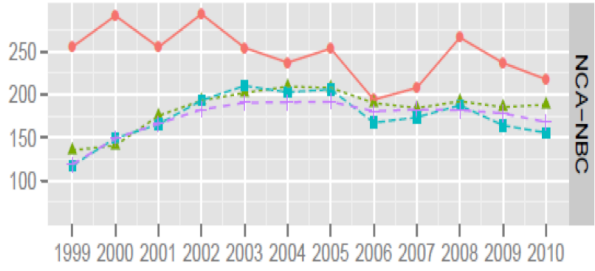

Figure 6. Estimates of the abundance of PCFG gray whales between northern California and northern British Columbia (NCA – NBC) using four different estimators based on photo-id data collected annually between 1998 and 2010. LP = Red Circle, JS1=Green Triangle, LLP=Blue Square, JS2=Purple Dotted Line

estimator was positively biased and the bias was greater at the beginning of the time series when there was more immigration and emigration into and out of the area used by the PCFG.

In discussion, the TF focused on whether the increase in the JS1 abundance estimates from 1999-2002 (Figure 6) was real or a reflection of the discovery of "new" whales that were present in the area used by the PCFG but not observed (i.e., photographed). Some of that discussion also focused on the related topic of recruitment described below. Laake responded that there were 13 whales not sighted in 1998 that were seen after 1998 (most of them were sighted in 1999) and were in the catalog for sightings prior to 1998. These results indicate that the assumption of JS1 (i.e., that any gray whale joining the PCFG is seen the first year it enters) was not met entirely. That being said, Laake argued that the bias was small or negligible after 1999 for the following reasons: (1) values from the JS1 estimator correspond closely to the value from the limited LP estimator which does not make the same assumption, (2) simulation results using similar values for capture probability estimated from the data showed a minimal amount of bias after 1999, and (3) the UME in 1999-2000 provides a plausible explanation for the coincident increase in PCFG abundance.

4.3 Pacific Coast Feeding Group IWC implementation review

Wade (AFSC) presented a brief overview of the status of the Implementation Review (IR) process conducted by the IWC. The IR includes trials based on three hypotheses: (1) Hypothesis P (Pulse) assumes that there is no bias in the PCFG abundance estimates (but dropping 1998) and that a pulse of immigration occurred in 1999 and 2000; (B) Hypothesis B (Bias) assumes a strong time-varying bias in the abundance estimate but no pulse of immigration; and (3) Hypothesis I (Intermediate) includes a moderate time-varying bias in the abundance estimates and a pulse of 10 immigrants into the PCFG in both 1999 and 2000. These hypotheses were evaluated because the model used in the IWC IR trials could not produce simulated abundance trajectories that fit the abundance estimates without incorporating a pulse or a bias into their model. For these trials the IWC Scientific Committee agreed that a sufficient fit to the data could be achieved with maximum annual immigration of up to six animals.

Wade noted that for the most part there was broad similarity between the population trajectories in the IWC trials and the population trajectories in the OSP determinations performed by Moore and Punt (pers. comm.), which only use Hypothesis P (a pulse of immigrants in 1999 and 2000, see related item below). The IWC implementation trials produce final statistics related to conservation status and catches.

There was some discussion about the need to evaluate trials that produced worrying conservation statistics and that it would be valuable to look at what the depletion level could be in those trials. Wade noted that the trials incorporating a low growth rate with little immigration or the trials in which the probability of taking a PCFG whale were doubled were the trials which do not do well with respect to conservation statistics such as final depletion level. Note that "final depletion level" is defined by the IWC to be the final population level as a percent of K. This is related to, but can be slightly different from, the U.S. MMPA definition of "depletion", which is defined to be a population level below the Maximum Net Productivity Level (MNPL). In U.S. MMPA depletion determinations, MNPL is generally assumed to either be a range from 50-70% of K, or a single value such as 50% or 60% of K. The only practical difference occurs when a range is used in MMPA determinations, where one calculates the probability a population is below MNPL over a range of percentages of K. If a single value is used for MNPL (e.g., 60%), than the IWC final depletion level is identical.

Some of the simulations conducted by the IWC with worrisome conservation performance (with respect to final depletion below 60%) are those using Maximum Sustained Yield Rate (MSYR) of 1% or 2%, implying a relatively low maximum population growth rate (Annex E, IWC 2012b). Note that the IWC Scientific Committee parameterizes population models with MSYR rather than Rmax (used in U.S. MMPA calculations). MSYR is the population growth rate at the Maximum Sustained Yield level, which is equivalent to MNPL if human-caused removals are unbiased with respect to age. Therefore, if MNPL is 50% of K, a population with an MSYR of 2% has an Rmax of 4%, and a population with an MSYR of 1% has an Rmax of 2%. Taylor noted that although she would have initially thought population growth rates that low were unlikely, after seeing some of the results presented she felt that relatively low population growth rates cannot be ruled out. She also noted that all trials in the table (which was a summary of trials that performed poorly with respect to conservation statistics) have annual immigration = 0 to 2, at the low end of the range considered. It appears that rates of annual immigration higher than 2 provide just enough of an offset to low MSYR rates of 1 or 2%.

The TF asked how the rescaled final depletion level was related to final depletion level in the IWC results. The rescaled final depletion statistic is used by IWC in trials whose specifications cause the population to decline even in the absence of catches. To evaluate those trials, the final population level for the trial (with catches) is compared to the final population level that would have been obtained in the absence of catches. That ratio is termed the rescaled final depletion, and represents the fraction of the population size that would have been obtained in the absence of catches. Since a low MSYR rate results in low population growth, the IWC found it is useful to compare depletion levels both with and without catches. The rescaled final depletion results for the PCFG only differ from the final depletion statistic for trials with a low value for MSYR, where the PCFG would decline and become depleted regardless of whether a hunt occurred due to the combination of a low population growth rate and bycatch.

4.4 Pacific Coast Feeding Group recruitment

Although new whales are identified each year in the range of the PCFG, about 50% of these individuals are seen in only one year and considered "transients" or "visitors" (Figure 7). Other whales are resighted in subsequent years and are considered "recruits" into the PCFG. Whales with a longer minimum tenure in the first year they were sighted have higher first year apparent survival and higher probability of return (i.e., do not permanently emigrate). This relationship might be expected given a hypothesis that whales are more likely to return if they find a suitable prey base during their first year in the seasonal range of the PCFG.

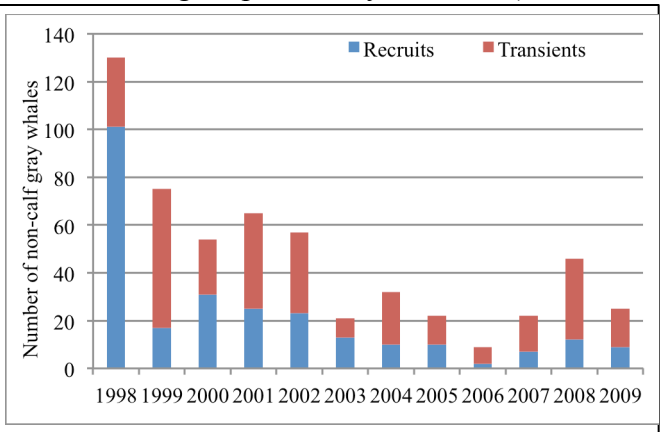

Figure 7. Number of "new" whales seen each year in the PCFG area that are transients (only seen in one year) and recruits (seen in more than one year).

Whales that recruited into the PCFG in 1999 or a subsequent year had lower first year apparent survival than whales that were first identified in 1998. Approximately 75% of the whales whose minimum tenure was 100 days or more in 1999 or later were resighted in a following year. For whales identified in 1998 (the first year of the study) whose minimum tenure was 100 days, nearly 100% were

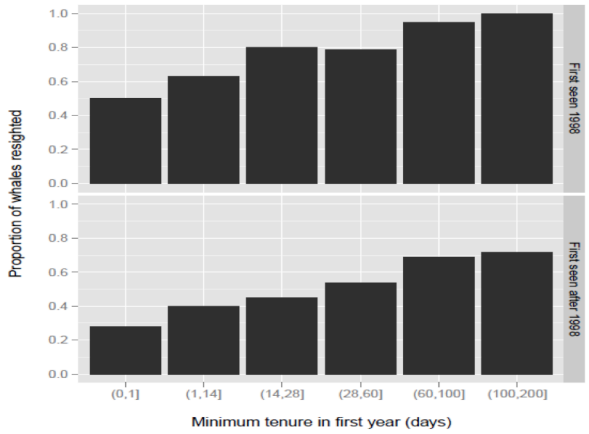

Figure 8. Relationship between minimum tenure in first year (# of days between first and last sighting plus 1) and the proportion resighted in at least one following year. The data series starts in 1998 so all whales are "new" so while the pattern is similar, the proportions are higher for 1998 because most whales are not truly new to the PCFG.

resighted in a following year (Figure 8). This suggests that some of the animals that recruited into the PCFG in 1999 or later may have subsequently emigrated out; this could explain why the abundance has declined somewhat in the later years (Figure 6). The high number of new whales identified in the seasonal range of the PCFG between 1999 and 2002 is hypothesized to have been in response to the 1999-2000 UME.

The TF discussed several alternative explanations for the relatively high numbers of recruits into the PCFG in the early part of the time series (1999-2002). For example, whether the increase in abundance during early years could be due to a "discovery" effect, such that it took a number of years for all the whales which were part of the PCFG to be photographed and "discovered". Alternatively, the heterogeneity in survey coverage over time and space could lead to some animals being considered "new" in a given year even if they had been utilizing areas with limited or no survey coverage in previous years. However, overall capture probabilities are high, suggesting it is unlikely a whale would be in the area for several years and not photographed. The TF concurred that on an annual basis, whales observed in the area used by the PCFG could be characterized as a collection of individuals whose residence patterns vary along a continuum such that some whales use the area for a single year (e.g., transients), some for a few years, and others on a consistent long-term basis.

By way of an analogy, Laake characterized the PCFG as a "leaky bucket", in that some whales are immigrating in while others are emigrating out. The "leaky bucket" phenomenon is not a random process, however, because a "core group" of whales appear to stay in the bucket over time. The dataset cannot discriminate between PCFG whales that die versus those that emigrate. Animals that recruit into the PCFG as non-calves may be more likely to emigrate out of the area than calves recruited to the PCFG in the year they were born. That is, calves of the year have been taught to feed on prey types common to the PCFG area (various swarming prey for instance) by their mothers and may obtain "local knowledge" that allows them to be successful long-term inhabitants of the PCFG area. To evaluate this, the TF recommended that the existing PCFG photo-identification time series be examined to see if moms/calves demonstrate higher degrees of fidelity than other whales.

In thinking about the "core group" of PCFG whales that return to the area on a consistent basis, the TF questioned if biopsy efforts in the area could be potentially biased towards these whales. If sampling efforts are unintentionally concentrating on the "core group" of PCFG whales, then the results of genetic comparisons may be driven by matrilineal fidelity of this "core group". In addition, the biopsy efforts are not spread evenly over time and space (more heterogeneity than the photo-identification survey efforts). If "core group" animals predominantly use the areas with high biopsy effort, then this potential bias could be magnified.

Some newly seen whales are calves with their mothers (Figure 9). As described in Calambokidis *et al.* (2012), much of the sighting effort occurs in August and later when many calves are likely to already be weaned and thereby more difficult to identify as a calf (versus a yearling). The TF noted that many of the whales identified as calves off Sakhalin Island in the WNP are not resighted for many years subsequent to their birth year but eventually they are again resighted in the area. This pattern suggests that young animals (1+ years old) may use other areas to feed during their first several years. Therefore, in the case of the PCFG, if a whale was not seen as a calf but returned in a later year it would appear to be an external rather than internal recruit. With that in mind, the TF recommended that the existing PCFG photo-identification time series be examined following a protocol developed by Bradford et al. (2011) that uses barnacle and pigmentation characteristics on young gray whales to reliably distinguish calves of the year from yearlings.

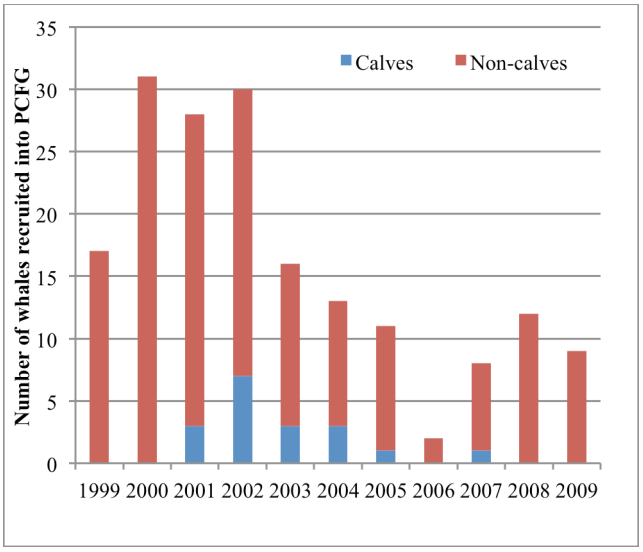

Figure 9. Number of whales first seen and recruited (seen in a following year) by year and calf and non-calf designation.

In summary, the TF discussion about the magnitude and source of recruitment into the PCFG focused on: (1) incomplete survey coverage of the entire seasonal range used by the PCFG and the potential for whales to be missed and then "recruited" in a subsequent year, (2) the proportion of "recruited" whales that were calves of mothers from the PCFG that may have been missed as a calf or misidentified as an external recruit, (3) the potential of the 1999/2000 UME to create a pulse of immigration into the PCFG, (4) to what degree gray whales recruited in 1999 or later were either emigrating back to the northern feeding areas or experiencing higher mortality, and (5) whether the biopsy sampling effort was prone to sample whales that spent more time in the range used by the PCFG.

All of these issues are relevant to assessing the amount of external recruitment into the PCFG and thereby especially pertinent to determining if it should be recognized as a population stock under the MMPA and GAMMS guidelines. That is, if the PCFG experiences little external recruitment then it would be considered demographically independent and should be recognized as a stock. If most of the recruitment into the PCFG were external, however, then it would not be considered demographically independent and would not be recognized as a stock. The TF concurred that the resolution of the existing photo-identification data in combination with uncertainly surrounding the accuracy of assigning whales as external or internal recruits prevent this question from being fully resolved. Increased genetic sampling in tandem with increased photo-id effort over both space and time may be the only way to better address this question.

4.5 Pacific Coast Feeding Group trend and optimum sustainable population determination

Moore presented an update on work he conducted in collaboration with Andre Punt (University of Washington) to determine if the PCFG, as a putative stock, is at OSP. The OSP assessment is based on the two-stock population model that has been developed as part of the IWC gray whale

Implementation Review (see section 4.3). Both assessments use the same definition for a PCFG whale. There are some differences, however, between the IWC model framework and the one used for the OSP assessment. First, in the OSP analysis, a Bayesian approach is used in which prior distributions are specified for input parameters and the time series of abundance estimates (for the ENP and PCFG) are used to the update priors and output posterior distributions. This contrasts with the IWC approach of generating outputs for many models each based on alternative fixed combinations of values for some parameters. Second, the IWC trials consider several hypotheses that attempt to explain the rapid increase in abundance estimates in the first few years of the time series; these include bias in the early abundance estimates, a pulse of immigration, and a combination of these two factors. In the OSP assessment, only the pulse immigration hypothesis is considered, based on work by Calambokidis *et al.* (2012) which suggested that the most recent abundance estimates should be fairly unbiased apart from the first estimate in 1998, which is not used in the OSP analysis.

At the time of the workshop, the OSP analysis considered two hypotheses pertaining to the regular annual immigration rate: one in which there is no immigration (PCFG is closed) and one in which the annual immigration rate is estimated, given a uniform prior distributed between 0 and 6 individuals per year. Different versions of the model allow the density-dependent (or inflection point) parameter θ to be estimated separately for each putative stock (PCFG vs. rest of the ENP) or to be constrained so that the two groups share a common θ. Outputs from both versions and immigration rate considerations (none vs. U[0, 6]) are similar in models run thus far. The primary parameter of interest in the OSP assessment is the probability that PCFG abundance is above MNPL (MSYL in IWC terms).

The analysis was not able to generate useful assessment results because, apart from the rapid population increase in the late 1990s attributed to an immigration pulse, the abundance time series is fairly flat and therefore not very informative for estimating *in situ* population growth parameters. The data have also not been informative for estimating population carrying capacity (K), a parameter necessary to determine whether current abundance is above MNPL. Posterior distributions for K have been strongly dependent on the upper bound used for the prior. Given that the abundance has been stable throughout most of the 2000s, it appears to be regulated at this level (of around 200 - 250 animals) by some factor, and thus it is somewhat puzzling that the data do not seem more informative with respect to estimating K. Moore suggested that annual levels of incidental take included in the model (about 2 animals per year) could be making it difficult to estimate whether the population is being regulated at K or some level below K, given that the data do not inform the estimates of MSYR (the population growth parameter in IWC models). For example, given annual bycatch mortality of 1%, a combination of being well below K and having a low MSYR may describe the data equally well as being close to K and having a high MSYR, since in both cases, the realized value for population growth would be low and potentially balanced by the additive mortality. It was also suggested that the population might be regulated at its current level as a result of emigration and bycatch offsetting the combination of immigration and *in situ* growth.

Moore and Punt were continuing to troubleshoot the problem by running alternative models that, for example, exclude incidental take from the model or constrain estimates of MSYR for the PCFG to be equal to those of the ENP. The goal of this troubleshooting is to explain why estimates of K and hence probability of being at OSP are elusive, which in turn may enable a decision as to whether an OSP assessment may be possible.

The TF thanked Moore and Punt for their work on this complicated matter and raised several points for clarification. It was asked where the estimates of incidental mortality for the model had come from. Moore reported that the bycatch estimate being used is based on a summary compiled at the 2011 IWC Aboriginal Whaling Management Procedure (AWMP) intersessional workshop (IWC 2012a). Carretta clarified that those estimates included data from over a 20-year period that tried to assign animals as being part of the PCFG (or not) based on time and space. Carretta also noted that the bycatch values used in the OSP analysis (as well as the SARs) account for only observed bycatch, which is likely to be an underestimate of actual bycatch.

It was also noted that emigration is a possible explanation for the difficulty in estimating K in spite of apparent PCFG population size stability. That is, all recruits are assumed in the model to have the same annual survival rate but as discussed above, whales that recruited into the PCFG in 1999 or later had lower first year survival than whales that were first identified in 1998. Not including this extra survival parameter may explain some of the lack of fit of the model to the abundance time series (plots show that the model underestimates abundance in the first half of the time series and overestimates abundance in the second half of the series).

The TF asked if the model assumed immigration was constant across years in the assessment given that in reality immigration into the PCFG is thought to vary across years. In the model, immigration to the PCFG occurs at a constant rate, with the number of immigrants being proportional to the northern stock (non-calf) abundance. The rate is equal to the estimated immigration parameter (I, specified with the uniform [0,6] prior) divided by 20,000. In other words, for recent abundance levels of the northern stock, annual immigration to the PCFG is approximately I individuals. Emigration from the PCFG group is similarly assumed to occur at a constant rate, specified by an additional survival parameter ($1 - S$), with the number of emigrants proportional to PCFG abundance. S is set so that when both stocks (northern and PCFG) are at carrying capacity, immigration and emigration to the PCFG is balanced, i.e., $IK_{north}/20000 = (1 - S)K_{PCFG.}$

Some members of the TF commented that based on this model it seems plausible that the pulse of immigration into the PCFG is larger than what the IWC is modeling or what the genetic simulations have modeled. If that were the case, then the estimates of regular annual immigration would be lower than estimated in the genetic simulations. In the light of this discussion, the TF noted that the genetic simulations should try pulses of 30 animals to see if that is consistent with the empirical genetic data. This line of thinking led to additional discussion as to how common pulse immigration events might be, and whether, for the purposes of the workshop and deliberations on internal versus external recruitment, the TF should be considering the pulse as part of the average level of immigration or if the pulse should be considered a one-time event and only annual immigration should be considered (in assessing how demographically independent the PCFG is).

It was further noted that if a UME event the size of the one in 1999-2000 had occurred previously, some record of it would be expected. Wade noted that it was due to this reasoning that they did not incorporate additional mortality events in the northern stock OSP analysis conducted by Punt and Wade (2012). Wade also noted, however, that there had been a drop in the northern stock abundance in earlier years of the time series but these were not accompanied by a record of increased strandings. The TF suggested that pulses could occur regularly on decadal time scales or as a result of a variety of other environmental or anthropogenic factors.

The TF discussed if the genetic data may reflect a sampling bias toward "core" PCFG animals. This follows other lines of evidence showing that there is a relationship between minimum tenure and probability of photographically capturing animals in the PCFG area (see section 4.4 above). If "core" PCFG whales are more approachable, then they are potentially more likely to be biopsied, meaning that these whales may be disproportionately selected for in the biopsy process.

Lang noted that she had looked at the current genetic sample set to see if the rare haplotypes found in the PCFG sample set came from animals that were sighted in 1999 or later, which might suggest that they were immigrants as the expectation would be that immigrants would be likely to bring in rare haplotypes. The results were mixed, with some rare haplotypes found in long-term PCFG whales while others were found in animals that came into the PCFG in 1999 or later.

This led to a discussion about what additional information might help the PCFG OSP assessment and improve inference generally about the level of internal versus external recruitment to the PCFG. The TF agreed that additional genetic sampling to improve estimates of immigration and residency times (emigration), and improved estimates of incidental mortality would be useful.

5. Probability of a Western North Pacific Gray Whale Being Taken by the Makah

Mixing of whales identified in the WNP and ENP has recently been reported (Weller *et al.* 2012). Lang (2010) reported that two adult individuals from the WNP, sampled off Sakhalin in 1998 and 2004, matched the microsatellite genotypes, mtDNA haplotypes, and sexes (one male, one female) of two whales sampled off Santa Barbara, California in March 1995. In 2010 and 2011, Mate and colleagues (Mate *et al.* 2011) satellite-tracked three whales from the WNP to the ENP (Mate *et al.* 2011; IWC 2012a; IWC 2012b). Finally, photographic matches between the WNP and ENP, including resightings between Sakhalin and Vancouver Island and Laguna San Ignacio, have further confirmed use of areas in the ENP by whales identified in the WNP (Urbán *et al.* 2012; Weller *et al.* 2012). Despite this level of mixing, significant mtDNA and nuclear genetic differences between whales in the WNP and ENP have been found (Lang *et al.* 2011b).

Observations of gray whales identified in the WNP migrating to areas off the coast of North America raise concern about placing the WNP population at potential risk of incurring mortality incidental to the ENP gray whale hunt proposed by the Makah Indian Tribe off northern Washington, USA (see IWC 2012a; IWC 2012b). Given the ongoing concern about conservation of the WNP population, in 2011 the Scientific Committee of the IWC emphasized the need to estimate the probability of a western gray whale being killed during aboriginal gray whale hunts (IWC 2012a). Additionally, NOAA is required by NEPA to prepare an Environmental Impact Statement (EIS) pertaining to the Makah's waiver request. The EIS will need to include an analysis of the likelihood of a western gray whale being killed during the proposed Makah gray whale hunt.

Moore summarized the work that he and Weller (SWFSC) have done to estimate the probability that a WNP whale might be taken during the proposed gray whale hunt (Moore and Weller 2013). Four alternative models were evaluated; these models made different assumptions about the proportion of WNP whales that would be available for the hunt or utilized different types of data to inform the probability of a WNP whale being taken. The probability of striking at least one WNP whale over the course of five years was estimated to range from 0.034 – 0.058 across different scenarios of the preferred model, with upper 95% CI estimates ranging from 0.107 –

0.170. This result may be compared to an estimate of PBR. If the recovery factor for calculating PBR is set to 0.1, and discounting the estimate for the proportion of the population that may be migrating through U.S. waters and the proportion of time (months out of a year) they are in U.S waters, then the 5-year PBR estimate is between 0.1 and 0.6 animals, depending on different assumptions about the amount of mixing between the WNP and ENP. Thus, if a WNP whale were to be struck during the 5-year period, PBR would be exceeded.

6. Status of Gray Whale Stocks as Defined by, MMPA, ESA and IUCN

At the request of the TF, Stone (NWR) provided a review of the status of ENP, WNP and PCFG gray whales under the MMPA, ESA, and the International Union for Conservation of Nature (IUCN) redlist.

(1) ENP – The ENP stock is not considered *"strategic/depleted"* under the MMPA and is listed as "*Least Concern*" by the IUCN. Gray whales in the ENP were delisted from the ESA in 1994. Although there have been two petitions (2001 and 2010) to relist the ENP stock under the ESA, both petitions were denied.

(2) WNP – The WNP stock is considered "*strategic/depleted*" under the MMPA and is redlisted as "*Critically Endangered*" by the IUCN. WNP whales are considered "*Endangered*" under the ESA, although there is no stand-alone SAR for WNP whales. Given that ENP whales were delisted in 1994, gray whales in the WNP would be considered a Distinct Population Segment (DPS) under the ESA. Use of the DPS terminology was not common at the time of the delisting and thus the listing documents do not describe the WNP as a DPS.

(3) PCFG - The PCFG does not have a formal status under the MMPA, IUCN nor ESA.

In addition to the above, the TF discussed the status of gray whale stocks as defined by the IWC. Under the IWC implementation review (IR) process, the IWC considers all plausible hypotheses of stock structure, and then determines which hypotheses have high or medium plausibility. Those stock hypotheses with high or medium plausibility are used to evaluate the management variants proposed by hunters. In the case of gray whales, the IWC traditionally considered only the hypothesis of a single ENP stock. New information presented to the IWC in 2010 (Frasier *et al.* 2011) suggesting that the PCFG could be a separate stock resulted in the IWC evaluating a two-stock hypothesis. Members of the TF reminded the group that the IWC does not have to decide if there are one or two gray whale stocks, but only if it is plausible that there is one stock and if it is plausible that there are two stocks (or three stocks). The objective of the IWC is to make sure that the stock or stocks are robust to the proposed hunt under all plausible scenarios. Thus, the IWC process is currently considering both stock hypotheses (1-stock and 2-stock). Future work by the IWC may need to incorporate a third stock (i.e., WNP) but for now the calculation of the probability of a WNP whale being killed during the Makah hunt (see section 5 above) is a stand-alone calculation.

7. Overview of Evidence Used in Recently Defined Population Stocks

Stone provided an overview of the lines of evidence used by NMFS to delineate stocks as inferred from the text of each SAR. It became clear during discussion of the summary that many of the SARs do not explicitly lay out the lines of evidence and justifications for originally delineating a stock but instead only present recent information. The killer whale SARs, for example, do not describe the acoustics data and other lines of evidence that were originally used

to identify the stocks. There was general agreement that an updated summary, in spreadsheet form, would be useful as it could capture the history and provide a long-term record of how each stock was delineated, but this would not be a trivial task. In the end, the TF concurred that agency practices for delineating stocks were not based on a set standard but were more variable and fact-specific so as to use the best available information.

8. Review of Stock Definition Cases Relevant to the Pacific Coast Feeding Group

The TF reviewed several examples of stock delineations for other species exhibiting some similar characteristics to the PCFG. Similar characteristics included: (1) use of mtDNA as the sole genetic marker necessary for stock structure determination and (2) mixing with individuals from other stocks during parts of the year.

8.1 Atlantic harbor porpoises

Rosel (SEFSC) presented an overview of stock structure in Atlantic harbor porpoises (*Phocoena phocoena*) with a focus on the Gulf of Maine/Bay of Fundy stock. A single stock was designated in U.S. waters of the Northwest Atlantic based on published literature of Gaskin (1984) who hypothesized four populations in the Northwest Atlantic (three in Canadian waters and one in U.S. waters). While following Gaskin (1984), the first SAR for U.S. Gulf of Maine/Bay of Fundy harbor porpoises stated "*Presently there is insufficient evidence to accept or reject this hypothesis*" (Blaylock *et al*. 1995). In subsequent years, mtDNA evidence supported four stocks in the Northwest Atlantic, including the Gulf of Maine stock, but nuclear microsatellite data did not (Rosel *et al.* 1999). Organopollutant levels (Westgate *et al.* 1997, Westgate and Tolley 1999) and life history characteristics (Read and Hohn 1995) also differed between the Gulf of Maine/Bay of Fundy and other populations in the Northwest Atlantic. The weight of evidence supported delineation of the Gulf of Maine/Bay of Fundy stock and the lack of nDNA differentiation between this stock and others in the Northwest Atlantic was taken to indicate female philopatry coupled with male-mediated gene flow. Microsatellite data indicated that porpoises from the Gulf of Maine/Bay of Fundy probably overlap in winter in the mid-Atlantic with porpoises from other regions of the Northwest Atlantic (Hiltunen 2006), but this is outside the breeding season.

8.2 Alaska harbor seals

Taylor summarized the history of recognizing stocks of harbor seals in Alaska. Harbor seals (*Phoca vitulina*) are continuously distributed throughout Alaskan waters, but mtDNA indicates that genetic differentiation among sampled sites increases with increasing geographic distance (O'Corry-Crowe *et al.* 2003). The continuous distribution implies that there will be movement of animals across stock boundaries drawn on a map, but if no stock boundaries are designated, there is the risk of local depletion and loss of portions of the species' range. The first SARs for Alaska harbor seals comprised three stocks- Bering Sea, Gulf of Alaska and Southeast Alaska (Hill and DeMaster 1998). In 2011, the three stocks were changed to twelve (Allen and Angliss 2012). MtDNA, satellite telemetry, trend and distributional data were used to delineate these 12 stocks. At that time, nDNA data were not available and mtDNA analyses were considered sufficient to meet the criteria of demographic independence under the GAMMS guidelines.

8.3 Humpback whales

Lang presented a review of humpback whale (*Megaptera novaeangliae*) stocks, with a focus on the North Atlantic. There are multiple humpback whale feeding grounds in the Northwest Atlantic, but individuals from these different feeding grounds share one breeding ground in the

West Indies. Humpback whales throughout the Northwest Atlantic were originally classified as a single stock (Waring *et al.* 1999). However, genetic studies have revealed small but significant differences in mtDNA between animals sampled on different feeding grounds (Palsbøll *et al.* 2001) and photo-identification studies have documented strong site fidelity of individuals to the Gulf of Maine feeding area (Clapham *et al.* 1993). The 2000 SAR recognized whales utilizing the Gulf of Maine feeding area as a separate stock (Waring *et al.* 2000). Although this SAR covers only Gulf of Maine whales, individuals from other feeding areas have been identified in U.S. mid-Atlantic waters (Barco *et al.* 2002).

The stock structure of humpback whales in the Pacific is complex (Baker *et al.* 2008; Calambokidis *et al.* 2008) and differs from the western North Atlantic with respect to the "interbreed when mature" criteria. That is, humpback whales from different feeding grounds in the NW Atlantic have the opportunity to interbreed with each other in a single breeding area, while in the North Pacific not all animals have the opportunity to interbreed with each other because there are multiple breeding areas. There is some similarity between North Pacific humpbacks and those in the central and eastern North Atlantic, in that whales on the Norway and Iceland feeding areas may breed in different areas (Palsbøll *et al.* 1997; Stevick *et al.* 1998; Wenzel *et al.* 2009). Three humpback whale stocks are currently recognized in the North Pacific, based on three feeding areas (Allen and Angliss 2012; Carretta *et al.* 2013). The SAR for the Central North Pacific stock includes calculations of PBR for three different feeding areas (Allen and Angliss 2012), as is done for the PCFG in the current SAR (Carretta *et al*. 2013).

9. Review of Gray Whale Genetic Research on Population Structure

Lang provided a chronological summary of genetic research performed on North Pacific gray whales. Steeves *et al*. (2001) used mtDNA control region sequence data to compare 16 samples collected in summer in Clayoquot Sound, British Columbia, representing the PCFG, to 41 samples collected elsewhere in the ENP. Some haplotypes were shared between the two groups and no significant differentiation was found between them. Additional genetic analysis utilizing an extended set of samples (n=45) collected from whales within the seasonal range of the PCFG indicated that the genetic diversity and the number of mtDNA haplotypes identified among these samples were inconsistent with measures that would be expected (based on simulations) if recruitment into the group were exclusively internal (Ramakrishnan *et al*. 2001). Alternative scenarios, such as limited dispersal of whales from other areas into the PCFG, were not explored. LeDuc *et al*. (2002) examined mtDNA control region differences between ENP and WNP gray whales. The ENP sample consisted primarily of stranded animals along the migratory route with some samples from Chukotka, Russia (no distinctions between PCFG and non-PCFG whales were made). The WNP samples were collected off the northeastern coast of Sakhalin Island, Russia. Seven of the 36 identified haplotypes were shared between the two regions and significant genetic differentiation was found. In addition, haplotypic diversity of the WNP sample was lower than that seen for the ENP samples.

Within the ENP, Goerlitz *et al*. (2003) made comparisons between two wintering lagoons and between females sampled in wintering lagoons and those sampled outside the lagoons (in Clayoquot Sound and along the migration route- *i.e.,* "non-lagoon females"). They found small but significant differences in mtDNA data between Laguna San Ignacio cows (females with calves) and non-lagoon females and between Laguna Ojo de Libre cows and non-lagoon females but not when cows from the two lagoons were compared. Alter *et al*. (2009) compared both

mitochondrial and nuclear microsatellite markers across three wintering lagoons and found small but significant differences between only one of the three pairwise comparisons using the microsatellite data set only. Similar to Goerlitz *et al.* (2003), they did not find significant differentiation between Laguna San Ignacio and Laguna Ojo de Libre at mitochondrial or nuclear DNA.

More recently, Frasier *et al*. (2011) examined mtDNA differences between whales sampled in Clayoquot Sound, British Columbia (representing the PCFG) and a more carefully constructed data set of ENP whales from LeDuc *et al.* (2002) in which known PCFG whales were specifically removed. They found significant genetic differentiation between the two sample sets and high levels of haplotype diversity in the PCFG sample, comparable to samples thought to represent the larger ENP population. Using this dataset, Frasier *et al.* (2011) also performed a likelihood ratio test using Theta (Θ) as a proxy for effective population size to examine whether the two sample sets come from the same population. The likelihood ratio test indicated that Θ for the PCFG did not equal Θ for the ENP and the authors concluded that the two groups were demographically independent.

D'Intino *et al*. (2012) made a comparison of whales sampled off Vancouver Island and representing the PCFG to whales sampled at the calving lagoon at San Ignacio. Using 15 microsatellite loci, they found no evidence for population differentiation between these two areas and concluded that the two sampled groups come from the same interbreeding population and that maternally-directed site fidelity to different feeding areas leads to genetic differentiation at mtDNA among feeding areas. Lang *et al*. (2011a) expanded on this result and compared whales sighted over two or more years within the PCFG seasonal range to animals sampled on the feeding ground(s) north of the Aleutians using both mtDNA and nuclear microsatellite markers. Significant differentiation was seen for the mtDNA data but not the microsatellite data, supporting the conclusion of Frasier *et al.* (2011) that structure is present among different feeding areas and this structure may be directed by matrilineal fidelity[5] to feeding grounds. Of note, when all samples collected on the PCFG seasonal range (including those collected from animals seen in only one year) were utilized in the mtDNA analyses, no significant differences were detected in the comparison to samples collected from whales off Chukotka. When all samples collected on the PCFG seasonal range were compared to all samples collected north of the Aleutians, the mtDNA F_{ST} comparison detected a significant difference although the χ^2 test did not.

Finally, Lang *et al.* (2011b) re-examined differences between ENP and WNP gray whales, expanding on the previous study of LeDuc *et al*. (2002) by using larger sample sizes, better characterized sampling and both mtDNA and nuclear microsatellite data. Comparisons of whales sampled off Sakhalin Island with whales feeding north of the Aleutians (i.e., ENP whales) and with the PCFG demonstrated significant differentiation at both nuclear and mtDNA markers. The extent of mtDNA differentiation between ENP strata (PCFG and whales feeding north of the Aleutians) and Sakhalin Island was higher than that observed in comparisons within ENP strata. As with previous studies, significant differentiation among ENP feeding areas was not seen in the microsatellite data. The Sakhalin stratum again displayed reduced haplotype diversity compared to the ENP strata. The authors conclude that the mtDNA data support demographic

[5] Matrilineal fidelity as used here means the learned behavior of a calf (male or female) returning to the feeding ground of its mother.

independence for ENP and WNP gray whales. However, in examining the microsatellite genotypes, Lang *et al.* (2011b) found two individuals biopsied at the Sakhalin feeding ground and off the coast of southern California. These matches, in combination with recent photo-identification and telemetry data (Mate *et al.* 2011; Urbán *et al*. 2012; Weller *et al.* 2012), suggest that some animals summering off Sakhalin overwinter in the ENP in at least some years. Given that recent records document gray whales in the waters off Japan and China during winter and spring (see review in Weller and Brownell 2012) these results suggest that population structure in gray whales may be more complex than previously believed, such that not all of the animals that feed off Sakhalin share a common wintering ground, or that some animals may switch between wintering grounds.

In discussion, TF members suggested some further avenues for exploration including examining whether any microsatellite loci were out of Hardy-Weinberg equilibrium (HWE) for the Sakhalin samples, which might be an indication of mixing of multiple breeding populations on that feeding ground. It was noted that at the 2012 IWC Scientific Committee meeting a paper evaluating the use of HWE tests to look at mixing of stocks was presented and it might be worthwhile to see if the approaches in this paper could be applied to the Sakhalin dataset (IWC 2012b). There was also discussion regarding what proportion of mixing would have to take place before it would be detected by a relatively weak test like HWE.

9.1 Genetic modeling of immigration rates

Lang presented an overview of recent work utilizing a simulation-based approach to evaluate the plausible level of immigration (i.e., a permanent change of feeding ground fidelity, used interchangeably with external recruitment) that might be occurring into the PCFG. While the empirical studies summarized above have shown significant differences in mtDNA between the PCFG and other ENP gray whale feeding areas, suggesting that matrilineal fidelity is important in structuring feeding ground use, other evidence (some from genetics, mostly from photo-id) suggests that some immigration into the PCFG may be occurring. Lang and Martien (2012) used simulations to examine how much immigration into the PCFG could occur to produce results consistent with the empirical genetic (mtDNA) analyses. The results suggested that the plausible range of immigration is >1 and <10 animals/year on top of a two-year pulse of immigration (of 20 animals each year in 2000 and 2001). Annual immigration of 4 animals (with the 2 year pulse of immigration) produced simulated results that were most consistent with the empirical data. If the PCFG had been founded more recently or the abundance of the PCFG is greater than used in the simulations, it is plausible that no annual immigration could be occurring (still assuming the occurrence of a 2-year pulse of immigration).

In discussion of these results, the TF noted several important caveats to the approach used by Lang and Martien (2012), including: (1) the results may be overly precise because so many model parameters are set, and (2) the simulated abundance trajectories do not match well with the mark-recapture estimates (Calambokidis *et al*. 2012) when immigration is 4 immigrants/yr or more. The simulated population trajectories assumed that the PCFG split from the larger ENP population in 1930. Task Force members thought that the 1930 split might be unrealistic, as oceanographic conditions during the Little Ice Age (and earlier) would have limited access to the northern feeding ground(s) and thus may have caused some gray whales to utilize more southern waters for feeding. Lang commented that there were plans to model a split of the PCFG from the larger ENP in the Little Ice Age, but that this work is not yet complete. She also noted that there were many possible histories and it would be difficult to encompass all of them.

10. Discussion of Makah Documents Concerning the Pacific Coast Feeding Group

Weller introduced three documents drafted by or on behalf of the Makah Indian Tribe regarding the PCFG. These documents were provided to the TF in advance of the meeting for review and consideration. In combination, these three documents provided important summary information on the PCFG, including reviews of what is known about the history of the PCFG and summaries of the current status of the group.

The 2011 Makah document (Makah 2011) was drafted by the Tribe and their attorneys and provided to the Pacific and Alaska SRGs as a background paper to help inform their respective reviews of the draft 2012 gray whale SAR (NMFS 2012). This document provides the Makah perspective on whether the PCFG should be recognized as a stock and was therefore deemed important for the TF to review and consider. Information provided in Scordino *et al*. (2011) is largely the same as that presented in the Makah 2011 document.

The 2012 Makah document (Makah 2012) contains comments from the Makah Tribe and their attorneys on the 2012 draft gray whale SAR (NMFS 2012). This document was considered important for the TF to review. In response to the Tribe's request for government-to-government consultation, the SWFSC met with representatives from the Makah Tribe and their attorneys in person to review comments provided in the 2012 document. These comments, where appropriate, were incorporated as changes to the draft text of the SAR (NMFS 2012).

10.1 Discussion of genetics sections of Makah documents

In discussion of these documents, the TF agreed that it was most important to focus on the Makah comments and perspective regarding genetics research on the PCFG. Rosel agreed to lead the TF through the genetics sections of the Makah documents that called into question the strength of the genetic data presented with respect to demographic independence of the PCFG. These points were summarized as: (1) the samples used to represent the overall ENP stock may not be a random sample of the entire stock but could come from different and unknown feeding grounds. This calls into question what the PCFG is being compared to in the genetic analyses, (2) sample sizes from many locations are small relative to overall population size (i.e., relative to the size of the larger ENP population) and to the total level of genetic diversity and that this could cause misleading results, (3) many population comparisons of gray whales have yielded significant but low-level differences in haplotype frequencies; if this is considered sufficient evidence to classify the PCFG as a stock then every group of gray whales utilizing a particular feeding area should be considered a stock, and (4) the genetics results do not support reproductive isolation of the PCFG.

The first two points were related to sampling effects. In discussion, some members of the TF noted that it is not necessarily the sample size that is potentially problematic but rather if related animals are grouped together and multiple biopsies are taken from that "group" then the effective sample size is much smaller. It was further noted that small sample sizes may add variability, but it would only be a problem if there were additional (unrecognized) structure in the samples. From a genetic standpoint, many analyses rely on haplotype frequencies, but if a good sample relative to the genetic diversity of the group is not obtained then the genetic diversity may not be well characterized, especially if there are many rare haplotypes. Since haplotype frequency data also go into analyses for F_{ST} and Chi-square, then poor frequency estimates due to small sample size could affect the accuracy of the genetic differentiation results as well. Lang noted that there

is some evidence from North Atlantic humpbacks that the migration to the West Indies is segregated according to feeding ground origin (Stevick *et al.* 2003).

The TF noted, however, that the recent PCFG genetic analyses show high diversity indicating that sampled animals have different haplotypes and are thus not related (maternally). The TF asked if the question at hand is whether gray whales have feeding aggregations or whether the group that migrates north of the Aleutians is different from the group that does not migrate north of the Aleutians. Lang noted that the original intent of the project was to compare samples collected from different feeding areas north of the Aleutians to the area used by the PCFG but in the end sample sizes were insufficient for areas other than Chukotka. Nevertheless, although there could be multiple feeding aggregations north of the Aleutians, one of the comparisons conducted by Lang *et al.* (2011a) used only samples collected off Chukotka to try to avoid including unrecognized structure.

The TF recognized the continuing need for additional data to be collected, but for the purposes of the workshop the focus was whether the lines of evidence from existing genetic analyses are strong enough to counter lines of evidence that put the demographic independence of the PCFG into question. The primary question in the short-term is what can be done with the information that is currently available.

The TF noted that Frasier *et al.* (2011) compared animals from the PCFG with a sample set primarily derived from stranded animals along the U.S. west coast during migration. They agreed that these samples might not be a random representation of the larger ENP, as was also pointed out in the Makah documents.

Overall, the TF felt it was important to recognize that the current research questions being addressed center around feeding-ground-based groups of animals. The genetics work has already shown that when the PCFG is compared to a sample set from northern feeding area (Chukotka) animals or to the Sakhalin animals (also a feeding area) differences have been found (Lang *et al.* 2011b). That is, the PCFG has been shown to be different from two other well-characterized feeding grounds.

While interpretation of the currently available genetic results as relevant to the PCFG has lead to debate amongst different groups, the TF concurred that it represents the best available science. In discussion, some members of the TF agreed that although more progress on this issue could be made over the next few years if resources were available for more intensive sampling, they did not think that the current interpretation of results would change much. That is, even if 1% of the 19,000 or so animals going through Unimak Pass were sampled, a mtDNA difference with the PCFG (as already observed) would remain. So far the PCFG has been compared to samples from feeding areas and from the migratory route and both comparisons detected a genetic difference. It was agreed that the critical issue for additional research to address was better determining the levels of internal versus external recruitment in the PCFG.

At this point the TF returned to discussing the remaining points raised by the Makah documents. The third point was that since multiple genetic comparisons have found low but significant differences, every group of gray whales should be considered a stock. The TF concurred and noted that there is nothing wrong with incrementally adding stocks as new evidence is uncovered, and that decisions have to be made based on the best available science.

The final point discussed was that the genetics results do not support reproductive isolation of the PCFG. The TF agreed in general that the pattern and timing of migration provide ample opportunity for breeding between PCFG whales and other ENP whales. Little is known about gray whale social and mating systems, however, and presently unrecognized mechanisms facilitating selective breeding could exist. If a form of selective breeding does exist, then it could be a long time before nDNA differences appear. A suggested approach to resolving this question is to look at the relatedness of animals in the PCFG. Despite this, the TF agreed that it is most likely that PCFG animals are interbreeding with animals coming from other areas.

11. Research Recommendations

The TF agreed that the following set of recommendations represent key research needs that could help provide additional insight regarding if the PCFG should be recognized as a population stock under the MMPA and GAMMS guidelines.

Given the limited photo-identification and biopsy effort north of 52°N but knowing that at least some observations of PCFG whales in northern feeding areas (e.g., Kodiak and Barrow, Alaska) have been recorded, the TF highlighted the importance of expanding the spatial and temporal coverage of the photo-identification and biopsy effort. In addition, the TF also recommended that further satellite tagging of known PCFG whales be conducted to better delineate habitat use and define the summer/fall feeding area boundaries.

The TF noted that PCFG animals might more regularly interact (compared to non-PCFG whales) with crab pots given their extended residency in coastal waters. Therefore, the TF recommended that the existing photo-identification time series be used to examine scarring patterns of PCFG whales to better understand the incidence of interactions with fishing gear.

Since much of the photo-identification sighting effort occurs in August and later, when many calves are likely to already be weaned and thereby more difficult to identify as a calf (versus a yearling), the TF recommended that the existing PCFG photo-identification time series be examined following a protocol developed by Bradford *et al*. (2011). This photo-based method uses barnacle and pigmentation characteristics on young gray whales to reliably distinguish calves of the year from yearlings.

Knowing that several lines of evidence demonstrate a relationship between minimum tenure and the probability of photographically capturing animals in the 42°N-52N° PCFG area, the TF recommended that the existing PCFG photo-identification time series be examined to see if moms/calves demonstrate higher degrees of fidelity than other whales.

Although photo-identification studies of the PCFG by Calambokidis and colleagues have been ongoing for over a decade, a relatively high number of "new" animals (not previously sighted in the area) are identified each year and subsequently show consistent return to the area (Calambokidis *et al*. 2012). These "new" animals could represent calves born into the group (i.e., internal recruitment) and not identified in their first year, or they could represent animals that traditionally feed in northern areas but now show fidelity to the seasonal range of the PCFG (i.e., external recruits). To better address this question, the TF recommended that relatedness analysis, in which microsatellite genotypes are used to identify animals that represent putative mother-offspring pairs, be used to assess the proportion of internal recruitment occurring within the PCFG. A sufficient understanding of recruitment to make a stock definition determination could

potentially be achieved with a concerted effort to sample known mothers and recruits and determine their relatedness.

Related to the recommendation above, some TF members felt that it was plausible that the pulse of immigration into the PCFG could be larger than what the genetic simulations have modeled. If so, then the estimates of annual immigration into the PCFG could be lower than that estimated in the genetic simulations. With this in mind, the TF recommended that the genetic simulations should try pulses of 30 animals and see if that is consistent with the empirical genetic data.

12. Structured Decision-Making Process

At the request of the TF, Bettridge provided an overview of the FEMAT-style structured decision-making process[6]. In some NMFS status reviews, Biological Review Teams (BRTs) formed pursuant to the ESA have adopted formal methods to express plausibility for use in guiding its analysis of DPSs and in assessing the risks to the population(s). These formal methods are important in a setting where quantitative measures of uncertainty derived from the empirical data are unavailable. This point allocation method is often referred to as the "FEMAT" method because it is a variation of a method used by scientific teams evaluating options under the Northwest Forest Plan (Forest Ecosystem Management Assessment Team). In this approach, for example, each expert is asked to distribute plausibility points among the choices/scenarios for a given decision, reflecting his or her opinion of how likely that choice or option correctly reflected the population status. If the expert is certain of a particular option, or feels it is the only plausible scenario, he or she could assign all points to that option. An expert with less certainty about which option best reflected reality or best reflected the population's status could split the points among two or more options. This method has been used in all status review updates for anadromous Pacific salmonids since 1999, as well as in reviews of Southern Resident killer whales, West Coast rockfishes, Pacific herring (*Clupea pallasii*), Pacific groundfish, North American green sturgeon (*Acipenser medirostris*), black abalone (*Haliotis cracherodii*), Hawaii false killer whale (*Pseudorca crassidens*), and humpback whales.

In the humpback whale status review, BRT members distributed 100 likelihood points among the defined scenarios or options, reflecting their expert opinion of the relative likelihood that the status of a specific DPS falls into each of three risk categories. Then the team discussed how they had allocated points and subsequently had a chance to revise their scores. Scorer identity was known.

In the Hawaii false killer whale status review, BRT members distributed 10 points between the arguments for and against each factor. Team members agreed to view resulting scores with names associated to facilitate discussion and assure that linguistic uncertainty was not responsible for any disparate votes. The BRT discussed the scores and, in some cases, adjusted scores when prior articulation of the arguments had been unclear.

After presentation of the structured decision-making approach, Bettridge asked the TF the following questions: (1) Does the TF want to use this approach? (2) If so, how many points will each member allocate among scenarios? (3) Does the TF wish to disclose names, or keep scores anonymous? (4) Does the TF wish to allow for rescoring after discussion? The TF members agreed to employ the structured decision-making approach, allocating 100 points per person. The

[6] The TF agreed that Bettridge, as leader of the decision-making process, should refrain from allocating points on the decision questions.

group agreed to disclose names with scores for the purposes of internal discussion and possible rescoring but to retain anonymity in the final report.

The TF further agreed that they needed to carefully formulate the questions to be addressed and clearly understand what it means to put likelihood points in one category or another so as to provide the necessary advice for management-related issues such as: (1) how future NMFS stock assessment reports will be drafted with regard to gray whale stock structure in the North Pacific and (2) how to interpret any new information in the context of the Makah Indian Tribe MMPA waiver request to resume hunting gray whales off Washington State, USA.

Some TF members with experience using this approach in other situations found that when one or a few members allocated points very differently it was often due to misunderstanding of the question or what the answers implied. Therefore, it was agreed that the questions and the categories of answers should be as clear as possible to make the process both efficient and transparent.

12.1 Question formulation

In keeping with the objectives stated above for developing questions, the TF dedicated significant time during day 2 of the workshop agreeing on questions to be considered during the decision-making process. A key objective of this exercise was to focus on existing lines of evidence to help create the questions while at the same time being mindful of the existing definitions of the terms (e.g., demographic independence, interbreed when mature, functioning element of the ecosystem) contained in the MMPA and GAMMS guidelines. For instance, a simple example of this might be; "*evidence of demographic independence is when the number of internal recruits is greater than the number of external recruits"*. In general, this philosophy of creating questions was adopted by the TF and maintained during its deliberations.

After considerable work, the TF agreed to 11 questions. Overnight, TF members privately completed their point allocations for each of the questions. Point allocations were tallied and ready for discussion on the final day of the workshop. Allocating points in this manner allowed individual TF members to express their level of certainty on each of the questions, such that placement of all points in a single category indicated relative certainty in the lines of evidence discussed during the workshop. The TF agreed to view resulting scores with names associated to facilitate discussion and assure that linguistic uncertainty was not responsible for any disparate votes. The TF discussed the scores and, in some cases, members adjusted them when prior articulation of the lines of evidence had been unclear. The final 11 questions and likelihood point allocations for each of the TF members (anonymous, labeled A – G), as well as the proportional distribution of points overall, are provided below.

Question 1.	Overall	A	B	C	D	E	F	G
	Does the ecosystem occupied by the PCFG when they are feeding differ from the ecosystems occupied by other ENP gray whales?							
Strongly Agree	53	100	0	80	100	90	0	0
Somewhat Agree	47	0	100	20	0	10	100	100
Neutral	0	0	0	0	0	0	0	0
Somewhat Disagree	0	0	0	0	0	0	0	0
Strongly Disagree	0	0	0	0	0	0	0	0

Question 2.	Overall	A	B	C	D	E	F	G
	If gray whales in the ENP continued to be managed as a single stock, would the future abundance of PCFG gray whales be maintained above 60% of their current abundance if annual HCM in the PCFG was 5?							
Strongly Agree	38	0	95	0	0	20	50	100
Somewhat Agree	23	20	5	5	0	80	50	0
Neutral	25	50	0	25	100	0	0	0
Somewhat Disagree	14	30	0	70	0	0	0	0
Strongly Disagree	0	0	0	0	0	0	0	0

Question 3.	Overall	A	B	C	D	E	F	G
	If gray whales in the ENP continued to be managed as a single stock, would the future abundance of PCFG gray whales be maintained above 60% of their current abundance if annual HCM in the PCFG was 10?							
Strongly Agree	10	0	50	0	0	0	0	20
Somewhat Agree	24	10	50	0	0	25	30	50
Neutral	21	40	0	0	0	25	50	30
Somewhat Disagree	17	40	0	10	0	50	20	0
Strongly Disagree	29	10	0	90	100	0	0	0

Question 4.	Overall	A	B	C	D	E	F	G
	If gray whales in the ENP continued to be managed as a single stock, would the future abundance of PCFG gray whales be maintained above 60% of their current abundance if annual HCM in the PCFG was 20?							
Strongly Agree	0	0	0	0	0	0	0	0
Somewhat Agree	4	0	25	0	0	0	0	0
Neutral	7	0	50	0	0	0	0	0
Somewhat Disagree	22	10	25	0	0	50	50	20
Strongly Disagree	67	90	0	100	100	50	50	80

Question 5.	Overall	A	B	C	D	E	F	G
	Given the lack of significant differences found in nuclear markers between PCFG whales and other eastern Pacific whales, how would you allot points to:							
There is complete random mating within the eastern NP	63	70	70	70	50	80	60	40
There could be some non-random mating within PCFG whales that is either too recent or at too low a level to be detected given current sample sizes and marker numbers	37	30	30	30	50	20	40	60
PCFG whales breed primarily with each other	0	0	0	0	0	0	0	0

Question 6.	Overall	A	B	C	D	E	F	G
	Based on the genetic data and simulations, how would you allot points to:							
Nearly all recruitment into the PCFG area results from external recruitment (immigration)	0	0	0	0	0	0	0	NA
Most recruitment into the PCFG area results from external recruitment	21	20	30	20	0	20	33	NA
Recruitment is about equal between internal (births) and external (immigration) recruitment	56	60	50	60	100	30	34	NA
Most recruitment into the PCFG area results from internal recruitment	24	20	20	20	0	50	33	NA

Question 7.	Overall	A	B	C	D	E	F	G
	Based on the photo-identification data, how would you allot points to:							
Nearly all recruitment into the PCFG area results from external recruitment (immigration)	0	0	0	0	0	0	0	0
Most recruitment into the PCFG area results from external recruitment	38	30	55	50	0	30	50	50
Recruitment is about equal between internal (births) and external (immigration) recruitment	48	40	35	35	100	50	35	40
Most recruitment into the PCFG area results from internal recruitment	14	30	10	15	0	20	15	10
Nearly all recruitment into the PCFG area results from internal recruitment	0	0	0	0	0	0	0	0

Question 8.	Overall	A	B	C	D	E	F	G
	Do the genetic and photo-identification data indicate that the PCFG is a demographically independent population?							
Strongly Agree	0	0	0	0	0	0	0	0
Somewhat Agree	35	25	10	80	100	30	0	0
Neutral	21	50	30	10	0	40	20	0
Somewhat Disagree	25	25	50	10	0	30	40	20
Strongly Disagree	19	0	10	0	0	0	40	80

Question 9.	Overall	A	B	C	D	E	F	G
	Given all lines of evidence, is the PCFG a "population stock" under the agency's interpretation of the MMPA?							
Strongly Agree	14	0	0	0	100	0	0	0
Somewhat Agree	22	25	10	80	0	30	10	0
Neutral	21	50	30	10	0	40	20	0
Somewhat Disagree	24	25	50	10	0	30	35	20
Strongly Disagree	18	0	10	0	0	0	35	80

Question 10.	Overall	A	B	C	D	E	F	G
	Given that some whales identified in the WNP migrate through U.S. waters to Mexico, should a separate SAR be developed for the WNP?							
Yes	79	100	70	100	100	50	80	50
No	21	0	30	0	0	50	20	50

Question 11.	Overall	A	B	C	D	E	F	G
	Given the differences found in mtDNA and nDNA between Sakhalin Island (WNP) and ENP gray whales, is there a "population stock" within the WNP under the agency's interpretation of the MMPA?							
Strongly Agree	100	100	100	100	100	100	100	100
Somewhat Agree	0	0	0	0	0	0	0	0
Neutral	0	0	0	0	0	0	0	0
Somewhat Disagree	0	0	0	0	0	0	0	0
Strongly Disagree	0	0	0	0	0	0	0	0

12.2 Question outcomes and discussion

The outcomes of each question above are discussed below and follow the convention of using "percentage of total points" to describe the results. For example, in Question 1 the "strongly agree" category was allotted 53% of the total available TF points (370 points allotted/700 total points = 53%).

Question 1

The TF expressed general agreement, by allocating 100% of the their combined points to the categories "somewhat agree" (47%) and "strongly agree" (53%) that PCFG whales seasonally feed in a unique ecosystem that differs from other gray whale feeding areas in the Pacific. Therefore, the TF concurred that it is reasonable to consider that if the PCFG no longer existed and the region was not reoccupied via immigration, summer feeding gray whales would no longer be a functioning element of the coastal Pacific Northwest ecosystem. Although such a circumstance is plausible, keeping all other things equal (e.g., habitat, prey availability), the current lines of evidence from photo-identification studies suggest it is unlikely that the level of annual immigration into the PCFG in the past decade would cease. Thus, the likelihood of gray whales not being found in the PCFG area seems low. However, the time it might take for "recolonization" of the PCFG via immigration is undetermined and thereby puts into question whether this scenario would meet the MMPA objectives of maintaining stocks not only for ecological purposes but also for aesthetic, recreational and economic reasons.

Questions 2, 3 and 4

These three questions were meant to address the MMPA objective of maintaining population stocks as significant functioning elements in the ecosystem of which they are part, and that population stocks should not be permitted to decline below OSP. GAMMS II state that where mortality is greater than a PBR level calculated from the abundance for the region where human caused mortality (HCM) occurs, serious consideration should be given to identifying an appropriate management unit in the region. While estimates of PBR and HCM for a putative PCFG stock have been generated (Carretta *et al*. 2013), there is uncertainty about both estimates, especially with respect to: (1) whether HCM (e.g., ship strikes and fisheries bycatch) for whales in the PCFG area is indeed higher than for whales that migrate through the area, and (2) where HCM actually occurs. In response to these questions, the TF expressed increasing concern about the ability of the PCFG to be maintained above 60%[7] of its current abundance once HCM exceeded 5 whales per year.

The point allocation in Question 2 indicates that the TF overall tended to agree that the future abundance of PCFG gray whales would be maintained above 60% of their current abundance if annual HCM in the PCFG was 5. However, the relatively equal distribution of likelihood points in all categories except "strongly agree" indicates a high level of uncertainty among the TF.

For Question 3, points were allocated more broadly across categories, indicating a higher level of uncertainty among TF members as to whether the PCFG could sustain levels of HCM at 10 whales per year.

There was increased consensus among the TF for Question 4 in that none of them responded "strongly agree". Overall, the TF concurred that it somewhat (22%) or strongly disagreed (67%) that the future abundance of PCFG gray whales would be maintained above 60% of their current abundance if annual HCM in the PCFG was 20.

Question 5

The TF found no evidence to suggest that PCFG whales breed primarily with each other. While there was general agreement (63%) that the lack of significant differences found in nuclear DNA markers between PCFG whales and other ENP whales suggests random interbreeding among all ENP whales, the allotment of 37% of the total points to the intermediate category suggests TF members thought it was possible that some breeding segregation may exist based on migratory timing (see Lang *et al*. 2011) but there is no direct evidence presently available to support or further test this theory.

Question 6

The TF found no evidence in the results from genetics studies to suggest that nearly all recruitment into the PCFG area results from external recruitment (immigration). Based on the genetic data and simulations discussed during the workshop, the highest average TF response (56%) indicates that TF members believe recruitment is most likely about equal between internal (births) and external (immigration) recruitment. That being said, the remaining 45% of the total points were split between most recruitment into the PCFG area resulting from either internal or

[7] The management goal of the MMPA is to prevent populations from "depletion". NMFS considers a population depleted if it fall below its Maximum Net Productivity Level (MNPL). For marine mammals, this level is thought to be between 50% and 85% of carrying capacity and is more likely to be in the lower portion of that range (Taylor and DeMaster 1993). Therefore, populations are considered depleted by the U.S. government if they are directly estimated to be below their MNPL, or if they are estimated to be below 50%-70% of a historic population size which it thought to represent carrying capacity (Gerrodette and DeMaster 1990).

external recruitment, indicating some overall uncertainty among members regarding the presently available lines of evidence about recruitment in the PCFG. It should be noted that one member of the TF refrained from assigning any points to this question, so these results represent 6 of 7 TF members actively involved in the point assignment process.

Question 7

Based on the photo-identification data, the TF found no evidence to suggest that nearly all recruitment was either external or internal, but rather some combination of the two. As with the genetics evidence, the highest average TF response (48%) indicates that the TF felt recruitment from internal (births) and external (immigration) sources are comparable. That being said, 38% of the total points were allocated to most recruitment into the PCFG area resulting from external recruitment. Therefore, a majority of the total points were allocated to either recruitment being about equal between internal (births) and external (immigration) recruitment (48%) or most recruitment into the PCFG area results from external recruitment (38%). As was also true with the genetic lines of evidence, these results from the TF suggest a fairly high level of uncertainty regarding recruitment into the PCFG.

Question 8

Based on the genetic and photo-identification data, the TF did not strongly agree that the PCFG is a demographically independent population. Although the highest average TF response (35%) was "somewhat agree" that the PCFG is a demographically independent population, the combined categories of "somewhat disagree" and "strongly disagree" elicited 44% of the total points allocated. Overall, these results from the TF suggest a high level of uncertainty regarding recruitment in the PCFG.

Question 9

Given all lines of evidence, the point allocation of the TF reflects broad uncertainty as to whether the PCFG should be regarded as a population stock under the MMPA and GAMMS guidelines. Perhaps more than all of the other questions considered, Question 9 reflects the highest degree of uncertainty. For instance, the "strongly agree" (14%) and somewhat agree (22%) categories are almost perfectly counter-balanced by the "somewhat disagree"(24%) and "strongly disagree" (18%) categories. An additional level of uncertainty is indicated by the "neutral" category (21%). Given these results, it seems clear that TF was unable to reach a definitive response with respect to the PCFG being a population stock. That is, members of the TF ranged in their opinions from strongly agree to strongly disagree as to whether the PCFG should be considered a separate stock.

Given that this question represents the primary purpose of the workshop, the following two sections provide insight into the deliberations of the TF with regard to arguments for and against the PCFG being a demographically independent unit.

❖ ***Arguments for the PCFG being a demographically independent unit***

The return of individual whales to specific feeding areas for as long as the PCFG has been studied (30+ years) strongly suggests that site fidelity is key to maintaining gray whales as a functioning element of this ecosystem. There was agreement that this ecosystem differs from other feeding ecosystems occupied by gray whales. Gray whales are unique among the great whales in being found in only a single ocean basin. Within this ocean basin the PCFG is the only feeding group that does not rely on the dynamics of a sub-arctic ecosystem. As such, the PCFG deserves the protections afforded by being an MMPA stock because the ecosystem role of these

animals is unique and also because it provides gray whales, as a species, the flexibility they may need given potential challenges in a changing sub-arctic ecosystem.

Although there is evidence of recruitment from other feeding aggregations, there is also evidence of direct internal recruitment because calves have been shown to return to the PCFG area and reside there. Furthermore, because photographic efforts take place after most claves would be weaned, the recruits into the population not first seen as calves are actually of unknown origin and cannot be definitively assigned as external recruits.

PCFG whales show a low but significant level of genetic differentiation at the mtDNA control region when compared to samples collected in Chukotka [representative of the ENP population and sampled at a single feeding location in the Bering Sea], and when compared to a set of samples collected primarily from animals that stranded along the west coast of the U.S. [representative of a broader sampling of the ENP population]. The significant differences found when the mtDNA haplotype data from the PCFG is compared with that of groups representing the larger ENP population provide indirect evidence of internal recruitment and matrilineally-directed site fidelity to feeding grounds. The level of differentiation is on par with levels identified among humpback whales feeding in different areas of the western North Atlantic (Palsbøll *et al*. 2001) as well as humpback whales using different breeding grounds in the Southern Hemisphere (Rosenbaum *et al*. 2009), suggesting that the PCFG exhibits demographic independence similar to what has been inferred for other large whales. Within the western North Atlantic, humpback whales feeding in the Gulf of Maine are managed as a separate stock despite the fact that they share a common breeding ground with humpbacks feeding in other areas. Although evidence for nuclear DNA differentiation between PCFG whales and other areas has not been found, nuclear genetic differentiation has not always been required for stock delimitation. Pacific harbor seal stocks were delimited on mtDNA differentiation alone (nuclear data were not available at the time), while the Gulf of Maine/Bay of Fundy stock of harbor porpoises was delimited based on significant differentiation at mtDNA, contaminant loads, and life history differences, and despite a lack of differentiation at nuclear markers.

❖ ***Arguments against the PCFG being a demographically independent unit***

The evidence that external recruitment is not a rare event is quite strong. The genetic data have numerous rare haplotypes that are not consistent with a small, closed population. Indeed, simulations are not consistent with a closed population. A sizable number of individuals seen in the main feeding season are identified as transients, which is consistent with an on-going level of the main ENP population investigating this new habitat but then moving on. Further, when all samples collected in summer in the PCFG area are used there is not a significant difference found in mtDNA frequencies compared to all samples collected north of the Aleutian Islands. The number of recruits into the PCFG has been estimated, through genetic data, to be 4 to as high as 8 individuals per year. Photo-identification data suggest similarly high numbers of non-calf recruits per year (8-11). These numbers exceed the estimated number of internal recruits and, given that PCFG numbers appear to be relatively stable, an addition of 4 or more external recruits per year cannot be considered trivial. These external recruitment rates suggest the PCFG is not demographically independent from the larger ENP population.

Furthermore, unlike other large whale populations, the annual coastal migration of the vast majority of ENP gray whales brings most individuals into contact with the habitat used by the PCFG. Should there be increased removals from this area, the continual visitation to this area by

a large number of gray whales would make it likely that external recruitment would increase to fill any voids. The apparent pulse recruitment in 1999-2000 when conditions in the sub-arctic feeding areas resulted in a large mortality event shows that gray whales can adapt to a new habitat when conditions dictate. Using data collected since 2002 (post-pulse recruitment event), an average of 29.3 new whales have been identified in summer in the area used by the PCFG, with 18.5 animals that are not seen in later years and 10.8 whales that are seen in later years. Given that an average of 18.5 new whales (at least, as this does not account for new whales not photographed) visit the PCFG area each summer but do not return, this suggests that something on the order of 10% of the whales that occur in the PCFG area each summer are transients that otherwise feed north of the Aleutians, and serve as a substantial and continuous source of potential recruitment into the PCFG.

To date, there is no evidence for nDNA differentiation between Chukotka and PCFG whales based on 8 microsatellite loci or between the PCFG and one Mexican calving lagoon based on 15 loci. These results may be interpreted as female directed site fidelity to the PCFG area coupled with random mating between PCFG and ENP whales on the breeding ground. Lack of nuclear differentiation diminishes support for demographic independence.

All lines of evidence (photo-identification and genetics) are consistent with ongoing external recruitment that could be at a magnitude that is not trivial to the persistence of the feeding aggregation (more than a percent or two per year). Uncertainty in the number of recruits per year and exactly who those recruits are (PCFG calves misidentified as recruits, true recruits of adults, temporary immigrants who do not stay more than a few years and may not even be contributing to the gene pool) creates significant uncertainty as to whether internal recruitment exceeds external recruitment. Given the high level of mtDNA haplotypic diversity, the precision of F_{ST} estimates is also uncertain. Taken together, the available evidence is weak for concluding the PCFG is demographically independent.

Question 10

Given that some whales identified in the WNP have been observed to migrate through U.S. waters to Mexico, in combination with the 1994 amendments to the MMPA requiring that SARs be published for all stocks of marine mammals in U.S. waters, the TF agreed to a high degree (79%) that a separate SAR should be developed in the future for the WNP stock of gray whales.

Question 11

Based on the differences found in mtDNA and nDNA between Sakhalin Island (WNP) and ENP gray whales, the TF unanimously (100%) agreed that it qualifies as a population stock under the MMPA and GAMMS guidelines.

13. Concluding Remarks

The implications of new data pertinent to stock structure, including considerable information related to the PCFG and WNP gray whales, were thoroughly reviewed during the workshop. Evaluating the new findings relevant to the status of the PCFG proved particularly complex. After review of results from photo-identification, genetics, tagging, and other studies within the context of the GAMMS guidelines there remains a substantial level of uncertainty in the strength of the lines of evidence supporting demographic independence of the PCFG. Consequently, the TF was unable to provide definitive advice as to whether the PCFG is a population stock under the MMPA and the GAMMS guidelines. Members of the TF ranged in their opinions from

strongly agreeing to strongly disagreeing about whether the PCFG should be recognized as a separate stock.

In the case of WNP gray whales, the work of the TF was more straightforward. The mitochondrial DNA and nuclear DNA genetic differentiation found between the WNP and ENP stocks provided convincing evidence that resulted in the TF providing unambiguous advice that the WNP stock should be recognized as a population stock pursuant to the GAMMS guidelines and the MMPA.

Additional research may narrow the uncertainty associated with the question of whether the PCFG should be recognized as a population stock. To work towards this objective, the TF recommended further investigation of recruitment into the PCFG. Presently, both the photo-identification and genetics data indicate that the levels of internal versus external recruitment are comparable, but these are not quantified well enough to determine if the population dynamics of the PCFG are more a consequence of births and deaths within the group (internal dynamics) rather than related to immigration and/or emigration (external dynamics). The TF offered a number of research recommendations, using the existing photo-identification and genetics datasets, that could provide increased resolution on the issue of recruitment and, in turn, the question of stock identification.

While the need for additional data collection was apparent, especially with regard to recruitment into the PCFG, the purpose of the workshop was for the TF to determine whether the *existing* best available science was sufficient to advise that the PCFG be recognized as a population stock under the language of the MMPA and GAMMS guidelines. Therefore, the advice of the TF offered in this report should be viewed as a contemporary "snapshot" taken from an emerging and ever-changing body of knowledge regarding the PCFG.

The TF emphasizes that the PCFG is relatively small in number and utilizes a largely different ecosystem from that of the main ENP stock. While the status of the PCFG as a population stock has yet to be resolved, continued research on these whales should be undertaken with particular attention dedicated to collecting data relevant to the question of stock identification.

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16. Appendix 1 – Workshop Agenda

GRAY WHALE STOCK IDENTIFICATION WORKSHOP AGENDA

Southwest Fisheries Science Center
La Jolla, California
31 July-2 August 2012

Day 1 (31 July 2012)

8:30-8:45
1. Introductory Items
1.1 Convenor's opening remarks (Ballance)
1.2 Arrangements for the meeting (Henry)
1.3 Appointment of chair, task force and rapporteurs
1.4 Adoption of agenda
1.5 Documents available

8:45-9:15
2. Workshop Objectives
2.1 Provide scientific advice on gray whale stock structure (Weller)
2.2 Workshop relationship to stock assessment reports (Carretta/Bettridge)
- 2.2.1 Confirm current stock structure
- 2.2.2 Assess new information on putative or prospective stocks
- 2.2.3 Provide advice on necessary changes to stock structure

2.3 Workshop relationship to Makah waiver request (Darm/Stone)
- 2.3.1 History
- 2.3.2 Key considerations
- 2.3.3 Current status of waiver request
- 2.3.4 Need to know information

9:15-10:30
3. Working Group on Stock Identification (Bettridge and Moore)
3.1 Overview of MMPA language and GAMMS guidelines pertaining to stock definition (Moore)
- 3.1.1 Existing GAMMS language
- 3.1.2 Proposed GAMMS revisions from the GAMMS III workshop

3.2 Overview of recent history pertaining to NMFS interpretation of "interbreed when mature" (Bettridge/Beale)
- 3.2.1 Draft GAMMS II language pertaining to "interbreed when mature"
- 3.2.2 Status of current legal analysis of NMFS proposed definition

3.3 Additional relevant history concerning definition of "population" for marine mammals (e.g., Taylor 1997, excerpts from Eagle *et al.* 2008) (Moore/ Taylor)

BREAK 10:30-10:45

10:45-12:00
3.4 Current status of gray whale SAR development (Bettridge)
3.5 Discuss key concepts: interbreed when mature, population, demographic independence, functioning element of ecosystem
3.6 Proposed TF voting protocol and process: examples from FEMAT and the ESA (humpback whale BRT, false killer whale BRT) (Bettridge)

3.7. Proposed questions to be voted on by the Task Force

12:00-12:45

4. Working Group on Other Information (Weller and Brownell)

4.1 Overview of gray whale "population stocks" (Lang)
- 4.1.1 Eastern North Pacific Stock
- 4.1.2 Western North Pacific Stock
  - 4.1.2.1 Genetic lines of evidence as being a stock
  - 4.1.2.2 Movements of whales between the WNP and ENP

4.2 Brief overview of the Pacific Coast Feeding Group (PCFG) putative stock (Lang)
- 4.2.1 History
- 4.2.2 Range
- 4.2.3 Abundance
- 4.2.4 Diet
- 4.2.5 Movements (tagging, photo-ID)
- 4.2.6 Incidental Take (Carretta)
- 4.2.7 Emerging issues and areas of uncertainty
  - 4.2.7.1 Probability of a WNP Being Taken by the Makah (Moore)

4.3 Status of the ENP, WNP and PCFG as stocks (NMFS/MMPA/ESA/IWC) (Stone)

4.4 Proposed questions to be voted on by the Task Force

LUNCH 12:45-1:30

13:30-14:15

5. Working Group on Genetic Population Structure (Taylor and Rosel)

5.1 Broad overview of evidence used in recently defined stocks (Stone)

5.2 Review of stock definition cases relevant to the PCFG case
- 5.2.1 Atlantic harbor porpoises (Rosel)
- 5.2.2 Alaska harbor seals (Taylor)
- 5.2.3 Humpback whales (Lang)

14:15-15:00

5.3 Review of gray whale genetic research relating to population structure (Lang)
- 5.3.1 Summary of early work (LeDuc, Ramakrishnan, Alter breeding lagoon)
- 5.3.2 Summary of recent work
  - 5.3.2.1 Frasier and D'Intino
  - 5.3.2.2 Lang – empirical genetics
  - 5.3.2.3 Lang – modeling genetics

5.4 Proposed questions to be voted on by the Task Force

BREAK 15:00-15:30

15:30-17:00

6. Discussion of Documents Drafted by the Makah Tribe and Other General Matters (Task Force)

6.1 Makah Tribe documents (Weller)
- 6.1.1 Introduce GWLJ33: "Is the Pacific feeding group of gray whales a "population stock" within the meaning of the Marine Mammal Protection Act?"
- 6.1.2 Introduce GWLJ32: "Comments on Draft 2012 Stock Assessment Report for eastern North Pacific stock of gray whales"
- 6.1.3 Introduce GWLJ34: "What is the PCFG? A review of available information"
- 6.1.4 Discuss genetics sections of Makah Tribe document GWLJ33 (Taylor/Rosel)

6.2 General discussion of Day 1 information

Day 2 (1 August 2012)

9:00-10:30
7. Working Group on Population Abundance and Trends (Laake and Wade)
7.1 Photo-identification and population dynamics of the PCFG (Laake)
- 7.1.1 Definition of PCFG whales based on timing/area
- 7.1.2 Movements of know PCFG whales (photo-identification and telemetry)
- 7.1.3 Abundance/survival estimates
- 7.1.4 Trends (Wade)
- 7.1.5 Recruitment
- 7.1.6 PCFG Trend/OSP (Moore)
- 7.1.7 Discuss photo-identification and telemetry sections of Makah Tribe document GWLJ33 (Laake/Wade)

7.2 Proposed questions to be voted on by the Task Force

BREAK 10:30-11:00

11:00-12:30
8. Review and Agree on Workshop Questions for Voting

LUNCH 12:30-13:30

13:30-15:30
9. Description of Vote Procedure (Bettridge)
10. TF Voting on Workshop Questions (TF Only)

Overnight
11. Compile and Tally Votes (Lang/Henry)

Day 3 (2 August 2012)

9:00-12:00
12. Review of Vote Outcomes (Lang/Henry)
13. Discussion of Vote Outcomes
14. Revision of Questions for voting if Necessary
15. Revote if Necessary

LUNCH 12:00-13:30

13:30-16:30
16. Review of Revote Results if Necessary (Lang/Henry)
17. Other Business
18. Workplan for Workshop Report Completion
19. Adjourn

17. Appendix 2 - Workshop Document List

GWLJ01

Moore, J. E., and Merrick, R., eds. *Guidelines for Assessing Marine Mammal Stocks: Report of the GAMMS III Workshop, February 15 – 18, 2011, La Jolla, California*. Dept. of Commerce, NOAA Technical Memorandum NMFS-OPR-47.

GWLJ02

Andrews, K. R., Karczmarski, L., AU, W. W. L., Rickards, S. H., Vanderlip, C. A., Bowen, B. W., Grau, E. G., and Toonen, R. J. (2010), Rolling stones and stable homes: social structure, habitat diversity and population genetics of the Hawaiian spinner dolphin (*Stenella longirostris*). Molecular Ecology **19**: 732–748.

GWLJ03

Chivers, S. J., Dizon, A. E., Gearin, P. J., and Robertson, K. M. 2002. Small-scale population structure of eastern North Pacific harbour porpoises (*Phocoena phocoena*) indicated by molecular genetic analyses. Journal of Cetacean Research and Management **4**: 111–122.

GWLJ04

Courbis, S. S. 2011. Population Structure of Island-Associated Pantropical Spotted Dolphins (*Stenella attenuata*) in Hawaiian Waters. PhD Thesis, Portland State University, Oregon.

GWLJ05

Taylor, B. L. 2005. Identifying Units to Conserve. In: J. E. Reynolds III, W. F. Perrin, R. R. Reeves, S. Montgomery, and T. J. Ragen, eds. *Marine Mammal Research: Conservation beyond Crisis*. The John Hopkins University Press, Baltimore, MD.

GWLJ06

Carretta, J. V., Oleson, E., Weller, D. W., Lang, A. R., Forney, K. A., Baker, J., Hanson, B., Martien, K. Muto, M. M., Lowry, M. S., Barlow, J., Lynch, D., Carswell, L., Brownell Jr., R. L., Mattila, D. K., and Hill, M. C. *In press*. DRAFT: Gray whale (*Eschrichtius robustus*): Eastern North Pacific Stock and Pacific Coast Feeding Group. In: U.S. Pacific Marine Mammal Stock Assessments: 2012. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-SWFSC-XXX.

GWLJ07

Lang, A. R. 2010. The population genetics of gray whales (*Eschrichtius robustus*) in the North Pacific. PhD Thesis, University of California, San Diego, California.

GWLJ08

N/A

GWLJ09

Pyenson N. D., and Lindberg, D. R. 2011. What Happened to Gray Whales during the Pleistocene? The Ecological Impact of Sea-Level Change on Benthic Feeding Areas in the North Pacific Ocean. PLoS ONE **6**: e21295. doi:10.1371/journal.pone.0021295.

GWLJ10

Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdana, Z. A., Finlayson, M. A. X., Halpern, B. S., Jorge, M. A., Lombana, A., Lourie, S. A., Martin, K. D., McManus, E., Molnar, J., Recchia, C. A., and Robertson, J. 2007. Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. BioScience **57**: 573-583.

GWLJ11

Calambokidis, J., Laake, J. L., and Klimek, A. 2010. Abundance and population structure of seasonal gray whales in the Pacific Northwest, 1998-2008. Paper SC/62/BRG32 presented to the IWC Scientific Committee.

GWLJ12

N/A

GWLJ13

Oleson, E. M., Boggs, C. H., Forney, K. A., Hanson, M. B., Kobayashi, D. R., Taylor, B. L., Wade, P. M. and Ylitalo, G. M. 2010. Status review of Hawaiian insular false killer whales (*Pseudorca crassidens*) under the Endangered Species Act. U. S. Dept Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-22.

GWLJ14

NMFS. 2005. Revisions to Guidelines for Assessing Marine Mammal Stocks. 24 pp. Available at: *http://www.nmfs.noaa.gov/pr/pdfs/sars/gamms2005.pdf*.

GWLJ15

Eagle, T. C., Cadrin, S. X., Caldwell, M. E., Methot, R. D., Nammack, M. F. 2008. Conservation Units of Managed Fish, Threatened or Endangered Species, and Marine Mammals Report of a Workshop: February 14-16, 2006 Silver Spring, Maryland. U. S. Dept of Commerce, NOAA Technical Memorandum NMFS-OPR-37.

GWLJ 16

Taylor, B. L. 1997. Defining "Population" to Meet Management Objectives for Marine Mammals. Molecular Genetics of Marine Mammals **3:** 49-65.

GWLJ17

DRAFT Status Review of the Humpback Whale under the Endangered Species Act (confidential)

GWLJ18

Lang, A. R., Weller, D. W., LeDuc, R., Burdin, A. M., Pease, V. L., Litovka, D., Burkanov, V., and Brownell Jr., R. L. 2011. Genetic analysis of stock structure and movements of gray whales in the eastern and western North Pacific. Paper SC/63/BRG32 presented to the IWC Scientific Committee.

GWLJ19

Lang, A. R., Taylor, B. L., Calambokidis, J. C., Pease, V. L., Klimek, A., Scordino, J. Robertson, K. M., Litovka, D., Burkanov, V., Gearin, P., George, J. C., and Mate, B. 2011. Assessment of stock structure among gray whales utilizing feeding grounds in the Eastern North Pacific. Paper SC/M11/AWMP4 presented to IWC Scientific Committee.

GWLJ20

Lang, A. R. and Martien, K. K. 2012. Update on the use of a simulation-based approach to evaluate plausible levels of recruitment into the Pacific Coast Feeding Group of gray whales. Paper SC/64/AWMP4 presented to IWC Scientific Committee.

GWLJ 21

Alter, S. E., Rynes, E., and Palumbi, S. R. 2007. DNA evidence for historic population size and past ecosystem impacts of gray whales. Proceedings of the National Academy of Sciences **104**: 15162-15167.

GWLJ22

Alter, S. E., Ramirez, S. F., Nigenda, S., Ramirez, J. U., Bracho, L. R., and Palumbi, S. R. 2009. Mitochondrial and nuclear genetic variation across calving lagoons in eastern North Pacific gray whales (*Eschrichtius robustus*). Journal of Heredity **100**: 34-46.

GWLJ23

Alter, S. E., Newsome, S. D., and Palumbi, S. R. 2012. Pre-whaling genetic diversity and population ecology in eastern Pacific gray whales: insights from ancient DNA and stable isotopes. PLoS ONE **7**:e35039. doi: 10.1371/journal.pone.0035039.

GWLJ24

D'Intino, A. M., Darling, J. D., Urbán-Raminez, J., and Frasier, T. R. 2012. Substructuring of mitochondrial, but not nuclear, markers in the "southern feeding group" of eastern North Pacific gray whales. Paper SC/64/AWMP2 presented to IWC Scientific Committee.

GWLJ25

Frasier, T. R., Koroscil, S. M., White, B. N., & Darling, J. D. 2011. Assessment of population substructure in relation to summer feeding ground use in the eastern North Pacific gray whale. Endangered Species Research **14**: 39-48.

GWLJ 26

Goerlitz, D. S., Urbán, J., Rojas-Bracho, L., Belson, M., and Schaeff, C. M. 2003. Mitochondrial DNA variation among Eastern North Pacific gray whales (*Eschrichtius robustus*) on winter breeding grounds in Baja California. Canadian Journal of Zoology, 81: 1965-1972.

GWLJ27

Lang, A. R., Weller, D. W., LeDuc, R. G., and Burdin, A M. 2010. Delineating Patterns of Male Reproductive Success in the Western Gray Whale (*Eschrichtius robustus*) Population. Paper SC/62/BRG10 presented to IWC Scientific Committee.

GWLJ28

LeDuc, R. G., Weller, D. W., Hyde, J., Burdin, A. M., Rosel, P. E., Brownell Jr., R. L., Würsig, B., and Dizon, A. E. 2002. Genetic differences between western and eastern North Pacific gray whales (*Eschrichtius robustus*). Journal of Cetacean Research and Management **4**: 1-6.

GWLJ29

Ramakrishnan, U., & Taylor, B. L. (2001). Can gray whale management units be assessed using mitochondrial DNA? Journal of Cetacean Research and Management **3:** 13-18.

GWLJ30

Ramakrishnan, U., LeDuc, R. G., Darling, J., Taylor, B. L., Gearin, P., Gosho, M., Calambokidis, J., Brownell Jr., R. L., Hyde, J., and Steeves, T. E. 2001. Are the southern feeding group of Eastern Pacific gray whales a maternal genetic isolate? Report of the International Whaling Commission SC53/SD8.

GWLJ31

Steeves, T. E., Darling, J. D., Rosel, P. E., Schaeff, C. M., and Fleischer, R. C. 2001. Preliminary analysis of mitochondrial DNA variation in a southern feeding group of eastern North Pacific gray whales. Conservation Genetics **2**: 379-384.

GWLJ32

Makah 2012. Comments on Draft 2012 Stock Assessment Report for the Eastern North Pacific Stock of Gray Whales (Revised 11/1/2011) - Submitted by the Makah Indian Tribe on January 17, 2012

GWLJ33

Makah 2011. Is the Pacific Coast Feeding Group of Gray Whales a "Population Stock" within the Meaning of the Marine Mammal Protection Act? A Preliminary Analysis by the Makah Indian Tribe, October 5, 2011. PCFG Stock Status Memo from Makah Indian Tribe 10-5-2011; PSRG-2011-B13.

GWLJ34

Scordino, J., Bickham, J., Brandon, J., and Ammajian, A. 2011. What is the PCFG? A review of available information. Paper SC/63/AWMP1 presented to IWC Scientific Committee.

GWLJ 35

Brandon, J. R., Scordino, J., Butterworth, D. S., Donovan, G. P., and Punt, A. E. 2012. Towards the Selection of a Final Set of Trials for the 2012 ENP Gray Whale Implementation Review. Paper SC/64/AWMP11 presented to IWC Scientific Committee.

GWLJ 36

Ford, J. K., Durban, J. W., Ellis, G. M., Towers, J. R., Pilkington, J. F., Barrett-Lennard, L. G., and Andrews, R. D. 2012. New insights into the northward migration route of gray whales between Vancouver Island, British Columbia, and southeastern Alaska. Marine Mammal Science. doi: 10.1111/j.1748-7692.2012.00572.x

GWLJ37

Gosho, M., Gearin, P., Jenkinson, R., Laake, J., Mazzuca, L., Kubiak, D., Calambokidis, J., Megill, W., Gisborne, B., Goley, D., Tombach, C., Darling, J., and Deecke, V. 2011. Movements and diet of gray whales (*Eschrichtius robustus*) off Kodiak Island, Alaska, 2002-2005. Paper SC/M11/AWMP2 presented to IWC Scientific Committee.

GWLJ38

Mate, B., Bradford, A., Tsidulko, G., Vertyankin, V., and Ilyashenko, V. 2011. Late-Feeding Season Movements of a Western North Pacific Gray Whale off Sakhalin Island, Russia and Subsequent Migration into the Eastern North Pacific. Paper SC/63/BRG23 presented to IWC Scientific Committee.

GWLJ39

Punt, A. E. 2012. Revised ENP Gray Whale Trials and Initial Conditioning Results. Paper SC/63/AWMP presented to IWC Scientific Committee.

GWLJ40

Baird, R. W., Stacey, P. J., Duffus, D. A., and Langelier, K. M. 2002. An evaluation of gray whale (*Eschrichtius robustus*) mortality incidental to fishing operations in British Columbia, Canada. Journal of Cetacean Research Management **4**: 289–296.

GWLJ41

Conner, L., Stelle, L. L., Najera-Hillman, E., Megill, W., Calambokidis, J., and Klimek, A. 2011. Using Photo ID to Examine Injuries in Eastern Pacific Gray Whales (*Eschrichtius robustus*). Poster presentation, 20th Biennial Conference on the Biology of Marine Mammals, Tampa, Florida.

GWLJ42

International Whaling Commission. 2011. Report of the 2011 AWMP Workshop with a focus on eastern gray whales. Paper SC/63/Report 2 presented to the IWC Scientific Committee.

GWLJ43

International Whaling Commission. 2012. Report of the AWMP Workshop focussing on the PCFG gray whale Implementation Review. Paper SC/64/Report 3 presented to the IWC Scientific Committee.

GWLJ44

International Whaling Commission. 2012. Report of the Scientific Committee, Panama City, Panama, 11-23 June 2012. Paper IWC/64/Report 1, Revision 1.

GWLJ45

International Whaling Commission. 2012. Annex E: Report of the Scientific Committee: International Whaling Commission, Panama City, 2012. Paper IWC/64/Report 1 Annex E.

GWLJ46

O'Corry-Crowe, G. M., Martien, K. K., and Taylor, B. L. 2003. The analysis of population genetic structure in Alaskan harbor seals, *Phoca vitulina*, as a framework for the identification of management stocks. Southwest Fisheries Science Center Administrative Report LJ-03-08.

GWLJ47

Mate, B., Lagerquist, B., and Irvine, L. 2010. Feeding habitats, migration, and winter reproductive range movements derived from satellite-monitored radio tags on eastern North Pacific gray whales. Paper SC/62/BRG21 presented to IWC Scientific Committee.

GWLJ48

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GWLJ49

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GWLJ58

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